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An evaluation of how "Samoverskudd" calculates the economic surplus in the Norwegian power market

Master's thesis in Economics
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I hope you enjoy the reading.

Trondheim, August 31, 2017

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[1] Samoverskudd has an English name, MPsurplus, but to stay consistent with the name that is used at SINTEF, I will henceforth use the name "Samoverskudd" in this thesis.

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1 Introduction

During the last decade, there has been more attention to the human impact on the environment, how to reduce greenhouse gas emissions and limit climate change. In 2015, 195 countries signed the Paris Agreement and agreed to reduce CO2 emissions to prevent a global warming of more than 2°C, preferably 1.5°C (Jakobsen, 2017). As a part of this, more renewable resource will be included in the production, which requires appropriate investments and infrastructures. When deciding whether or not to implement large projects, such as building new power plants, economic analyses play a crucial rule. One of the tools used to evaluate such projects in the power market is the program Samoverskudd, which calculates the economic surplus based on relevant components in the market (Wolfgang, 2011). Samoverskudd is a program that is part of the EMPS model (EFI's[2] Multi-area Power market Simulator), which is a long-term hydro scheduling model used by many agents in Norway and the other Nordic countries (Wolfgang et al., 2009). Since Samoverskudd is so central in large investment decisions, it is important that it calculates the economic surplus correctly.

This leads to the research question: Is it possible to improve the way that Samoverskudd calculates the economic surplus in the power market? Through combining economic theory with knowledge about the power market, I will evaluate Samoverskudd and provide suggestions of how to improve the way it calculates the economic surplus in the power market. The evaluation will be based on the description of Samoverskudd in the report *Samfunnsøkonomisk overskudd og Samoverskudd*[3] (Wolfgang, 2011).

The motivation behind this thesis is that Samoverskudd is a program that is central in the evaluation of large projects with a yearly production of more than one TWh in the Norwegian power market, and hence improving Samoverskudd could make an impact (Jensen, Haugen, & Magnussen, 2003a). This is important, because a higher proportion of renewable resources will be included in the European power market, which suggests that more projects will require correct evaluation in the future (Helseth, Fodstad, & Henden, 2016). To accept projects with a negative net present value, or to reject projects with a positive net present value, could lead to an inefficient use of resources. As climate changes

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[2] EFI is the "Norwegian Electricity Supply Research Institute," which is now a part of SINTEF.

[3] In English: *Economic surplus and Samoverskudd*

have consequences for both humans, animals and plants, this should concern everyone (Jonsson, 2016).

This thesis will be restricted to the Norwegian power market. The Nordic power market is synchronized, but there are differences between the countries. Additionally, there already exist many different markets within each power market in every country. And even though the EMPS model can be used to optimize the Nordic system (Wolfgang et al., 2009), the EMPS model is meant to simulate power markets with a lot of hydro power. The combination of production resources varies between the Nordic countries, but Norway has the most hydro power (Førsund, Mo, Singh, & Wolfgang, 2005).

To address the research question, I will start by explaining how the power market works in chapter 2. This gives the advantage of being familiar with the concepts used to explain Samoverskudd later on. In addition to the theory about the power market, I will go through the theory of economic surplus in chapter 3, both how it is calculated generally and specifically for the power market. This will be the economic tool that I use in my evaluation. As Samoverskudd is a result program of the EMPS model, chapter 4 gives a description of the EMPS model that can be useful to understand how Samoverskudd works. Moreover, based on a report written about Samoverskudd, chapter 5 describes in detail how Samoverskudd calculates the economic surplus in the power market. This will be evaluated along with suggestions for how Samoverskudd could be improved in chapter 6. Furthermore, a discussion of strengths and limitations of these suggestions will be provided in chapter 7, as well as how future changes in the power market can affect the way that the surplus is calculated. With regard to the future's importance of the topic, there will also be remarks of how to extend this work further. To summarize the key findings, I will make some concluding remarks in chapter 8.

2 The power market

The Norwegian power market will be presented in this chapter. This will make it easier to understand the description of how Samoverskudd calculates the economic surplus in the power market. What determines supply and demand for electricity is central when looking at the economic surplus in the power market. Also, knowing the market structure and the agents are relevant for the analysis.

2.1 Deregulation of the power market

With the Norwegian Energy Act in 1991, the Norwegian power market experienced substantial changes. The Norwegian power market used to be a regulated market, consisting of several local monopolies. Norway was divided into geographical areas, to which the monopolies were committed to deliver power. The consumers had no choice, but to buy power from the local supplier and distributor. The previously planned market was deregulated and liberalized. Then, in 1991, the Norwegian Energy Act ensured a more effective use of resources and enabled a more economic distribution between production and consumption (Amundsen & Bergman, 2006). Consumers could choose to purchase power from whichever supplier they desired and competition was introduced to the market. Norway was one of the first nations to deregulate its power market. In the following years, the Norwegian power market integrated with other Nordic countries. Today, the Nordic power market also has some connections to other European markets (Bakken, 2011).

2.2 Production and consumption

There are many types of resources that can be used to produce electricity, such as bioenergy, nuclear and solar power. However, the EMPS model is a model mainly for hydro-thermal systems (Wolfgang et al., 2009). Also, the production in Norway is highly dominated by hydro power, in addition to some wind and thermal power. Therefore, I will concentrate on these production resources in this thesis.

Hydro and wind energy are examples of renewable resources. Unlike wind power, hydro power is a renewable resource that is also possible to regulate (Bye, Bjørndal, Doorman, Kjølle, & Riis, 2010). Reservoirs and dams can be used to store water until needed for production, which means that the water has an alternative value. The amount of water stored depends on the weather (e.g. rainfall and melted snow) and the demand that varies throughout seasons and time of day. It is also possible to produce hydro power from river power plants, which are not possible to regulate. Still, this kind of production is more predictable than many other energy resources, as variations in the seasons make the weather relatively easy to anticipate (NVE, Enova, Norges forskningsråd, & Innovasjon Norge, n.d.-a).

One of the characteristics of wind power is that the resource is free. Installing wind turbines requires large investments, and a small amount of the costs is related to operation and maintenance. However, when the investments are completed, there are no production costs. The cost of producing one more unit, i.e. the marginal cost, is zero. This means that as long as the wind blows, producers would want to produce and sell electricity. This is because the alternative is to let the energy in the wind blow without taking advantage of it. Another way to put it, is to say that the alternative value of the energy is equal to zero (NVE et al., n.d.-a). Thus, wind producers wish to produce electricity even when receiving low prices for it. In 2015, only 1.7 percent of the total production came from wind power (SSB, 2016). However, Statkraft, the largest power producer in Norway (Statkraft, n.d.-a), is now in the process of building Europe's largest wind power project on land in Fosen in Norway. This will produce enough electricity for 170,000 households and contribute to more renewable resources in the Norwegian power market (Statkraft, n.d.-b).

Coal and gas are examples of non-renewable resources and fuels of thermal power plants. These resources are possible to regulate. The production related to these resources can be adjusted based on when the energy is needed, and can be planned independently of time and weather. However, the coal or gas have to be bought. The profitability of the production therefore depends on both the price of gas and coal, in addition to the price of power in the market. Also, in contrast to for instance wind power, fuel has an alternative value. Instead of producing today, the gas and coal can be sold, used for something else or saved and used for production when the prices are higher. While one advantage is the possibility of turning thermal power plants on and off when needed, it also comes with a cost. Depending on the type of power plant, the time it takes to stop the production and the costs associated with it varies. For instance, stopping a gas power plant takes less time than to stop a coal power plant (NVE et al., n.d.-a).

The electricity has to be provided the moment someone wants to use an electrical outlet. Therefore, it is important to maintain a balance between production and consumption (Alnæs & Grøndahl, 2011). As more renewable resources are included in the market, the more challenging it is to keep this balance. Luckily, hydro power dominates the Norwegian production, in addition to some wind and thermal power. Of the total production of 144,511 GWh in 2015, figure 2.1 shows how much Norway produced of each of the production resources (SSB, 2016). The reason why hydro power is so suitable as a tool to maintain the balance in the system, is because it can be stored and easily regulated. So, when a larger fraction of unpredictable wind power contribute to uncertainty and instability, hydro power can be used in the hours where there is less wind than anticipated.

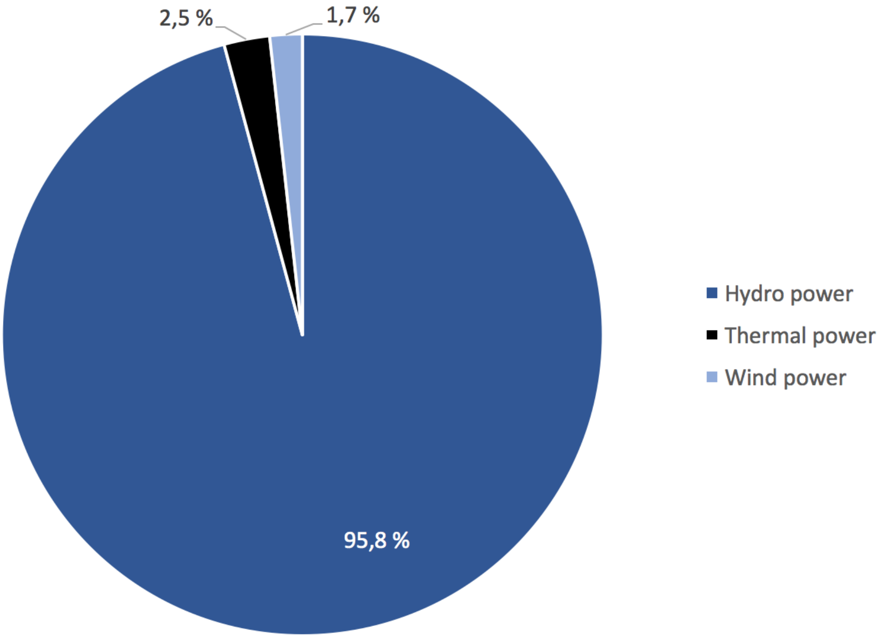

Figure 2.1: How much hydro, thermal and wind power that was produced in Norway in 2015 (SSB, 2016)

The power market is a grid system. All producers deliver the power to the grids, which transports the electricity to the consumers. Hence, the consumers never know from which power plant the electricity comes. In 2015, the electricity consumption in Norway was 120,049 GWh, excluding transaction and distribution losses, as well as the power plants' own use.[4] The consumers in the power market are households, the manufacturing

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[4] When transferring power, there are always losses.

industry, services and so on. How large their share is of the total consumption is illustrated in figure 2.2 (SSB, 2016).

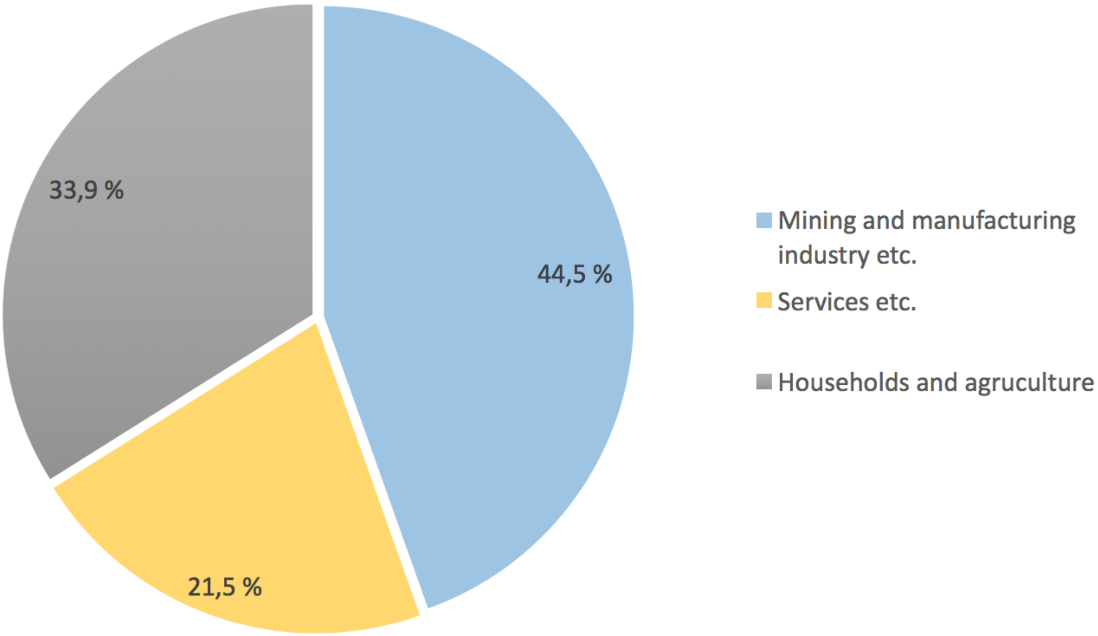

Figure 2.2: Consumption of electricity in Norway by type (SSB, 2016)

2.3 Price determination

A market is in equilibrium when supply equals demand. However, the power market is special in the way that it has to be in a physical equilibrium. If the demand exceeds the supply in real time, or vice versa, the system can potentially break down. Small deviations are accepted, but the balance must be restored within minutes. Large enough imbalances for a sufficient amount of time can result in lower quality, equipment damages and system collapse. So, maintaining the balance between supply and demand is in particularly important for the power market. Because of potentially very high costs in case of imbalances between supply and demand, and the inability to store enough power in batteries, Adam Smith's “Invisible Hand” is replaced by a visible hand to secure the system (NordPool, n.d.-c). The transmission system operator (TSO) is responsible for the short run and long run balance in the power system. In principle, the TSO must keep the frequency stable and maintain the balance between supply and demand at all times (Bye et al., 2010).

In the power market, the demand varies a lot. The peak load describes the highest demand for a certain time period, like a day, week or year. During a day, the peak load is in the morning, when people are having breakfast and go to work. The next peak load is in the afternoon, when people come home after work. During night, the demand is especially low, as most people are asleep. Throughout the week, the load is lower during the weekend compared to the rest of the week. Due to changes in temperatures and weather conditions, the power demand also varies with a seasonal pattern. In Norway, there are large temperature differences between summer and winter. The seasonal peak load is in the winter, when temperatures are low. During the summer, temperatures are higher, which contributes to a lower demand (Førsund et al., 2005).

