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Electricity or the Environment? Better Economic Use of the Water Resources in the Grytten Power Plant.

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Abstract

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The once highly controversial Grytten hydroelectric plant that lead to the Mardøla campaign in 1970, will have its concession reevaluated in 2020. With its construction two waterfalls of highest national importance, Mardalsfossen and Mongefossen, were laid bare. The *Norwegian Water Resources and Energy Directorate* proposes that a minimum water flow in Mongefossen be considered for the upcoming revision of the concession, as was earlier adopted in Mardalsfossen in 1990. By employing an environmental benefit-cost analysis (EBCA) as a social appraisal procedure, this thesis evaluates whether or not this proposal is welfare enhancing. With the growing values on tourism, recreational fishing and higher environmental standards combined with current low electricity prices, the conditions surrounding the concession have changed significantly with respect to those of the 1970s and 1980s. For this reason, this thesis also considers other possible measures to enhance social welfare in terms of flow rates and flow periods. This thesis finds that a greater net present value of the EBCA can be achieved if other methods than those proposed by NVE are adopted and that greater quantity of water is better allocated to other purposes than the production of electricity. Three characteristics are identified to be important in this respect: higher flows, longer periods and the possibility daytime/nighttime flow adjustment. Tourism is seen to be crucially important with regards to decision-making between different possible measures.

Of sixteen cases considered for Mardalsfossen and Mongefossen, the solution than delivers the highest social surplus is found when daytime/nighttime adjustment of the flow in the waterfalls is combined with higher flow rates at daytime during the high tourist season. Compared to the minimum flow proposal of NVE, the increase in NPV is found to be 105% for Mardalsfossen with an increase in costs incurred by Grytten of 18%. For Mongefossen the corresponding increase in NPV is found to be 83% with an increase in costs of 60%.

Preface

Deep calls to deep
at the roar of your waterfalls

Psalm 42:7

There have been many contributors to this work that must be acknowledged. I would like to thank my main supervisor Eirik Romstad my co-supervisor Olvar Bergland for their availability and thorough help in all stages of the work, and also Ståle Navrud for helpful feedback. I must also thank Torunn Dyrkorn, marketing chief in *Visit Molde*, Are Sæther, maintenance manager at Grytten power plant, Vidar Skiri, director of Rauma river-owner's association, and Marit Wadsten, lecturer at Volda University College and upcoming author of a book on the Mardøla campaign, all of who made time to meet me and help with finding relevant data for the analysis of this thesis. I must also thank my family for all of their encouragement along the way, and especially my husband for all of his support. To my son, who will not be able to read this for some years, I must thank you for handling a busy mom with such gracefulness.

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Chapter 1

Introduction

On the 25th of July 1970 a group of locals and urban environmentalists demonstrated against the construction of Grytten hydroelectric plant, in what is possibly the world's first act of civil disobedience for the protection of environment [Andr, 2014]. Lead by eco-philosopher Sigmund Kvaløy Setreng (1934-2014), the demonstrators chained themselves to the mountain in the face of heavy machinery with the purpose of saving one of the highest waterfalls in Norway, Mardalsfossen. The movement, which came to be known as the Mardøla campaign, is often referred to as the *'mother of all Norwegian environmental campaigns'* since it has served as a model for Norwegian environmental activism ever since [for the Conservation of Nature NSCN, 2010], culminating in the Alta campaign in 1981. Despite unsuccessful in preventing Grytten's construction, the mardøla campaign played a pivotal part in the awakening of environmental concern in Norwegian society [Aardal, 1993], leading two years later to the Norwegian government's first Ministry of Environment. Although not in the epicenter of the controversy surrounding the construction of Grytten, the watercourse regulation would also close another waterfall of national importance, Mongefossen.

In the Norwegian 70's and 80's, heavy industries such us aluminum production required an increase in production of electrical power. The electricity exchange possibilities were more limited than today, meaning that aluminum production required energy production in close vicinity. The abundance of watercourses on the west coast were well suited for hydro power developments, which were comparatively cheaper than other forms of power. Hydroelectric plants were therefore seen as an attractive way to achieve economic growth and a source of securing employment [Hammarstrøm, 1970]. However, the high demand of energy in this period was often combined with a low awareness of the importance of the local environment.

In 2012 the Norwegian Water Resource and Energy Directorate (NVE) evaluated which of the concessions given for hydro power in Norway should be prioritized for revision within the year 2022 NVE [2012]. The report identifies environmental measures that should be considered: In 67% and 75% of the prioritized watercourses, measures concerning improvement of fish stocks and landscape/tourism, respectively, are especially emphasized. In 86% of the prioritized watercourses, including Mongefossen, a measure of minimum flow is proposed for future consideration. Such a measure was introduced in Mardalsfossen in 1990 whereby Grytten became required to allow a flow through the waterfall of 2.5 m^3/s from the 20th of June until the 30th of July and 2 m^3/s from the 1st of August until the 20th of August.