On the supply side, rain and inflow to the reservoirs matter for the production potential and the price (Bogstrand, 2008). Also, changes in the price of fuel for thermal power plants can affect the power price. As the Nordic and European markets get more integrated, the European price signals will affect the Nordic prices to a larger extent. The power production in the other European countries is dominated with thermal power plants, such as coal and gas power, which have higher production costs (Bogstrand, 2008). So, if the price of coal increases, and coal is used in the production, this would increase the price.

2.4 Market segments

The market consists of different segments. The wholesale market consists of traders at the power exchange, the end-user market is where the power is sold to the end-users and the balancing market is where the system balance is obtained.

2.4.1 Wholesale market - Nord Pool

Nord Pool is a power exchange and a market place for trade of physical power. This is where the price and quantity of power is determined. Only large agents can trade directly at Nord Pool, such as power producers, power suppliers, large end-users and industries. Households and small end-users usually buy contracts in the end-user market. The power exchange was established after the deregulation, and Sweden joined the market not long after. Today, Nord Pool is owned by the Nordic and Baltic transmission system operators (TSOs). The Norwegian TSO is Statnett, who is in charge of maintaining stability in the grid and balance between demand and supply in the Norwegian power market (Norang, 2015).

The day-ahead market, called Elspot, is the market for contracts of physical delivery of power for each hour the next day. The Norwegian market is divided into bidding areas, as shown in figure 2.3. The members can submit bids for given bidding areas until 12:00 CET for the next day. Hence the name "day-ahead market." The power producers submit bids for which they are willing to sell their power for each hour the next day (NordPool, n.d.-a). The power suppliers are those who buy the power and sell it to the end-users. They give bids of how much they are willing to pay for the power at the wholesale market for each hour the next day. Through this auction, the market clears where the demand meets the supply of power. The power is delivered on an hourly basis, starting the next day. Based on the bidding rounds, the price is set and announced for each hour for the following day (Statnett, n.d.).

Elbas is the intra-day market of Nord Pool. It is used to support the day-ahead market and maintain the balance in the power market. The balance is usually maintained at the day-ahead market. However, incidences may occur, such as power plants stopping unexpectedly or changes in the weather causing higher generations than anticipated. If these kinds of incidents were to happen, the members can adjust their position in the intra-day market until one hour before delivery. In real time, the supply and demand are matched by the TSO. As more unpredictable renewable resources are entering the grid, the intra-day market becomes more central and the need of balancing services increases (NordPool, n.d.-b).

2.4.2 Balancing markets

The day-ahead and intra-day markets are used to trade physical power hour by hour. Balancing markets, on the other hand, are used to resolve the imbalances within real time. Real time is after the intra-day market has closed, and the physical supply has to match demand hour for hour. When the system is in balance, the voltage frequency is 50.00 Hz. Acceptable deviations are within what is called the normal range, which is between 49.9 and 50.1 Hz. The TSO is in charge of keeping this frequency, as well as

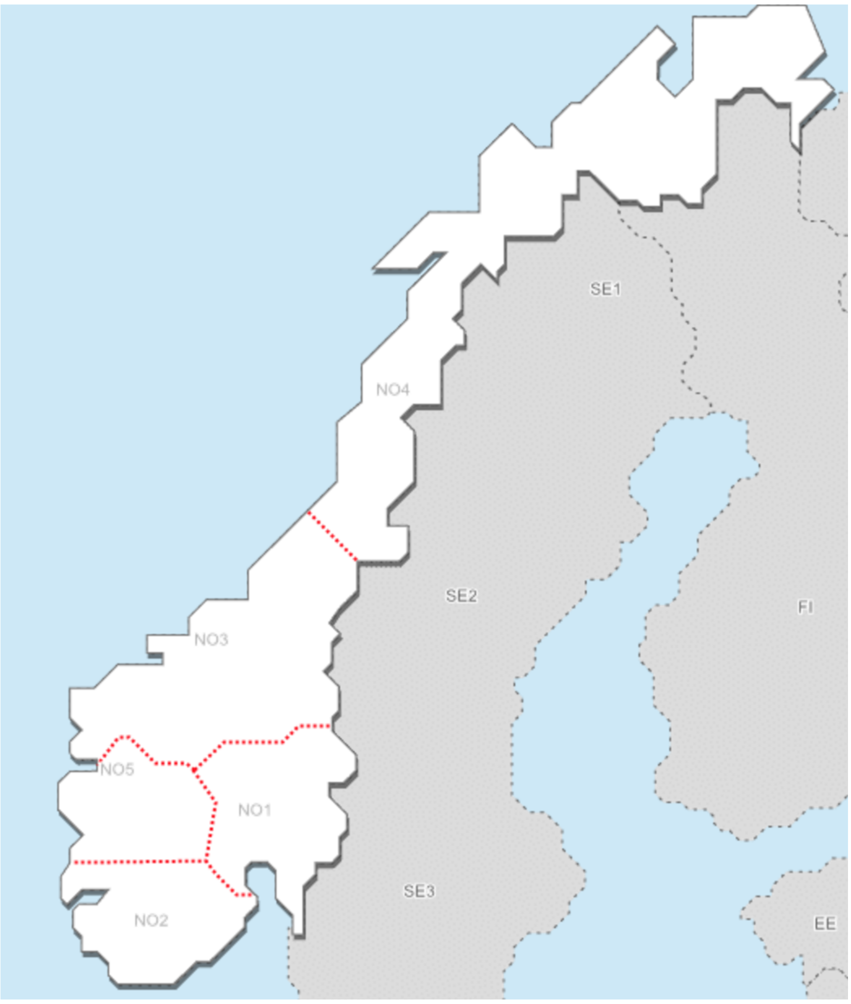

Figure 2.3: The day-ahead bidding areas in Norway as of 07.03.2016 (Statnett, 2016)

maintain grid stability and system security. In order to maintain the system balance, the TSO needs to have balancing services available for disposal, for instance reserve capacity (MW). The more imbalances there are at the intra-day market, the larger is the need of balancing services. The three different types are called primary, secondary and tertiary reserves. In case of imbalances, they are activated one at a time, depending on how large the imbalances are. An overview of the balancing services and their time response is shown in figure 2.4. They are generating capacities that must be available in case of generator breakdown or other supply disruptions. If the frequency deviates from the normal range, the primary reserves are automatically activated. Those providing primary reserves must keep them spinning and ready to adjust to momentary imbalances. If the deviations are not solved within a couple of minutes, the secondary reserves take over, also automatically activated. If the frequency is not back to normal after activating both the primary and secondary reserve, the TSO manually activates the tertiary reserves (Helseth et al., 2016).

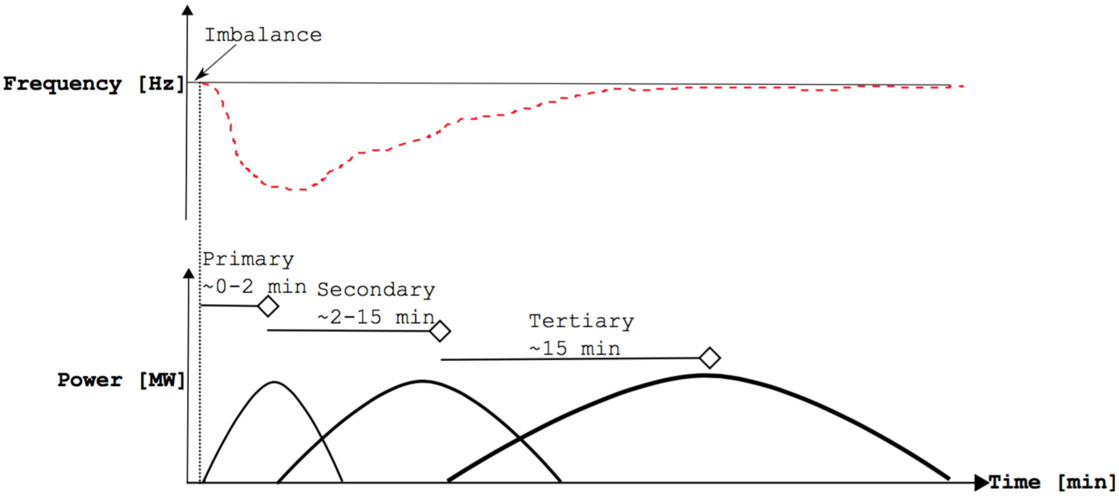

Figure 2.4: The balancing reserves and their activation sequences (Helseth et al., 2016)

In Norway, there is a lot of hydro power that has the perfect characteristics for reserves: flexible, possible to store, short start up time and so on. Since the TSO does not have its own production resources, it must request them from the producers in the power market. This is done at the balancing markets, where balancing services (primary, secondary and tertiary reserves) are provided (Helseth et al., 2016). There are several producers, but the TSO is the only buyer. This characterizes a monopsony (Bhaskar, Manning, & To, 2002). Furthermore, in the balancing markets, producers can get paid for guaranteeing to keep reserves available instead of producing and selling at the wholesale market. The producers specify quantities of reserves and prices for each hour the next day and send it to the TSO the day before. When placing these bids, the producers are obliged to deliver. If given bids are not available when Statnett asks for activation, this will be reported to NVE (The Norwegian Water Resources and Energy Directorate) (Statnett, 2013).

2.4.3 Why do we need reserves?

According to the First Theorem of Welfare Economics, "a free, competitive market will provide an efficient outcome in the absence of externalities" (Varian, 2009, p. 665). In the power market, this also means that the security and reliability of electricity supply[5] is maintained through price mechanisms (Jensen et al., 2003a). Households and the industry count on the power being both present and stable. Despite the theory about the market finding its own way to the optimal solution, there is a need of regulation and reserves. First of all, there is a lag between the production planning and the actual consumption. Between the clearing of the intra-day market and operating hours, a lot can happen. The demand can change due to fluctuations in the temperatures and other weather conditions (Førsund et al., 2005). Also, weather forecast errors make the demand difficult to anticipate. Similarly, production can change due to generation outage in power plants and malfunctions in the transmission lines. Therefore, the market is only perfect if the society accepts large fluctuations.

Secondly, more intermittent renewable energy will be included in the power market. Larger fluctuations and more uncertainty in the market will complicate the production planning and hydro power scheduling. As long as it is profitable to produce, there are no incentives to hold back water for later use. Consequently, if there are no reserves available to correct sudden imbalances, it could cause both large system damages, as well as consequences for electricity intensive industries. Therefore, the TSO must provide sufficient reserves to respond to all unpredictable system imbalances and unseen events, and correct any mismatches between supply and demand in real time (Helseth et al., 2016).

2.4.4 End-user market

The end-user market consists of mainly three agents, which are distributors, suppliers and end-users. Whoever purchases power for own consumption is an end-user. The large end-users, like industries or companies, often buy power directly from the wholesale market. Smaller end-users, such as households, buy power from suppliers. End-users can freely choose a supplier from which they want to buy power. The end-user's power bill consists of several components: payment to the distributor, payment to the supplier and different types of taxes. All end-users have to pay their local distributor where they live, for owning, building and operating the local grids that transport the power to the house. The distributors are characterized as natural monopolies, i.e when average costs decrease as production increases, in their geographical area (Garaas, 2006). Building new grids

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[5] I will from here refer to ”security and reliability of electricity supply” as “delivery reliability.”

are very expensive, so it is not economically rational to build more competing grids. The monopolistic distributors are therefore highly regulated by the Norwegian Water Resources and Energy Directorate (NVE), concerning delivery duties to the consumers, revenue limitations and how to interact with the suppliers.

The end-users also have to pay for the electricity to the suppliers. The suppliers can either purchase electricity at the wholesale market, produce the electricity themselves or purchase it from other producers. Then, the suppliers can offer contracts to the end-user of different characteristics. When an end-user pays for its electricity consumption, the consumption is usually based on the average consumption profile in the area of where the end-user lives. The distribution and supply of power can be executed by the same company. If the end-users choose another supplier, they will get two separate bills (Garaas, 2006).

The rest of the power bill consists of different types of taxes and fees. There is a consumption fee on electricity of 16,32 øre/kWh, except for end-users in Finnmark and some municipalities in Nord-Troms (Skatteetaten, n.d.). As for most goods and services in Norway, there is a 25 percent value-added tax on electricity. There is an exemption of the value-added tax as well, for households in Nordland, Troms and Finnmark. Lastly, there is a fee paid to the energy fund, called Enova, who promote effective energy use, renewable production and environmental use of natural gases. The Enova fee is 1 øre/kWh for households and 800 NOK per year for each meter-ID for the remaining end-users (av Vasskraftkommunar, n.d.).

3 Theory of economic surplus

This chapter will contribute with the theoretical framework needed to evaluate how Samoverskudd calculates the economic surplus in the power market. Economic surplus, also called total welfare, is described as the benefits that producers get when they sell a good or service to a greater price than their reservation price, and the benefits that consumers get when they purchase a good or service for a lower price than their reservation price (Boulding, 1945). Before investigating the relevant components for the economic surplus in the power market, the general concepts will be explained.

3.1 Economic surplus in the general case

3.1.1 Consumers' surplus and producers' surplus

The demand curve represents the consumers' marginal willingness to pay for certain units of goods or services. Each consumer has a reservation price for a good or service, above which he or she is not willing to pay. Whenever a consumer makes a purchase at a price lower than the reservation price, the consumer gets a benefit. This is called the consumer's surplus, which measures the surplus of a single consumer. In a market with several consumers, it is possible to add each consumer's surplus to get the aggregated measure of consumers' surplus (Varian, 2009). This is represented in figure 3.1. The demand curve represents the consumers' marginal utility and their willingness to pay. The consumers' surplus is hence the price subtracted from the maximum willingness to pay, summarized for all the consumers. The market demand is usually described with consumers that are ranged after their decreasing willingness to pay. One interpretation, is that along the demand curve in the market, the first unit is demanded by the consumer with the highest reservation price. Correspondingly, the demand curve declines as the consumers with decreasingly lower reservation price are included (Hansen, 2006).

The demand curve measures how much will be demanded at each price. Likewise, the supply curve measures how much will be supplied at each price. And in the same way that the consumers benefit from a purchase where they pay less than they were willing to, the producers benefit from receiving more than they were willing to sell for. The consumers' surplus is found between the demand the equilibrium price. By analogy, the area between

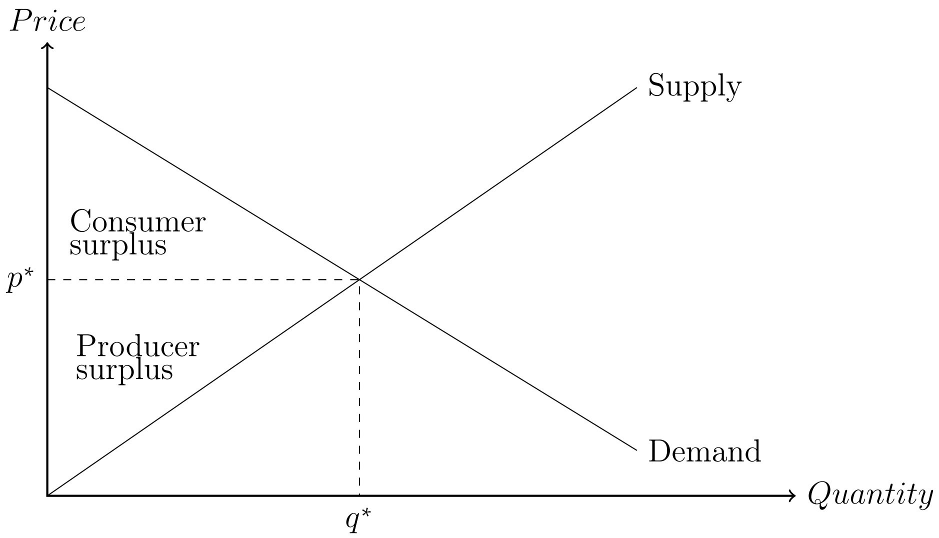

Figure 3.1: Market equilibrium with consumers' and producers' surplus

the equilibrium price and the supply curve is called producers' surplus (Varian, 2009).

3.1.2 Total economic surplus

The total economic surplus is the sum of the consumers' and producers' surplus, as illustrated in figure 3.1. The market equilibrium is given at the intercept between the demand and supply curve. The equilibrium price is represented by p^* and q^* is the equilibrium quantity. It is now possible to see how the consumers' and producers' surplus together form the total economic surplus: It is under the demand curve and above the supply curve, between the origin and the equilibrium quantity, q^*. At a price above the equilibrium price, p^*, the producer gets a higher surplus. This causes the consumers' surplus to decrease. If the price is below the market price, the consumers' surplus increases at the expense of the producers' surplus.

In order to secure efficient use of resources, all agents in the market must be exposed to the economically correct prices (Jensen et al., 2003a). Whenever the price differs from the equilibrium price, this affects the quantity demanded and supplied: If the price is higher (lower) than the market price, there is an excess supply (demand). Both cases reduce the surplus, which illustrates that it is when the price is equal to the market equilibrium price that the total economic surplus is maximized. This allocation is also the most efficient, as only the sellers who are the most efficient can manage to produce at a price lower than the market price. Deviations from the optimal market solution,

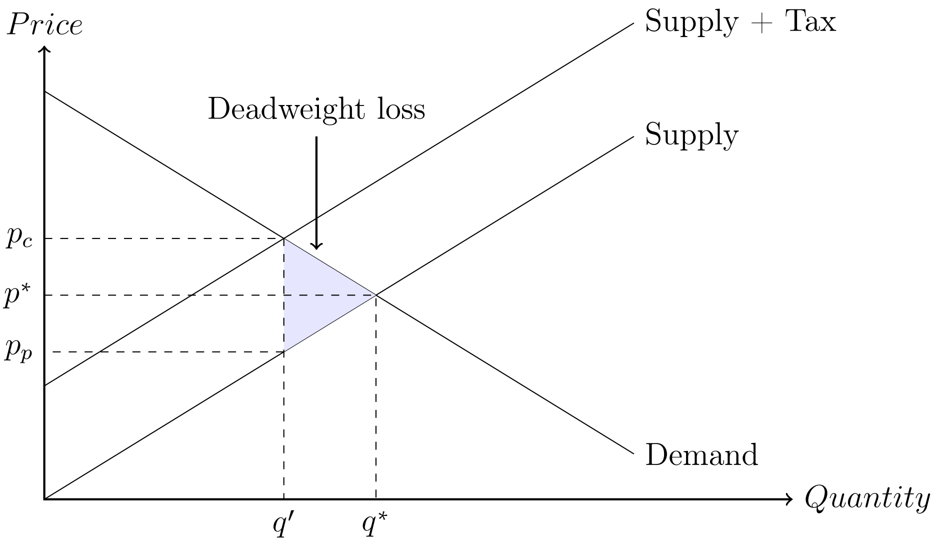

Figure 3.2: Deadweight loss due to taxes

which lead to an inefficient allocation of the resources in the market, are called market failures. Examples are for instance taxes, curtailment, monopoly pricing and externalities. Note that when evaluating an investment or project, it is the change in surplus that is interesting, and not so much the absolute levels (Varian, 2009).

In case of a market failure, there is a reduction in the total surplus that is called a deadweight loss. It reflects the inefficient allocation of resources, as the prices no longer reflect the economic costs of producing the good or service. This is illustrated in figure 3.2, with a tax as an example of a market failure that leads to a deadweight loss. In case of efficiency, the optimal quantity would be q^*. For simplicity, assume that there are only variable production costs. The taxes can then be represented by a shift in the supply curve. In stead of price p^*, the producer and consumer now receive p_p and p_c respectively. Also, the production is reduced from q^* to q'. Consequently, there occurs a deadweight loss represented by the blue area, which is the reduction in total surplus. The size of this loss depends on factors such as the size of the tax, as well as the price elasticities of demand and supply. The rest of the surplus reduction for the consumers and producers is added to the total surplus as a tax revenue, usually received by the government. Furthermore, in reality, a project has both variable and fixed costs. Thus, the fixed costs and costs from external effects must be withdrawn after the producers' surplus is calculated (Jensen et al., 2003a).

Lastly, when using economic welfare as a tool to decide whether to make a certain investment, the future potential costs and benefits are considered. Hence, it is important that the values are comparable over time. As 100 kroner is not worth the same in the future as it is today, this has to be accounted for when summarizing costs and benefits over time, i.e. discounted (Jensen et al., 2003a).

3.2 Economic surplus in the power market

The economic surplus consists of the consumers' and producers' surplus. The previous section showed how the government also receives a surplus from tax revenues, and how market failures affect the economic surplus. In the following, some of the components that are relevant for the economic surplus in the power market will be mentioned. Some of the components also apply to other markets, but examples will be given to point out the relevance of each component. They show how the economic surplus consists of all consequences for a society, and not just for the consumer and producer. The components explained here are relevant to understand the evaluation in chapter 6. Afterwards, there will be a further explanation of some of the challenges related to calculating the economic surplus in the power market.

3.2.1 Components relevant for the power market

3.2.1.1 Market power

The market solution in figure 3.2 relies on the assumptions of a perfect competition, such as many consumers and producers who are price takers in a market with no barriers to enter or exit (Varian, 2009). The deregulation in the beginning of the 1990s contributed to increased competition and efficiency in the power market (Amundsen & Bergman, 2006). However, in some of the markets, there are both examples of monopoly and monopsony, i.e markets with a single seller and a single buyer respectively (Varian, 2009). The grid companies have a natural monopoly, as explained in chapter 2, and the TSO in the balancing markets is the only one purchasing reserves from the producers.

3.2.1.2 Congestion rent

As explained in chapter 2, there are five bidding areas in Norway. When there is not sufficient transmission capacity between these geographical areas, the price in the different areas do not coincide. Therefore, in addition to setting the system price, Nord Pool sets the area prices. Restrictions in the transmission capacity between areas are called congestions.[6] If there is excess production in one area, the area price will be lower than the system price. Likewise, the area price is higher than the system price in case of production shortage. The area prices maintain the balance between supply and demand within each area, at the same time as the congestions are taken into account. The difference between the system and area price, multiplied with the transferred volume, is called a congestion rent (Bøhnsdalen, Kringstad, & Christiansen, 2013).

3.2.1.3 Agents

Normally, the surplus of consumers, producers and the government are included in the calculation of economic surplus. In the power market, there are also other agents who's surplus are relevant. The congestion rent is collected by the owner of the grid (Bøhnsdalen et al., 2013). In Norway, it is the TSO who has usually collected this congestion rent. Therefore, the surplus of the system operator is included. The grid companies and distributors are other relevant agents to consider (Wolfgang, 2011).

3.2.1.4 Uncertainty

Uncertainty is not a factor that is unique for the power market. Nonetheless, it plays an increasingly large role, as more renewable resources are integrated in the market. Future changes in temperatures and inflow are typical uncertainty components for the power market (Førsund et al., 2005). Economic analyses are usually conducted before starting a project with a long life span. Therefore, there will be a lot of uncertainty concerning the different elements of the analysis, especially those in the distant future. The physical life span of hydro power plants are between 60 and 100 years. However, due to different life spans of different construction components, and since the uncertainty concerning the reinvestment is large, the analysis period of hydro power plants is usually 40 years and the physical life span 60 years (Jensen, Haugen, & Magnussen, 2003b). A lot can change in that time, such as changing business cycles, technological changes and cost estimates.

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[6] Directly translated from Norwegian, and perhaps more intuitive, this is called "bottlenecks." However, I will continue to use the English term.

3.2.1.5 Environmental effects

When NVE evaluates the environmental costs of energy projects, they look at nature interference, aesthetics and emissions. The effects of hydro and wind power are usually related to nature interference and aesthetics, while gas and coal contribute to increased greenhouse gas emissions. Grids can hurt birds and other animals, as well as discontent the people living where the grid is built. For instance, if people fear the health effects and the aesthetic consequence of a grid, this could potentially hurt the property value. These effects can be classified as negative externalities (Varian, 2009). Additionally, there can be environmental gains associated with a project. For instance, when shutting down a power plant leads to reduced greenhouse gas emissions (Jensen et al., 2003a). This is a positive externality (Varian, 2009).

3.2.1.6 Delivery reliability

The energy system is a grid system. Accordingly, whatever happens to the grid can affect other parts of the infrastructure. For instance, a breakdown on a grid can lead to overloads and breakdowns of other grids and again lead to new overloads and breakdowns. In theory, a market with perfect competition would result in an optimal equilibrium between supply and demand, and hence maintain the delivery reliability through the price mechanisms. In a system based on hydro power though, varying inflow can lead to price fluctuations between seasons and years. As mentioned earlier, the market is only sufficiently maintaining the delivery reliability if the society accepts large electricity price fluctuations (Jensen et al., 2003b). Since the Norwegian production is dominated by hydro power, hydro reserves play a crucial role as a balancing service and in maintaining the delivery reliability (Helseth et al., 2016).

3.2.1.7 Start-up costs

For some production methods, there are costs related to starting the power plant after it has been shut down, such as thermal power plants. These kinds of costs will not be reflected under the curves of marginal costs, thus it must be calculated separately from the producers' surplus (Wolfgang, 2011).

3.2.1.8 Taxes

In the power market, there are different types of taxes, such as quantity taxes per unit and lump sum taxes as a fixed amount (Varian, 2009). There are some examples in the power market, as explained in chapter 2. For instance, the Enova fee is a quantity tax of one øre/kWh for households, but a lump sum tax of 800 kroner per year for the remaining end-users.

3.2.2 Challenges

There are some challenges related to calculating the economic surplus in the power market. This will partly be explained through figure 3.3 and 3.4. They are useful, as they illustrate concepts that will reoccur in the graphical illustration of Samoverskudd, figure 5.1, in chapter 5.

One of the common challenges when finding the economic surplus in the power market is due to lack of consumer flexibility. As the invoices are not based on each individual's consumption for each hour, which is how often the market clears, the price elasticity of demand of electric power is low. The consumption used for the invoices have traditionally been based on an average of several consumers. If the demand does not respond to the price for a given hour, this results in a vertical demand curve as shown in figure 3.3. As the demand curve is considered indefinite, the consumers' surplus is not defined. The problem is that it is not possible to observe the short run price elasticity of demand. A solution to this problem when doing the calculations is represented in figure 3.4, where the curtailment price is used to reflect the disadvantage of a forced reduction in the consumption. The consumers' surplus is shown as the area A (Wolfgang, 2011).

Another challenge concerning the calculation of the welfare in the power market is free hydro power. The producers are faced with a trade-off between higher revenues in this period at the expense of a lower production potential in the future. Increased production today leads to a higher surplus, but lower reservoir fillings gives an expected loss in revenues in the future. In a graph, as shown in figure 3.1, the producers' surplus is the area between the supply curve and the price received for the goods or services. Since the water is free, however, the producer receives the entire surplus from the sales income, which is shown in the area C in figure 3.4.

As already mentioned, the TSO gain surplus in terms of congestion rents. It can be interpreted as the TSO buying the power cheap in one area, and selling and "exporting" it more expensive to another area, and thus gaining a benefit. The length of the green horizontal segment in figure 3.3 represents the export possibilities and the vertical position of the green segment reflects the price in the area to where the power is exported. The demand curve shifts from the red to the green curve below the export price, as the export quantity comes in addition to the demand within the area. The TSO surplus is shown by area B in figure 3.4 (Wolfgang, 2011).

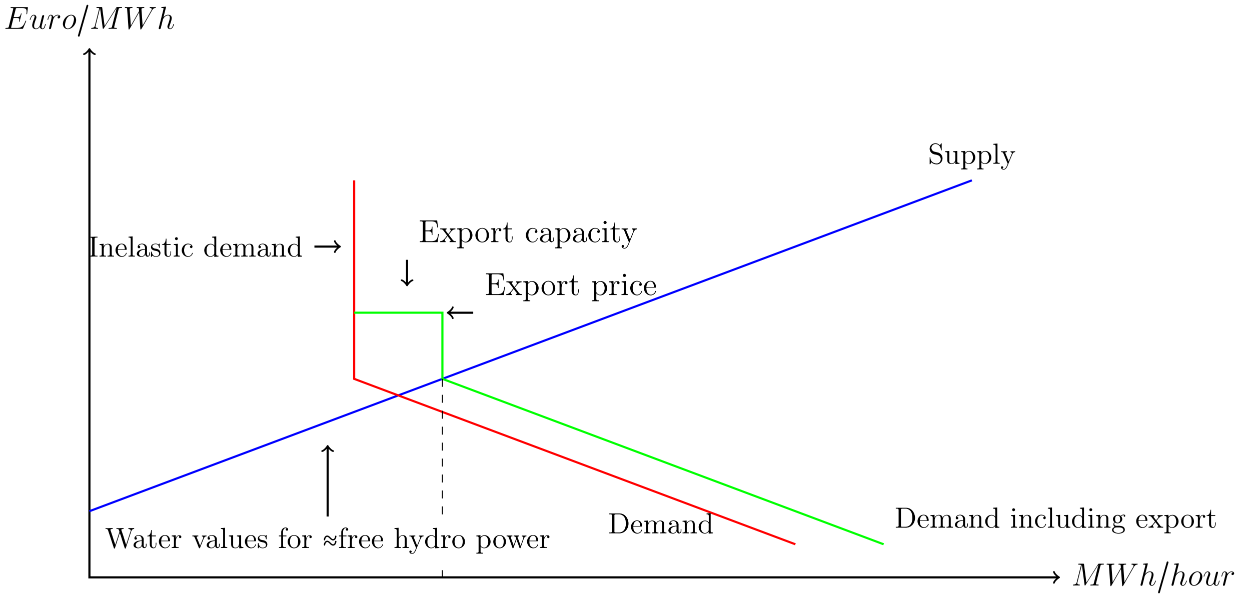

Figure 3.3: Challenges in the power market

Another challenge arising when estimating the welfare in the power market concerns environmental effects. They are important in an economic analyses, especially within the energy sector. As already mentioned, there are clearly positive and negative environmental externalities associated with different projects and investments. Unfortunately, there are not enough robust estimates of environmental costs, as there are not enough analyses of environmental costs to generalize. Nature interference is systematically related to hydro and wind power, while emissions are often connected with fossil fuels. Whereas the empirical ground base for determining environmental damages related to emissions is reasonable, there are limited empirical research results concerning the environmental costs

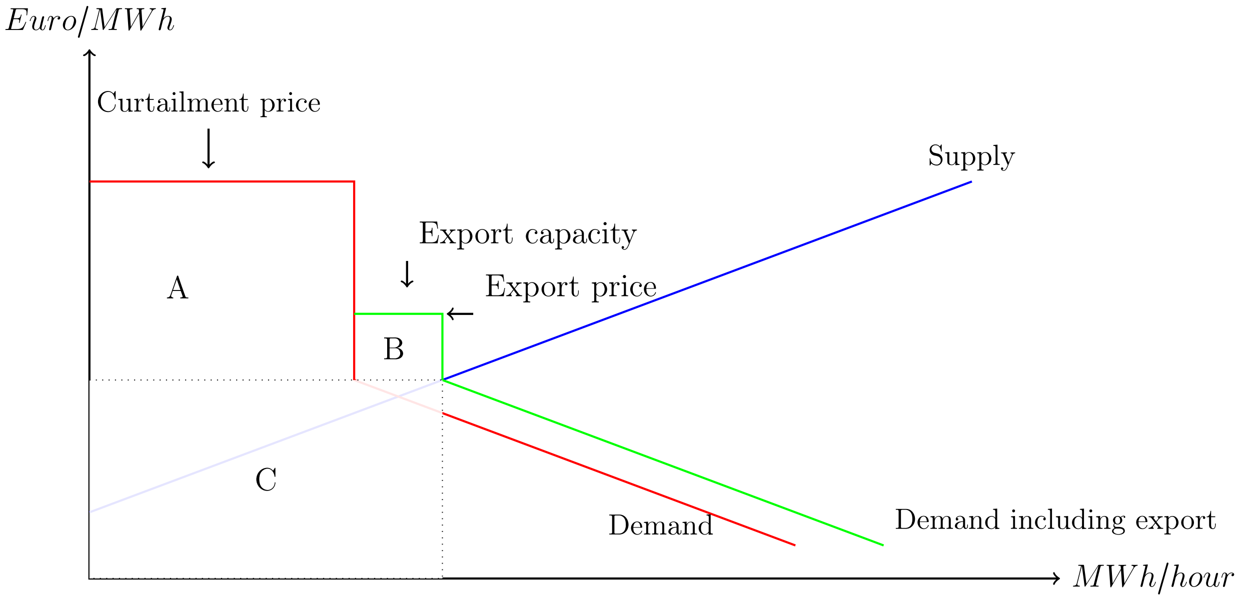

Figure 3.4: Challenges in the power market and the economic surplus

of nature interference. When these costs cannot be quantified, it makes it problematic to use the emission costs. Excluding one type of environmental costs can cause biases when investigating alternatives, for instance when the alternatives are large nature interference and large emissions (Jensen et al., 2003b).

Quantifying the delivery reliability of power is also a challenge. Instability or interruptions can cause large consequences for the society, which implies that being able to rely on the delivery and availability of the power matters for the consumers, not just the price. However, it is not easy to set a value on this reliability. This will be further discussed in chapter 6.

3.3 Limitations of economic analyses

Even though economic analyses and welfare play a central role when evaluating projects, they are not flawless concepts without limitations. In theory, all relevant positive and negative effects for the society should be taken into account. In reality, however, there are some limitations. For instance, how is the "society" defined? Does it include Norway, the Nordic area or Europe? And what about future generations, should they be acknowledged? If so, how many generations should be considered in the analysis? It is not always obvious where to draw the line. Still, the analysis has to be somewhat restricted. There also exist limitations concerning data access and possibilities of quantifying effects, such as estimating future prices and quantifying environmental effects. Moreover, it is difficult to compare the negative effects for one group against the positive effects for another group. Economic analyses contribute with important information about a project's effects on the society, but it should not be the sole element in the decision (Jensen et al., 2003b).

4 The EMPS model

Chapter 2 described the Norwegian power market and the theory of economic surplus was explained in chapter 3. With the theoretical background established, I will start to look at the program descriptions. Since Samoverskudd is a result program of the EMPS model, I find it useful to first describe the EMPS model and its functionalities, to give a better foundation for understanding the description and evaluation of Samoverskudd in the next chapters.

4.1 Introduction

The EMPS model is a simulation tool that is used in optimization and simulation of the hydrothermal power systems with a large fraction of hydro power. It models the Nordic power system with connections to the European market. The objective is to find the strategy that maximizes the expected economic surplus in the power market. The EMPS model is a complex model that consists of several modules. Samoverskudd is one of them. In addition to hydro power, the EMPS model includes thermal and wind power. When looking at the allocation of water, the time resolution is a week. On the demand side, however, the week is further divided according to demand periods (e.g. peak, off-peak, night and weekend) (Førsund et al., 2005).

The development of the EMPS model started at the EFI (the Norwegian Electricity Supply Research Institute) in the 1970s and has been used in the Nordic and North-European power market ever since. Today, several agents use the model, such as major agents at the Nord Pool market, the producers, TSOs, regulators and consultants. After the deregulation of the power market, the EMPS model was used in spot price forecasts. Also, by using the EMPS model, the user can acquire information about how to handle both hydro and thermal power plants in the system, power market analyses, exchange between areas, environmental analyses, economic results and marginal utility values. Some examples are economic surplus and costs related to grid and power plant investments (Holm, 2011).

4.2 Strategy and simulation part

The EMPS model consists of a strategy and a simulation part. The strategy part estimates a strategy for reservoir handling. Afterwards, the simulation part is executed to find out what to do in different stochastic situations as the optimal strategy is followed.

4.2.1 Strategy part and water values

The strategy part gives a strategy for how to utilize the hydro power throughout the analysis period. Scheduling production with hydro power is challenging, partly due to the stochastic inflow. It is impossible to predict exactly how large the reservoir fillings will be in the future. Thus, there is a need of a strategy for how to handle the reservoirs. The strategy part is based on calculations of the expected marginal value of stored water, i.e. water values. Water is in principle free, but it still has a value. The water value is a function of reservoir, time, future load and hydro system inflow and gives the basis for the optimal handling of the hydro power plant. For instance, if it is expected to rain a lot during the next months, the water values will be lower than if little rain was expected. Thus, water value tables can be used to represent the strategies (SINTEF, n.d.-a). The optimal strategy gives the rule that maximizes the expected economic surplus in the market and applies to all potential reservoir situations. The rule states that: “if the power price is higher than the water value in an area, the hydro power produces until the reservoir filling equals the level where the water value equals the price. The remaining water is stored” (NVE, 2016). This rule is followed as long as the physical capacity allows it.

4.2.2 Simulation part

After the strategy calculation is carried out, the power marked is simulated to investigate how the system behaves in different scenarios for a given number of historical years of inflow. In the simulation part, the estimated water values are used to make weekly decisions concerning how to allocate the hydro power in each aggregated area. Based on historical inflow and temperature scenarios, as well as observations of how the power marked behaves with different inflow alternatives, one can get an idea of the variations in the power market. The economic surplus can be estimated for different stochastic outcomes and for different organizations of the energy system (Førsund et al., 2005).

4.3 Extensions: Samlast and Samnett

The EMPS model is under constant development and extensions are made to fulfil the gaps in the functions that the EMPS model cannot deliver. "Samlast" and "Samnett" are the names of two extensions and integrated simulation modes in the EMPS model, which are also possible to use with Samoverskudd. Samlast and Samnett check for overloads in the simulation part and calculate losses. With these programs, it is possible to do combine the EMPS market model with a detailed network analysis. Based on the results from the simulation part, Samlast and Samnett compute losses and detect overloads on lines and interconnections. This information is returned to the EMPS model, where constraints are created and added to the optimization problem, to make sure that power flow limits are maintained. Their specific functions are: if overloads are detected, Samnett generates the constraints and Samlast reduces the available transmission capacities between areas, before the optimization problem is updated. This process is repeated until all overloads are detected and recorded (SINTEF, n.d.-d). In addition to combining detailed power flow analysis with the EMPS model, Samlast and Samnett give higher consistency in calculating economic surplus (Bakken, 2011). For this reason, the evaluations in this thesis will revolve around Samoverskudd when using Samlast and Samnett, as opposed to purely the EMPS model.

5 Description of Samoverskudd

This chapter is dedicated to explain how Samoverskudd calculates the economic surplus in the power market today. This program description is based on SINTEF's description of Samoverskudd, in the report *Samfunnsøkonomisk overskudd og Samoverskudd*, written by Wolfgang (2011). This is the report on which I will base my evaluation. Chapter 5 is one of the most relevant chapters for the evaluation in chapter 6, because it explains the functionalities that I will evaluate.

First, the practical difference of using the EMPS model compared to Samlast or Samnett will be explained. Second, I will go through the different economic components in Samoverskudd through a graphical representation of the calculations, in figure 5.1. This figure will also be evaluated in the next chapter. Third, all the components used by Samoverskudd to calculate the economic surplus will be displayed in an example of a Samoverskudd output-file, that shows the surplus for different sub-areas. This output-file is important, because much of the evaluation will relate to this directly.

As the essence of this thesis is to evaluate Samoverskudd, I want to clearly separate the description of Samoverskudd from my own comments and suggestions. Hence, this chapter will not be corrected for any shortcomings or faults. This means that all the functions that are unchanged since the report was written, will be described and illustrated as they are in the report.[7] Chapter 6 will contain my own comments and evaluation, clearly separated from this chapter.

5.1 Samlast and Samnett vs the EMPS model

Samoverskudd is a program that calculates and presents the economic surplus when using the EMPS model, including the model extensions Samlast and Samnett. Samlast and Samnett are used to simulate with detailed power flow. One way of putting it, is to say that the EMPS model estimates the market solution based on how the power flow is expected to be. So, sometimes the flow can be larger or lower than anticipated. The EMPS model can even calculate a market solution with a flow that is not physically possible to transmit, or that could end up in heating the system, and worst case a system blackout.

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[7] There are some updates since the report was written, which are described with help from SINTEF Energy.

If the capacities given in the EMPS model are reasonable, then there is less of a need to do changes afterwards. Samlast and Samnett, on the other hand, consider the actual flow and the physical laws. So, if overloads are detected, the optimization problem is assigned new capacities and restrictions. In addition, Samlast and Samnett compute losses and the following costs (SINTEF, n.d.-d).

There are two types of loss costs that will be presented in the figure in 5.1: the costs due to transmission losses between areas and the loss costs that occur within an area. Samlast and Samnett model the losses within an area, which is referred to as "internal losses cost" in the output-file in figure 5.2. The loss that occurs in a transmission between areas is called "transmission losses cost" in the output-file (Wolfgang, 2011). These loss costs can be explained with a simple example. Imagine a hypothetical producer in area A that sells 100 MW to a hypothetical consumer in area B. During the transmission from area A to B, there will be a loss of for instance 2 MW. Hence, the consumer receives 98 MW. This way it is possible to see why production must equal consumption plus the losses to balance and why it is more accurate to use Samlast or Samnett when calculating the economic surplus.[8] To simplify and shorten the description, Samoverskudd will primarily be described when using Samlast and Samnett. Also, the core of this thesis is to evaluate Samoverskudd, and the settings do not matter for my evaluation in chapter 6.

5.2 Describing Samoverskudd graphically

In this section, the method of Samoverskudd will be explained by using a graphical illustration of the market solution and how the surplus of each agent is calculated, shown in figure 5.1. It illustrates the market solution for a given hour, in the same way that the demand and supply in the wholesale market is matched hour by hour. The equilibrium can also be presented for a given week. It should be noted that the producers in figure 5.1 are the power producers and the consumers are those who buy electricity at the wholesale market (e.g. the suppliers). In addition to the producer surplus and consumer surplus, Samoverskudd also include the TSO surplus, internal loss costs, transmission loss costs, reservoir changes, congestion rent and total surplus. Also, the titles of the concepts used in here are the same as the ones used in the output-file in figure 5.2, which will be explained

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[8] Example provided by SINTEF in meeting, August 10, 2017.

in section 5.3. Figure 5.1 will also be evaluated in the next chapter.

5.2.1 Producer surplus

As defined in chapter 3, the producer surplus is found between the price and the supply curve. The supply curve is represented by a blue step curve, giving the marginal costs for the producer, in figure 5.1. The different steps show the marginal costs of the different production methods. When analyzing the market within a given hour, it is possible to assume that the marginal costs of the hydro and wind power are set to zero. The other types of power production have increasingly higher marginal costs, and are arranged accordingly. The producer surplus is found between the supply curve and the equilibrium price, represented by the sum of the areas E, F, G, H and I.

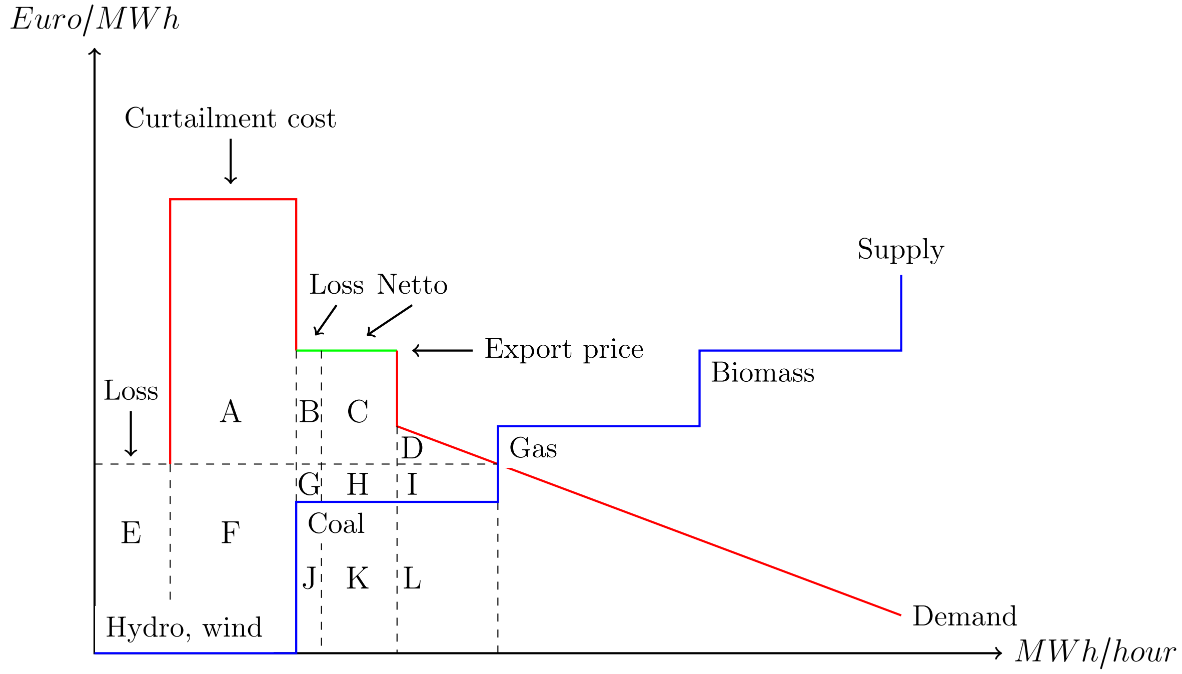

Figure 5.1: Graphical illustration of how Samoverskudd calculates the economic surplus for a given hour

5.2.2 Consumer surplus

The demand curve in figure 5.1 represents the suppliers, who place bids on the spot market. They forecast the hourly consumption of the end-users for the next day based on historical consumption patterns. As they get penalties from the system operator for causing imbalances between production and consumption in real time, the suppliers have no incentives to deviate from their bids in real time. The demand within an area is divided into two parts of the red curve: one inelastic and one linear. The first part reflects the lack of elasticity of demand as the consumers do not respond to changes in the price. Thus, the willingness to pay is set equal to the curtailment cost, as can be seen in figure 5.1. The second part of the demand curve is a decreasing linear function of the price (which in reality consists of steps given by price and volume). The consumer surplus is calculated as usual between the demand curve and price, which gives a surplus of the area A and D.

5.2.3 Internal losses cost

Samlast and Samnett calculate the losses within areas through an iteration process. The TSO buys this loss at market price. The internal losses are considered a constant and added to the total consumption. Since consumption and losses must equal production in order to balance, the cost of the internal losses is added to the left of the demand in the figure, i.e. area E.

5.2.4 Congestion rent

When there are congestions, due to restrictions in the capacity, power is transferred between areas. More specifically, power is transferred from the low-price area to the high-price area. This was explained in chapter 3. In figure 5.1, the vertical position of the green segment gives the price in the area to where the power is exported, and the length of the green segment gives the volume that is exported. According to Wolfgang (2011), the congestion rent is thus represented by area $C + H + K$.

5.2.5 Transmission losses cost

When there are price differences between areas, power will be exported to the area where the price is highest. As already explained, there are losses when transferring power. In addition to the internal loss cost, the TSO also has to buy this loss. The Transmission loss cost is represented as area $G + J + H + K$.

5.2.6 TSO (the transmission system operator) surplus

Usually, it is the TSO who collects the congestion rent. The TSO gets the benefits from congestions, but it also has to pay for the costs of the losses. Therefore, both the transmission loss cost $G + J + H + K$ and the internal loss cost (E) have to be subtracted from the congestion rent $C + H + K$. This gives the TSO surplus $C - (G + J + E)$ (Wolfgang, 2011).

5.3 The output-file of Samoverskudd

This sub-section is meant to show what the Samoverskudd output-file look like. This is central for the thesis, as the some of the components from this output-file are subject to my evaluation in the next chapter. Figure 5.2 shows an example of a Samoverskudd output-file, which is a result presentation from the simulation part in the EMPS model (as explained in chapter 4). The components of interest are in the top row. These are the same as the components explained above in the graphical illustration.

In addition, the output-file in figure 5.2 includes the reservoir changes and total economic surplus. **The reservoir change** is included to correct for the producer surplus. When the producer reduces the reservoir fillings, production resources are removed. Therefore, a decrease (increase) in the component “reservoir changes” contributes to decrease (increase) the producer surplus.[9] To get the **total economic surplus**, all the components must be added together: the producer surplus, consumer surplus, TSO surplus, internal losses cost, transmission losses cost, congestion rent and the reservoir change. All these components are shown in the output-file in figure 5.2. There are also some components that are not explicitly represented, neither in the graph nor the output-file, but are included in the calculation of the surplus. One example is start-up costs, i.e. the cost of starting a power plant, that are withdrawn from the producer surplus in Samoverskudd (Wolfgang, 2011).

In figure 5.2, the simulation results are mean values from week 1 to 52, based on historical inflow data. All economic components are given in million kroner. Samoverskudd also calculates energy results (GWh) for consumption, production and losses, but these results are excluded from the output-file to make the size of the table reasonable (Wolfgang

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[9] From meeting with SINTEF August 10, 2017.

samoverskudd

```
--------------------------------------------------------------------------------------------------------------
Area       : Producer : Consumer   : Congestion : TSO     : Internal : Transmission : Reservoir : Social     :
           : surplus  : surplus    : rent       : surplus : losses   : losses cost  : change    : surplus    :
           :    Mkr   :     Mkr    :     Mkr    :    Mkr  : cost Mkr :      Mkr     :    Mkr    :    Mkr     :
--------------------------------------------------------------------------------------------------------------
FINNMARK   :   217.40 :    2440.21 :       0.08 :    0.08 :     0.00 :        -0.00 :      5.94 :    2663.62 :
TROMS      :   540.29 :    2666.26 :       0.54 :    0.54 :     0.00 :         0.00 :   -111.11 :    3095.98 :
SVARTISEN  :   211.69 :       0.47 :       0.34 :    0.34 :     0.00 :         0.00 :    -77.45 :     135.04 :
HELGELAND  :   529.01 :    2481.61 :       0.73 :    0.73 :     0.00 :         0.00 :    -49.75 :    2961.60 :
TRONDELAG  :   438.80 :    3454.24 :       1.61 :    1.61 :     0.00 :        -0.00 :     35.92 :    3930.57 :
MORE       :   350.31 :    5281.40 :       1.17 :    1.17 :     0.00 :        -0.00 :     28.79 :    5661.67 :
NORDVEST   :   203.13 :    1314.73 :       0.37 :    0.37 :     0.00 :         0.00 :     31.96 :    1550.19 :
INDRESOGN  :   235.16 :    1468.64 :       0.13 :    0.13 :     0.00 :        -0.00 :      8.45 :    1712.38 :
BKK        :   429.66 :    4321.72 :       0.20 :    0.20 :     0.00 :         0.00 :     16.77 :    4768.35 :
SKL        :   256.13 :    3620.06 :       0.19 :    0.19 :     0.00 :         0.00 :     29.23 :    3905.61 :
VESTSYD    :   535.72 :     313.73 :     142.41 :  142.41 :     0.00 :        -0.00 :    -41.46 :     950.39 :
NORGESYD   :  1138.76 :    5287.82 :     172.91 :  172.91 :     0.00 :         0.00 :     10.49 :    6609.98 :
HALLINGDAL :   724.08 :     402.24 :       0.39 :    0.39 :     0.00 :        -0.00 :     15.35 :    1142.07 :
TELEMARK   :   616.06 :    3467.59 :       1.62 :    1.62 :     0.00 :        -0.00 :      9.32 :    4094.58 :
NORGEOST   :   654.14 :   15855.72 :       1.75 :    1.75 :     0.00 :        -0.00 :    106.79 :   16618.40 :
SVER-SNO1  :  1127.77 :   19047.62 :       2.38 :    2.38 :     0.00 :         0.00 :    -25.51 :   20152.26 :
SVER-SNO2  :  2233.15 :   38710.11 :       1.24 :    1.24 :     0.00 :         0.00 :    -71.78 :   40872.71 :
SVER-SNO3  :  4063.48 :  232559.75 :       8.76 :    8.76 :     0.00 :         0.00 :    -38.31 :  236593.69 :
SVER-SNO4  :   483.92 :   69231.54 :     121.08 :  121.08 :     0.00 :        -0.00 :      0.14 :   69836.67 :
FIN-NORD   :   568.94 :   36066.60 :       1.72 :    1.72 :     0.00 :         0.00 :     92.49 :   36729.75 :
FIN-SYD    :  3220.74 :  230609.42 :      12.16 :   12.16 :     0.00 :        -0.00 :      0.22 :  233842.53 :
DANM-OST   :   435.24 :   33454.55 :      49.68 :   49.68 :     0.00 :         0.00 :      0.00 :   33939.47 :
JYLL-NORD  :   219.73 :    9104.85 :      15.00 :   15.00 :     0.00 :         0.00 :      0.00 :    9339.58 :
JYLL-SYD   :   523.75 :   32429.59 :     176.30 :  176.30 :     0.00 :         0.00 :      0.00 :   33129.64 :
FYN        :   158.03 :    6835.40 :       2.90 :    2.90 :     0.00 :         0.00 :      0.00 :    6996.33 :
TYSKLAND   :     0.00 :  641522.19 :     369.17 :  369.17 :     0.00 :         0.00 :      0.00 :  641891.38 :
NEDERLAND  :     0.00 :  641104.25 :      58.48 :   58.48 :     0.00 :         0.00 :      0.00 :  641162.75 :
POLEN      :     0.00 :  639427.12 :     146.84 :  146.84 :     0.00 :        -0.00 :      0.00 :  639573.94 :
ESTONIA    :   249.20 :   29651.35 :      17.00 :   17.00 :     0.00 :        -0.00 :      0.00 :   29917.55 :
LATVIA     :   262.64 :   27239.56 :       6.92 :    6.92 :     0.00 :        -0.00 :      0.00 :   27509.13 :
LITHUANIA  :    84.11 :   35978.90 :      97.61 :   97.61 :     0.00 :         0.00 :      0.00 :   36160.62 :
GB         :     0.00 :  639770.75 :     142.15 :  142.15 :     0.00 :        -0.00 :      0.00 :  639912.88 :
--------------------------------------------------------------------------------------------------------------
   Sum     : 20711.06 : 3415120.00 :    1553.83 : 1553.83 :     0.00 :         0.00 :    -23.52 : 3437361.25 :
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```

Figure 5.2: An example of a Samoverskudd output-file (received via e-mail from SINTEF on August 11, 2017)

& Skjelbred, 2012). The user of the model can choose for what areas to calculate the surplus, which are listed in the column to the left of the table. The total economic surplus for each area is given in the column to the right, and the aggregated values for each economic component are in the last row. Notice that while there are mean values over time in the output-file in figure 5.2, the situation in figure 5.1 is one market solution in a given hour. Also, this output-file is included to evaluate the components that Samoverskudd uses to calculate the surplus, and not the numbers or areas.

6 Evaluation and suggested improvements of Samoverskudd

In this chapter, I will evaluate Samoverskudd and how it calculates the economic surplus in the power market. Using economic theory, combined with the knowledge that I possess about the power market, I will provide suggestions for how I believe that Samoverskudd can be improved. As a result of my evaluation, I have found several suggestions that could improve Samoverskudd. While some of the suggestions can be related directly to the output-file in figure 5.2, there are also some suggestions that concerns components that are not included in the calculations of Samoverskudd (which I think should be included). My last comments in this chapter are related to the graphical illustration of Samoverskudd, given in figure 5.1.

As the economic surplus is more accurately calculated with Samlast and Samnett, the evaluation will focus on the results based on their calculation logic.

6.1 TSO surplus

The two following suggestions are directly related to the Samoverskudd output-file in figure 5.2. The relevant columns are "TSO surplus," "congestion rent," "transmissions losses cost" and "internal losses cost."

6.1.1 Counting the congestion rent and the losses twice

In Samoverskudd, the TSO surplus is calculated as the internal loss costs and transmission loss costs subtracted from the congestion rent (Wolfgang, 2011). However, in addition to including the TSO surplus in the output-file in figure 5.2, all the components that add up to the TSO surplus (TSO surplus = congestion rent - transmission losses costs - internal losses costs) are included as well. As shown in the figure, congestion rent, transmission losses costs and internal losses costs are included as independent columns, in addition to a column with the TSO surplus. This, I believe, may result in components being counted twice. It may be that Samoverksudd includes other components of the TSO surplus as well, so the suggestion is not to remove this from the output-file. However, the three components that add up to the TSO surplus (the congestion rent, transmission losses costs and internal losses costs) should be revised. If it is the case, that Samoverskudd counts some components twice, it clearly contributes to incorrect results.

6.1.2 Rename the component from "TSO surplus"

In Norway, it has usually been the TSO, Statnett, that has collected the congestion rent and carried the burden of loss costs when there are congestions and price differences between areas. In the output-file in figure 5.2, "TSO surplus" is the name of the component. However, the correct definition is that the owners of the grid get the congestion rent (Bøhnsdalen et al., 2013). This can also include grid companies, and possibly producers in the future. Therefore, in the future it is suggested to rename this component to from "TSO surplus" to “Grid owner surplus.” To change the title does not affect the calculations. On the other hand, if it is relevant to include the congestion rent and loss costs of other agents than the TSO, then this should nevertheless be included in the calculation.

6.2 Reserves

Today, there is no explanation in the report by Wolfgang (2011) concerning how to take reserves into account in Samoverskudd. Reserve procurements define how much reserves to keep out of the market clearing, so that it can be available to cover any unbalances (de Brisis, 2016). When defining the reserve procurements in the EMPS model, they appear as a restriction. Thus, when producers withhold for instance hydro power from the production, this is excluded from the current market solution and hence higher reserves lead to a reduction in the economic surplus.[10] In the market solution given in the description of Samoverskudd, this make sense: When withholding water that could have been used in production, the producers get lower revenues in the wholesale market than they could have gotten if the retained water was used in production. However, this does not give a proper representation of the role of the reserves in the power market.

The reserves do in fact contribute with positive value to the surplus. First of all, the producers get paid for keeping the reserves, and they are paid additionally if called upon to use the reserves (Statnett, 2013). So, instead of excluding the reserves from the calculations, it should be considered as an alternative way of generating profits. This is

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[10] Provided by SINTEF in e-mail, April 18, 2017.

one reason why the reserves should be included in the producer surplus.

Secondly, the potential cost of not keeping reserves is very large. System imbalances would be more difficult to solve and power plants and the system could in worst case experience breakdowns. As explained in chapters 2 and 3, the reserves play a crucial role in strengthening the delivery reliability and preventing potential breakdowns. When more unpredictable renewable resources enter the production, and make the system planning more difficult due to uncertainty and instability, the need of reserves will increase (Bye et al., 2010). This is very valuable and I argue that the reserves should be better integrated into Samoverskudd.

Exactly how to include the reserves into the calculation of the economic surplus is currently not obvious. Still, I have some ideas to a possible approach. Wind power is an example that illustrates a type of energy that cannot be stored, but needs to be used for production in the moment of availability (Bye et al., 2010). Because it is impossible to know exactly how much wind that will come in the future, the bids are based on historical data and expectations (Norang, 2015). To illustrate the possible approach, consider the bid for an hour to be $\bar{x}$ MW, which is the expected value of the wind power. As the bids for the next day are given hour for hour, consider the probability that the wind power that arrive coincides with the expected value of the wind power ($\bar{x}$) at a certain hour. This is illustrated in figure 6.1, where the probability follows a standard normal distribution. Figure 6.1 represents the situation without reserves, and the figure 6.2 illustrates the situation with reserves.

Consider first of the situation without reserves. Assume the system is still in balance as long as the actual wind is not lower than half a standard deviation, represented by the blue area in figure 6.1. However, if the actual wind is lower than half a standard deviation from the expected value of the bids, then the supply is lower than the demand that hour, and the imbalances could cause severe system damages. The probability of a system breakdown in this situation is approximately 30 percent,[11] which is represented by the red area.[12] In the case without reserves, the probability that the imbalances can cause a lot of damage, is quite large. In the wholesale market, there is no production retained from the market, but there are potentially large costs due to imbalances.

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[11] Because the blue area is $0,5\sigma$ in a standard normal distribution, which is approximately 20 percent.

[12] If the wind is stronger than indicated in the bids, then the TSO has other methods to get the system back in balance.

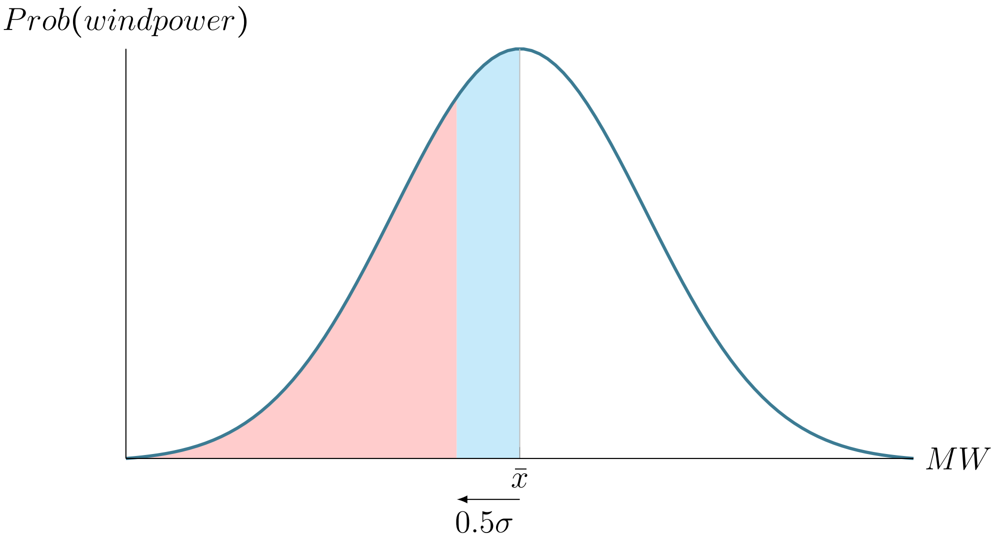

Figure 6.1: A power market without reserves

Also, if the actual wind for the given hour is smaller than expected, and production is lower than the optimal production level, there will be a deadweight loss. Figure 3.2 from chapter 3, illustrated how a tax causes a deadweight loss. The same figure can be used to illustrate the deadweight loss that occurs due to deviations from the optimal quantity q^*. This is the case both if the production is lower or exceeds q^*.

In a situation without reserves, it is not given that the TSO manages to balance the system before the damages have occurred. However, the situation is quite different when there are reserves held by the producers and the probability that any imbalances could lead to system damages would decrease. This is illustrated in the of figure 6.2, where the actual wind at the given hour can be down to 2σ lower than the expected value, $\bar{x}$, without the system collapsing, and the probability of system damages has decreased to approximately 2 percent. The more reserves that are ready to correct momentary and long run imbalances, the less likely it is that there will be a breakdown.

This examples was used to highlight the relevance of reserves and why I believe that regarding the reserves as a restriction seems unreasonable. If it is possible to estimate the cost of a potential breakdown, and the probabilities of breakdowns according to how much reserves are held, it should be possible to calculate the expected values. These values could somehow be used to value the function and role of the reserves, instead of regarding them as pure restrictions in the wholesale market.

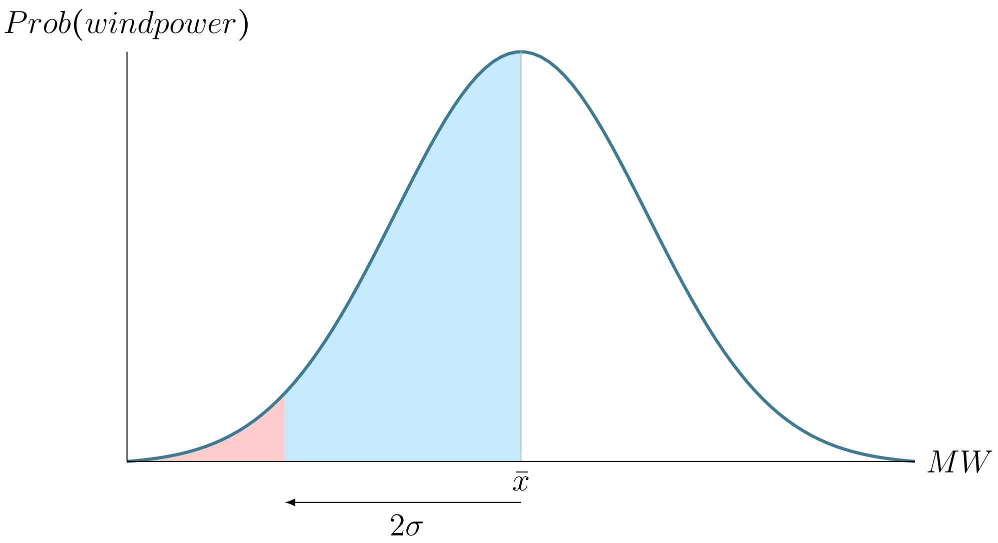

Figure 6.2: A power market with reserves

6.3 The other markets

In chapter 2, the wholesale market, the balancing markets and the end-user market were described. In Samoverskudd, the market solution represents wholesale market, as it was shown in the graphical illustration in figure 5.1. The producers are producers of hydro, wind and thermal power, and the consumers are those who place bids and buy electricity at the wholesale market, such as the suppliers. Hence, these are the producers and consumers in figure 5.1 and the output-file in figure 5.2. However, in the same way that the suppliers get a consumer surplus in the wholesale market, they also receive a producer surplus in the end-user market where they sell electricity to the end-users. Furthermore, the end-users get a consumer surplus when they buy electricity of the suppliers. When not including this, it seems like the simplification of the power market excludes relevant elements to the economic surplus. Therefore, my suggestion is that an additional market equilibrium is considered, so that the producer surplus of the suppliers and the consumer surplus of the end-users are included in the calculation. In the output-file, in figure 5.2, a solution to this could be to separate the surplus of the producers and consumers in the wholesale market with separate columns for the surplus of the producers and consumers in the end-user market.

Moreover, I also believe that the current market solution excludes components that should have been included in the producer surplus. As explained above, Samoverskudd considers reserves as a restriction and do not include the positive contributions to the economic surplus. Since the producers get paid for keeping reserves, as well as an additional payment if they are used, I argue that this should be included in the producer surplus. If this surplus does not belong in the wholesale market, as it is not a surplus gained due to trades at the wholesale market, then I suggest that this is further revised to find a method to include it in the calculation in Samoverskudd. I want to emphasize that there might be a reason for the way that the market is defined in the EMPS model today. However, based on the information given in the description of Samoverskudd, and the fact that it seems to ignore relevant surplus, I recommend that this is looked further into.

6.4 Changes in the tax revenues

In today's versions of Samoverskudd, taxes are included as a constant term, but they are not affected or adjusted in the investment analyses.[13] According to economic theory, as shown in chapter 3, taxes affect the consumers' and producers' surplus, and hence the total economic surplus. Surely, when there are changes in the tax revenues, this should be included. So, when using Samoverskudd to decide to invest in a project or not, the change in tax revenues should be considered, and not just added as a constant term. For instance, when building a power plant, this generates tax revenues. Statkraft, the largest power producer in Norway (Statkraft, n.d.-a), is building a hydro power plant that will have an average production of 60 GWh per year, which is the equivalent of providing electricity for around about 3000 Norwegian households (Statkraft, n.d.-c). By law, the owners of a power plant must pay a natural resource tax of 1,3 øre/kWh to the municipality in which the power plant is located (KPMG, 2017). This add up to 780,000 kroner each year, and 62,400,000 kroner after 80 years (which is the average physical life span of a hydro power plant, from the experience of NVE (Jensen et al., 2003a)). In this particular example, the AF Gruppen[14] is hired to build the power plant and the value of the contract is 130 million kroner, and this is excluding the value-added tax (AFgruppen, n.d.).

This is simply to illustrate that there are taxes involved when building a power plant, and that they contribute to changes in the tax revenues. Furthermore, there are different types of fees on electricity consumption. This was explained in chapter 2, about

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[13] Provided by SINTEF in e-mail, April 18, 2017.

[14] A Norwegian construction company

the end-users in the end-user market. If a project leads to changes in the consumption, this would again lead to changes in the tax revenues. Lastly, there are tariffs on imports and export of electricity. Hence, if investments in new cables affect how much is imported or exported, more tax would be paid in terms of these kinds of tariffs. With this in mind, I argue that changes in tax revenues should be acknowledged in Samoverskudd in a new way, and not as a constant term.

Also, the EMPS model[15] is used to evaluate grid investments, facilities with a yearly production above one TWh and end-user projects with more than one TWh in energy savings (Jensen et al., 2003a). It thus appears that there are potentially significant changes in tax revenues for the different projects that are considered. Even with the exemption system, I believe that the results of Samoverksudd would be more accurate if including the changes in the tax revenues generated by the project that is considered.

The report about Samoverskudd by Wolfgang (2011) do suggest that tax revenues should be included. However, it is not the absolute value of the tax revenues that are interesting, but the change in tax revenues as a result of the project (Varian, 2009). And nowhere is it mentioned that the changes in tax revenues related to an investment or project should be included.

6.5 Discounting future values

As mentioned in chapter 3, future benefits and costs have to be discounted in order to make the values comparable to present values. Samoverskudd can give results from calculations of the surplus for one given year in the future and as an average of many years in the future. When evaluating an alternative, or comparing alternatives to each other, then all future costs and benefits should be discounted. Also, I wonder if there should be any adjustments when using historical values from previous decades. As I did not see any mentions of how Samoverskudd discounts future or past values, I recommend that this is either included in Samoverskudd or in the description of Samoverskudd to make it clear.

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[15] Or Samlast or Samnett

6.6 Demand curve and consumer surplus

In the description of Samoverskudd, it says that “if parts of the demand do not respond to the price in a given hour, the demand curve becomes vertical” (Wolfgang, 2011). Thus, a part of the demand in Samoverskudd is considered perfectly inelastic in, as shown in figure 5.1. Consequently, the consumer surplus is not defined, because it is indefinitely large. The current solution is a horizontal segment, set by the curtailment price, to reflect the consumer’s disadvantage of lower consumption. The explanation for this demand curve, is that the end-user’s invoice is not based on the hourly consumption of each consumer, but is instead calculated as an average of several consumers. Thus, the consumers are not exposed to a short run price variation and do not respond to changes in the price hour for hour (Wolfgang, 2011).

There are two problems with this. First of all, the structure of the demand response is changing. New technology and a “smart electricity meter” (AMS) will make it possible for the consumers to get better information about their electricity consumption, as well as more accurate invoices for the customers. Many consumers (both households and large industrial end-users) are already using this new technology, and within January the 1st, 2019, all electricity end-users in Norway will use the smart electricity meters. It will also be possible for the customers to access to their exact hourly electricity consumption directly from the meter, using a home area network (HAN). This information will be updated at least every 10th second, and will make it possible for the customer to adjust the consumption and thus reduce their electricity bills (NVE, 2015). As more smart meters are installed and the end-users respond to the short run prices, Samoverskudd should maybe consider the left part of the demand curve as a linear decreasing function. This is illustrated in figure 6.3. As the consumers respond to the price at a given hour, it would be possible to observe the price elasticity.

The second problem with the current way of considering the left part of the demand curve is that perfect inelastic demand extremely rarely occurs in reality. According to economic theory, perfect inelastic demand is when the quantity demanded does not change no matter the percentage change in price (Amadeo, 2017). Even if the demand is inelastic, it is maybe not perfectly inelastic in reality. The solution in Samoverskudd, where the curtailment price is set for a certain amount of consumers, contribute to a rather inaccurate

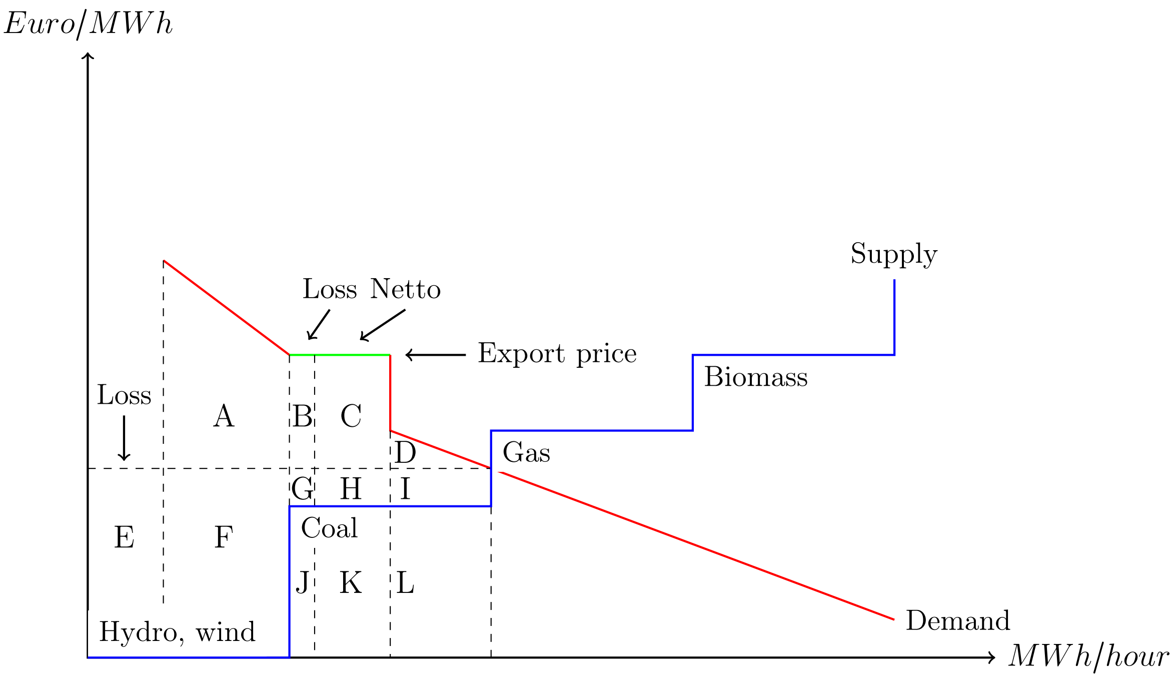

Figure 6.3: The left part of the demand curve

calculation of the consumer surplus.

How to calculate the consumer surplus with a lack of price response is not obvious. Despite the fact that not all electricity customers will have the smart meter installed until 2019, the smart meters are already installed some places. Figure 6.4 shows an overview of where the smart meters are installed so far in 2017. These already installed smart meters could be used to estimate a price elasticity and hence the demand curve. Figure 6.5 illustrates what the demand curve could look like with different potential elasticities. Using the estimated left part of the demand curve, and the quantity demanded, it is maybe possible to estimate the consumer surplus more accurately than it is done today.

To summarize, I believe that there is potential for improvements related to the current way of estimating the left part of the demand curve and hence the consumer surplus. Smart meters are in the process of being installed for all end-users, which will contribute to the rest of the demand being exposed to short run prices within 2019. Until then, the second best would be to look into an alternative way of considering the left part of the demand curve, for instance to calculate price elasticities from the smart meters already installed.

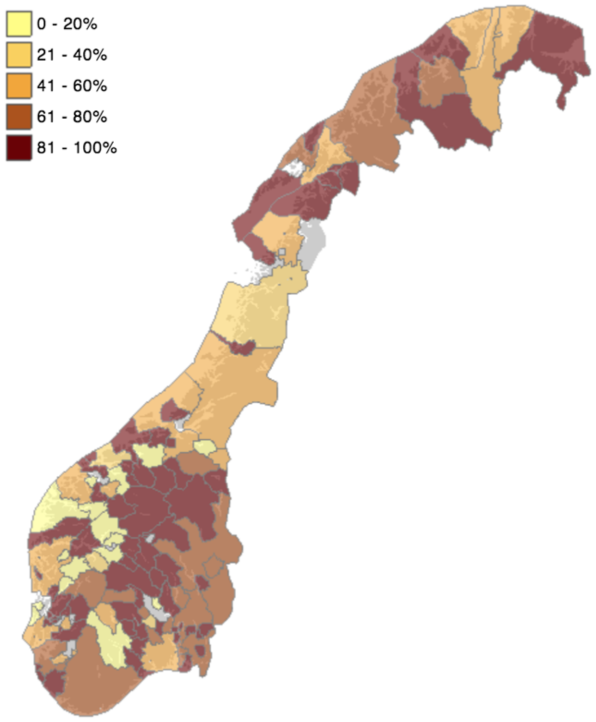

Figure 6.4: An overview of the deployed AMS in 2017 (NVE, 2015)

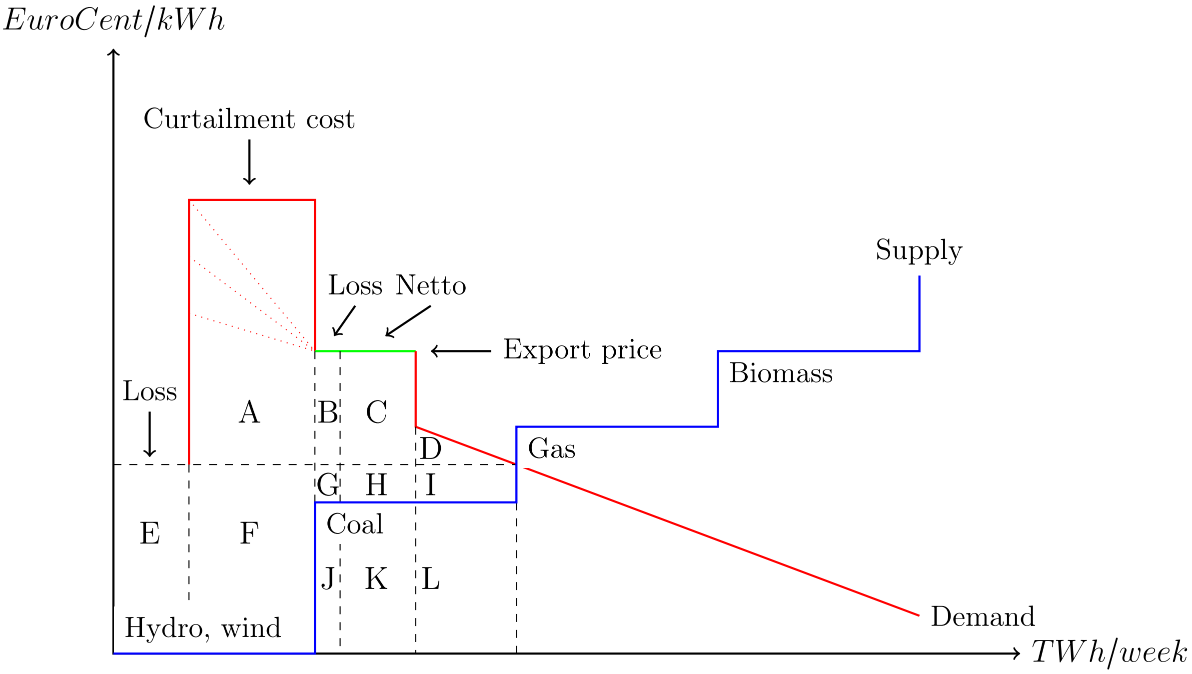

Figure 6.5: The left part of the demand curve calculated with different price elasticities of demand

6.7 Environmental effects

It is clearly challenging to measure environmental effects of investments in the power market. Yet, as the economic surplus consists of all consequences in a society (Wolfgang, 2011), they might also be relevant to include in the calculations in Samoverskudd. On the one hand, environmental effects can be regarded as positive. For instance, if a power plant with high greenhouse gas emissions is shut down, it means that there will be less emissions in the future. Melkøya is an example of this. At Melkøya, an island in Finnmark, there is a gas facility that emits around 1 million tons of CO2 each year. According to the Norwegian Environment Agency, it would be possible to electrify the facilities at Melkøya. Closing this facility could contribute to a reduction of Norway's CO2 emissions of about 2 percent (Miljødirektoratet, 2011). I believe that these kinds of positive externalities, or reduction of negative externalities, should be acknowledged in the surplus of the society.

On the other hand, environmental effects can be considered as negative, as explained in chapter 3. Some types of power plants emit CO2 or other gases, while other power plants have dominating negative effects in terms of visual effects, noise and consequences for the fauna. Even though assessing these affects can be challenging, there exist techniques for just this purpose. Life-cycle analysis (LCA) is a method used to evaluate the environmental effects related to all the steps in the life of a product, such as power plants (NVE, Enova, Norges forskningsråd, & Innovasjon Norge, n.d.-b).

In the report that describes Samoverskudd, it is said that "in addition to the surplus, it is often relevant to consider environmental effects" (Wolfgang, 2011). They are not, however, discussed related to Samoverskudd or suggested that they should be included in the calculations.

6.8 Delivery reliability

Our society depends on the electricity being delivered. It needs to be both on time and stable. Problems with the electricity increase the costs for the society, hence I believe that the delivery reliability is relevant to consider when calculating the economic surplus. If an investment contributes to increase the delivery reliability in an area or for the whole country, this reduces the probability of curtailment or system damages and this seems reasonable to include as a benefit or cost reduction. Melkeøya can again be used as an example. Today, there is not enough access to electricity in the area at Melkøya to electrify it and shut down the gas power plant. So, electrifying Melkøya requires that Statnett builds more grids in the area. Finland, which is close to Finnmark, is also planning on building grids not far from the border, which would give infeeds from two sides (Kjølle, 2011). This would strengthen the delivery reliability, which should count as a benefit in the calculation of the surplus.

To include the delivery reliability is not trivial, but there exist techniques to valuate it. The concept "Costs of energy not supplied" (CENS) is for instance used as an economic measure for the costs for the end-users when the electricity supply is interrupted. CENS is based on a survey from 2001-2003, that includes end-users from households, public businesses, agriculture, industry, trade and services, and wood processing and electricity intensive industry. For instance, the absolute costs of 4 hours of electricity outage are around 50 000 Norwegian kroner for industry, and more than 10 million kroner within wood processing and electricity intensive industry (Kjølle, 2011). In Norway, the total CENS are around 800 million kroner each year. This includes short run and long run interruptions, both warned and not warned (SINTEF, n.d.-b). These kinds of measures might be useful to value the delivery reliability.

Together with the environmental effects, the delivery reliability was mentioned in the report about Samoverskudd: "In addition to the surplus, it is often relevant to consider delivery reliability and environmental effects" (Wolfgang, 2011). However, the delivery reliability was referred to as something else than the economic surplus. I, on the other hand, believe that the delivery reliability should count as part of the surplus, as it is related to the costs and benefits of the society, and affects the economic development. For instance, power shortages is one of the key structural bottlenecks in South Africa, and reliable electricity supply is mentioned as a growth prospect (African Development Bank, 2017).

In addition to the environmental effects, the delivery reliability was not suggested to be included in the calculations of Samoverskudd either.

6.9 The graphical illustration of Samoverskudd

In the figure that illustrates the calculations method of Samoverskudd, figure 5.1 from chapter 5, some of the areas used to describe the surplus and loss costs do not fit the definitions. The graphical illustration in the report about Samoverskudd (Wolfgang, 2011) does not have impact on how Samoverskudd calculates the economic surplus. However, I still think that incorrect illustrations can lead to misunderstandings and confusion that can affect the explanation of how Samoverskudd works. Especially, if a new report about Samoverskudd is going to be written in the future, these suggestions about changes in the graph should be taken into account.

The consumer and producer surplus are illustrated correctly according to their economical theoretical description, i.e. between the demand and supply curve and the equilibrium price (or consumer and producer price, in case of for instance taxes). The congestion rent and the transmissions loss costs, on the other hand, appear to be incorrectly illustrated. As both components are part of the TSO surplus, this means that the TSO surplus is also misrepresented. In the report written by Wolfgang (2011), the congestion rent is described by area $C + H + K$. The transmission loss costs are $G + J + H + K$ and the internal loss costs is area E, which gives a TSO surplus of $C - (G + J + E)$ (Wolfgang, 2011). This was explained in section 5.2. The surplus of the different agents is summarized in a table from the report by Wolfgang (2011), which can be found in appendix A.1, table A.1. The area B is not included in this description.

However, I think that there are perhaps some mistakes here. First of all, the definition of the congestion rent is the product of the volume transferred multiplied with the price *difference* between the system price and the price in the area to where the power is transported (Bøhnsdalen et al., 2013). Also, in the report description, it says that the vertical position of the green segment is given by the price in the area to where it is exported and the system price is given in the intercept of the demand and supply curve (Wolfgang, 2011). Hence, I believe that the congestion rent would be equivalent to only area C, and not $C+H+K$. This is because area C is the result of multiplying the exported volume with price difference between the green segment and the equilibrium price.

Second of all, it seems like the transmission loss cost is also incorrectly illustrated. This is represented by $G + J + H + K$ (Wolfgang, 2011). By looking at figure 5.1, I think that including area B as a part of the transmission loss cost appears to be correct. Also, I am sceptic about area J and K, because they are between the supply curve and the x-axis. So, I suggest a revision of these areas. In the report (table A.1 in appendix A.1), area K is included both as part of the congestion rent and as a part of the transmission loss costs, which I do not find logical.

To summarize, I believe that the congestion rent and transmission loss cost should be represented by area C and $B + G$ respectively, in stead of $C + H + K$ and $G + J + H + K$. As the internal loss costs are illustrated by area E, this results in a TSO surplus of $C - (B + G + E)$, instead of $C - (G + J + E)$. This can be illustrated in figure 6.6, where area J, K and L are removed.

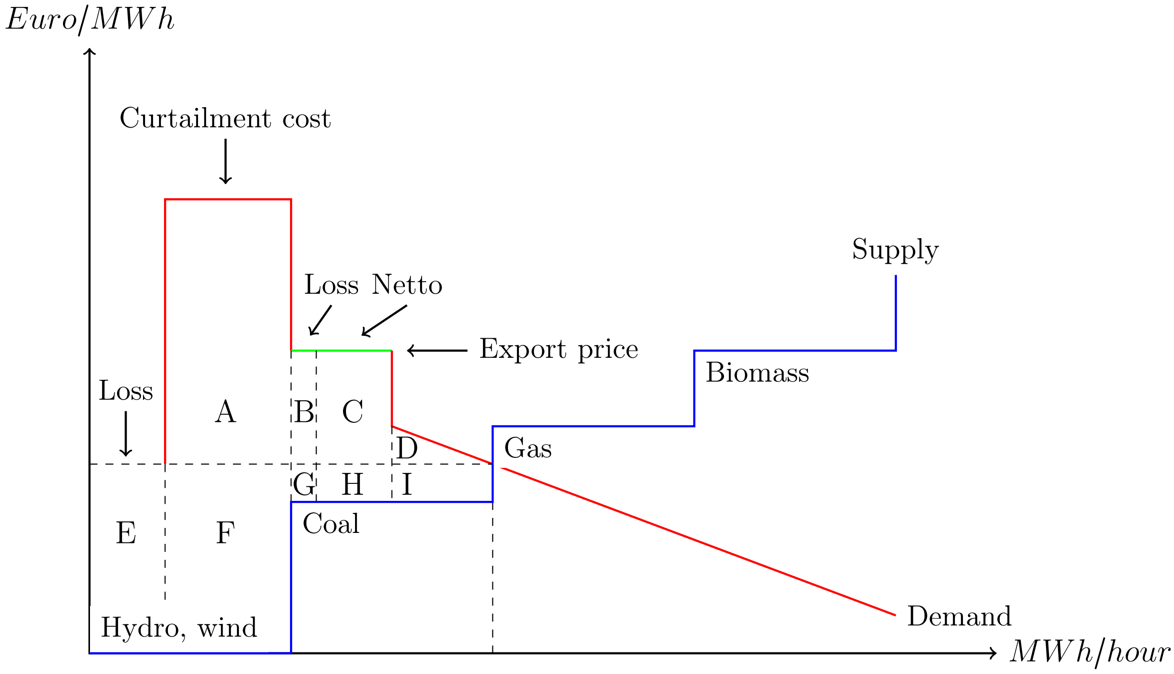

Figure 6.6: A suggestion for the graphical illustration of Samoverskudd, which excludes area J, K and L

7 Discussion and further work

7.1 Summary and limitations

I have acquired information and understanding of both the power market and the model, to give the best possible evaluation and suggestions for improvements of Samoverskudd. There are limitations to my knowledge about both the power market and the EMPS model, as the complexity of both the market and the model require in depth comprehension. At the same time, there seems to be an improvement potential that suggests that my evaluation is useful for further development of Samoverskudd. This is important, as a higher proportion of renewable resources will be included the power market, which requires assessments that contributes to an efficient use of resources. In the following, I will discuss the strengths and limitations to my evaluation.

As a result of my evaluation, I have found several suggestions that could improve Samoverskudd. In the Samoverskudd output-file, I found room for improvement concerning the TSO surplus. Firstly, it seems like Samoverskudd counts some components twice, as all the components that add up to the TSO surplus as also included separately. This can be seen in the Samoverskudd output-file in figure 5.2. It might be that Samoverskudd already accounts for this. For instance, the same way that start-up costs are added to the total surplus outside of the output-file, it might be that the components that I think are counted twice are withdrawn in some way outside of the out-out file. Still, it does not mention this in the report on which I base my evaluation. Therefore, I withstand my suggestion to investigate how these components are added in the output-file. Secondly, I suggested that the title of the TSO surplus should be revised. As it is the owner of the grid who receives the congestion rent, and possibly have to bear the costs as well, it might be an idea to change the title from "TSO surplus" to "Grid owner surplus." Consequently, it should be investigated which agents that should be included in the calculations, such as grid companies and producers. A limitation could potentially be that there are not enough grid companies and producers who collect congestion rent to make the changes significant. However, it appears that more producers will own grids in the future,[16] which implies that this should in fact be considered.

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[16] Provided by SINTEF in meeting, August 10, 2017.

Furthermore, reserves are getting increasingly important as more renewable resources will enter the market (Helseth et al., 2016). Therefore, I explained why and how I think reserves should be better integrated in Samoverskudd. As reserves are currently considered a restriction in the calculations, there are clearly an improvement potential concerning a new implementation of reserves. Although, the suggested approach to include reserves is not necessarily possible to practically implement, it introduces a new way of thinking of the reserves, which is a benefit to the society. For much of the same reasons, the delivery reliability was discussed. There are limitations concerning how to value delivery reliability, but I also discussed the "costs of energy not supplied" (CENS). For instance, if strengthening the grid could increase the delivery reliability, these benefits seem relevant to include in the calculations.

The suggestion in section 6.3 was related to including more than just one market in Samoverskudd. The current market can be interpreted as the wholesale market, but this excludes the consumers' and producers' surplus in the end-user market and balancing markets. However, there might be reasons unknown to me why there are not more markets included. For instance, it has been argued that simplifications of the EMPS model are made to shorten the calculation time (SINTEF, n.d.-c). Still, the exclusion of apparent relevant surplus calls for further investigation. If using the economic surplus as a tool to evaluate projects, the calculations should be accurate.

Next, I have argued that including changes in tax revenues could improve Samoverskudd. To investigate whether this is of a significant size, it could have been interesting to compare the tax quantities generated by a project to the surplus in the area in which the project found place calculated by Samoverskudd. I did not do this, but it is not within the scope of this thesis. Due to the tax exemption system, not all producers and end-users pay taxes. Nevertheless, with the economic arguments at hand from chapter 3, it seems that including changes in tax revenues can improve Samoverskudd.

Moreover, I found that changing the left part of the demand curve could lead to a more accurate calculation of the consumer surplus. Smart meters will make it possible for the end-users to adjust to short run prices and will be installed with all end-users within January 1, 2019. Though, it might have been correct to regard the left part of the demand as inelastic within a given hour, like it is done in the report, before the smart meters were introduced. However, with the smart meters already installed with some end-users in

Norway, this should be exploited to estimate the price elasticity and perhaps get a more correct calculation of the consumer surplus. Also, even though I have limited knowledge about challenges with the smart meters, the prospects look promising (NVE, 2015).

Concerning the environmental effects, approving projects can cause costs and benefits to the society, such as building power plants. Hence it appears reasonable to include in the calculations. Though, this might be too difficult to implement, as there are limited empirical estimates (Jensen et al., 2003b). Yet again, the life-cycle analysis (LCA) that can be used to estimate costs related to environmental effects suggests that it is still worth investigating (NVE et al., n.d.-b).

Moreover, discounting future benefit and cost flows are important to get the correct surplus and make decisions on the right terms. In fact, it might be that Samoverskudd already does it, even though it was not included in the description. Then again, I can only base my evaluation on the information that I have received. And based on the report I suggest that Samoverskudd discount future costs and benefits.

Furthermore, there were details of the graphical illustration that I think are incorrect and that should be revised, especially the congestion rent and transmission loss costs. Also, there appears to be a gap between the description of the surplus of the different agents and the table that summarizes them (in the figures in appendix A). However, the critique concerning the area between the supply curve and the x-axix, area $J + K + L$, is not so straight forward. Even though I am sceptic about including these areas, it does not mean that it is economically wrong. In any case, there are some mistake in the graph, and investigating it thoroughly can reveal exactly how to change it.

Lastly, and more generally, I wanted to restrict the evaluation to the Norwegian power market. In stead of describing the overall markets in the Nordic or North-European countries, I could thereby investigate the Norwegian power market in more detail. On the other hand, the Norwegian system is connected to the Nordic and some European countries, and thus the international system affects the Norwegian power market. It can be argued that this should be included in the analysis. Then again, the EMPS model is specifically meant for systems with a lot of hydro power, which describe the Norwegian power market better than the rest of the countries (Førsund et al., 2005). Hence, it makes sense to develop Samoverskudd to suit the Norwegian market in particular.

As a result of this thesis, I have found that Samoverskudd could be improved. Even though there are limitations to my evaluation, it still highlights shortcomings with how Samoverskudd calculates the economic surplus in the power market. My suggestions can contribute to further investigations and improvements that can have an impact in the Norwegian power market and how resources are used in new investments and projects. My thoughts of how to extend my work are described in the end of this chapter, in section 7.3. First, in section 7.2, I will discuss how future technological changes can affect the way the economic surplus is calculated in the power market.

7.2 A glance forward

The Norwegian power market is experiencing changes, such as integrating with Europe (Helseth et al., 2016) and smart meters (NVE, 2015). In light of future changes, it will be interesting to see how they will affect the way that the economic surplus is calculated in the power market. A change that has already started, is the possibility for consumers to become producers, or “prosumers.” Through for instance rooftop solar cells, consumers can both generate electricity and sell the excess electricity it to the grid. It is apparently expected that the electricity consumption in the world will increase by 49 percent between 2007 and 2035 (Rathnayaka, Potdar, Dillon, Hussain, & Kuruppu, 2012). Hence, prosumers could be a solution to this development. Some of the reasons why people have become prosumers, are because of consideration to the environment and climate change or to reduce electricity bills. In the future, this could completely change the market structure the way we know it today. An interesting question is: “How are we then going to calculate the economic surplus?” Perhaps there will not be the same need of producers as there is today, and that most households generate their own electricity. Then, perhaps there could be a market where one type of agent plays the role as both consumer and producer. Regarding the future, intriguing questions can be raised. How will the consumers’ and producers’ surplus be calculated, when the consumers are also the producers? And will traditional economic theory manage to explain the dynamics of this new market situation, or is there a need of new models?

7.3 Further work

With regard to the future development of the Samoverskudd, I have some thoughts as to how to extent this work further. The first step would be for researchers to investigate if the suggestions are possible to implement in Samoverskudd. Some of the suggestions have a larger potential of contributing with significant improvements than other, such as including the reserves, the changes in tax revenue and perhaps the environmental effects and delivery reliability. Another way to extent this work, is to widen the horizon by including imports and exports. That way, the Norwegian power market will be even more realistically presented. In addition, the analysis could be extended to include the Nordic and European markets. Lastly, for Samoverskudd to keep up with the technological changes, attention should be showed to developments in the power market and how this can affect the way that the economic surplus is calculated. Technology within smart meters and prosumers can develop before we know it, and then innovative research is crucial.

8 Conclusion

In this thesis, I have evaluated how Samoverskudd calculates the economic surplus in the power market and provided suggestions for how Samoverskudd could improve. Trough combining knowledge about the power market and economic surplus, I provided some specific suggestions. I pointed out that Samoverskudd might be counting the components of the TSO surplus twice and that the title of TSO surplus perhaps should be changed to "grid owner surplus" instead. Furthermore, I argued that reserves should be better accounted for, and not just be considered as a restriction. Also, unless it is too complicated to include in the EMPS model, there are also reasons for including more than just a representation of the wholesale market. This is because the surplus in the balancing markets and the end-user market are currently not included in the total economic surplus.

Additionally, as smart meters will enable the end-users to respond to short run prices, I suggest that it should be considered to change the left part of the demand curve in order to calculate the consumer surplus more accurately. Moreover, including changes in tax revenues in the calculations could improve Samoverskudd. Discounting past and future revenue and cost flows are also important when comparing projects. Lastly, environmental effects and delivery reliability should also be considered to include in the calculations, because they affect the surplus of the society.

Although further research is needed to investigate the strengths of the suggestions provided, the evaluation and suggestions could contribute to improve Samoverskudd. The EMPS model, and thus Samoverskudd, play a central role in evaluating large projects in the power market (Wolfgang, 2011). Any improvements are important, as wrongly approving or rejecting projects due to wrong estimations can make a significant impact. The thesis' relevance is also emphasized because of its focus on including more renewable resources, which will transform the way we produce electricity in the future (Helseth et al., 2016).

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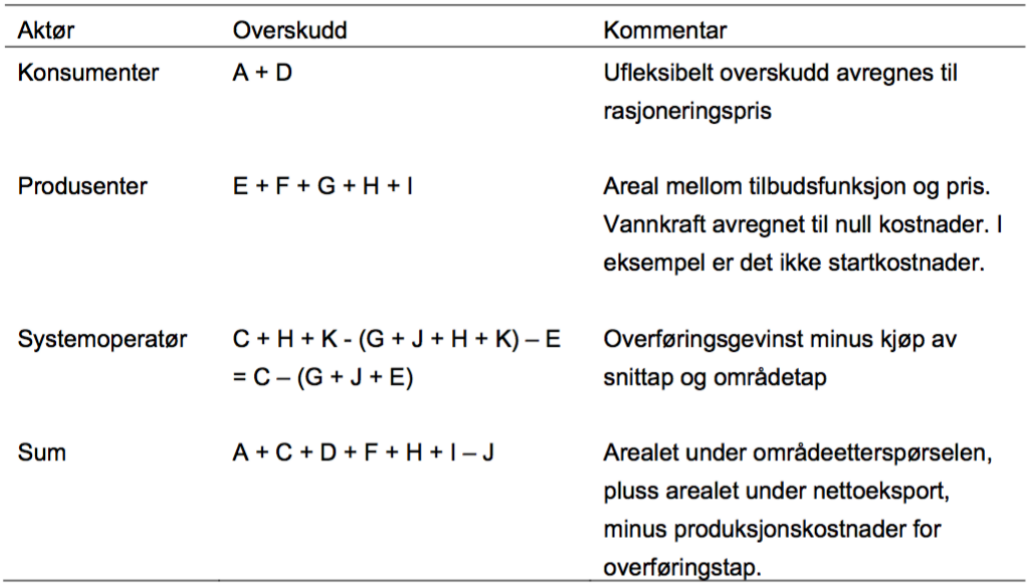
A Appendix

A.1 Table from the report *Samfunnsøkonomisk overskudd og Samoverskudd* (Wolfgang, 2011)

Table A.1 gives an overview of the areas illustrated in figure 5.1 from chapter 5. The relevant element is the TSO surplus ("Systemoperatør" in table A.1). According to A.1, the congestion rent is represented by the area $C + H + K$, the transmission loss cost is $G + J + H + K$ and the internal loss cost is area E. A discussion of these components are given in section 6.9.



Aktør	Overskudd	Kommentar
Konsumenter	A + D	Ufleksibelt overskudd avregnes til rasjoneringspris
Produsenter	E + F + G + H + I	Areal mellom tilbudsfunksjon og pris. Vannkraft avregnet til null kostnader. I eksempel er det ikke startkostnader.
Systemoperatør	C + H + K - (G + J + H + K) – E = C – (G + J + E)	Overføringsgevinst minus kjøp av snittap og områdetap
Sum	A + C + D + F + H + I – J	Arealet under områdeetterspørselen, pluss arealet under nettoeksport, minus produksjonskostnader for overføringstap.

Table A.1: Overview of the areas from figure 5.1 (Wolfgang, 2011)