Although fifty years is a moment in the lifetime of a waterfall, by the time of the upcoming concession-reevaluation for the Grytten hydroelectric power plant in 2020, the underlying operational conditions will have changed considerably. As of today, higher value is placed on tourism, recreational activities such as hiking and fishing, and environmental standards. Furthermore, low energy prices may be expected for the foreseeable future due to political incentives towards clean energy. The 2020 reevaluation of the Grytten concession should therefore not be approached with an a priori attitude of maintaining the status quo: that would entail missing out on the new possibilities now opened up. The environmental benefit-cost analysis (EBCA) employed in this thesis will work as a social appraisal procedure that corrects for market failure and enables that positive externalities related to an increased flow can become relevant for decision-making.

This thesis will explore the economic implications of allowing a minimum flow, as well as other flow rates, combined with varying periods of time. A welfare enhancing application of the environmental measure will call for allocation of water to the purpose where its value is the highest (as measured by the Net Present Value, NPV). It is likely that when internalizing the environmental benefits of releasing water, the application that delivers the highest NPV entails a higher loss of energy production compared to what it would have yielded in 1970. Therefore, the question that remains is not just if a minimum flow is socially beneficial, but rather, in a bigger picture: How much water should be released so that the environmental measure delivers the highest social surplus?

1.0.1 Background

From the 70's onwards, the price of aluminum took off. There was a high demand for power, and little awareness on the value of biodiversity and the environmental impacts that hydro power plants could result in. In the 80's, Norwegian aluminum industry was strong and exported almost 90 percent of its production[1] [Klette, 1988]. These circumstances favored the construction of controversial hydro power stations like that of of Grytten. Nearby, in Sunndalsøra an aluminum had been constructed in 1954 plant which increased the local demand of electricity. Today this plant, owned by Hydro, is the largest primary aluminum plant in the whole of Europe with a total capacity production of over 400.000 metric tones per year [Norsk Hydro ASA, n.d.].

With an abundance of watercourses available, hydro power came to be regarded as an almost unlimited source of power. Combined with the need for more power, a large increase in the number of regulated watercourses followed. From 1906 to 1989 the Norwegian authorities had granted the permission of 500 watercourses, with only 2% of the total applications being rejected[Norwegian Environmental Agency, 1984]. The concession for Grytten power plant was given on the 31st of July 1970 [Stortinget, 1970], and production started in 1977 [Statkraft, 2015]. At the time of the concession the director of the Norwegian Water Resources and Energy Directorate (NVE)[2], Vidkunn Hverding, considered the construction as the only option for covering the expected future rise in demand at a low cost [Hammarstrøm, 1970]. The production at the time of the license was around 60 TWh, of which the industry consumed about 24 TWh. A 20% increase was expected in the industry consumption by 1975, along with a similar rate for general consumption (from 6% to 8% per year), meaning that a demand of more than 100 TWh was expected by 1980. In order to cover the envisioned electricity needs, the public authorities deemed it necessary to invest in hydroelectric projects that gave a sufficient supply also for dry years. The comparatively low prices of hydro electricity with respect to thermal and nuclear power[3], was used as an argument in favor of this.

The hydroelectric project of Grytten regulated a network of lakes, three of which are the sources of the waterfalls Mongefossen and Mardalsfossen. The latter is among some rankings considered to be the fourth highest waterfall in the world[4] [for the Conservation of Nature NSCN, 2010] and the second highest in Norway [SSB, 2013]. Mardalsfossen falls 705 meters into the river of Mardøla leading into the forest area of Mardalen and discharging its water in the lake of Eikesdalsvatnet (see Fig. 1.1). The waterfall is formed by two free falls, where the upper one has the highest fall, measuring 250 m. The waterfall collects water from the basins of Fossafjellvatn and Sandgrovvatn,

[1] Averaged over the years 1983-86.

[2] In that time called the Norwegian Water Resources and Electricity Administration, *Norges Vassdrags- og Elektrisitetsvesen.*

[3] 2.5-3 øre NOK against 4.2 and 4.4 øre NOK respectively

[4] There exist various ways of defining a waterfall, so the measures do not always agree among difference sources. According to NVE a waterfall is a part of the river where the water has an almost vertical drop. That is, steeper than 30 degrees or about 2 meters drop per horizontal meter. With this criterion, Mongefossen is ranked as the third highest waterfall in Norway, while Mardalsfossen is the tenth. According to the national ranking by Statistics Norway (SSB), Mardalsfossen and Mongefossen are ranked second and third, respectively, in Norway.

which are regulated by the hydropower plant. Mongefossen is considered to be the third highest waterfalls in Norway [SSB, 2013]. The river Mongeelv descends from the basin Mongevatn, which is regulated (see Fig. 1.2). The waterfall has been left dry since the construction of the hydroelectric plant (except in periods of flooding when the dam capacity is breached).

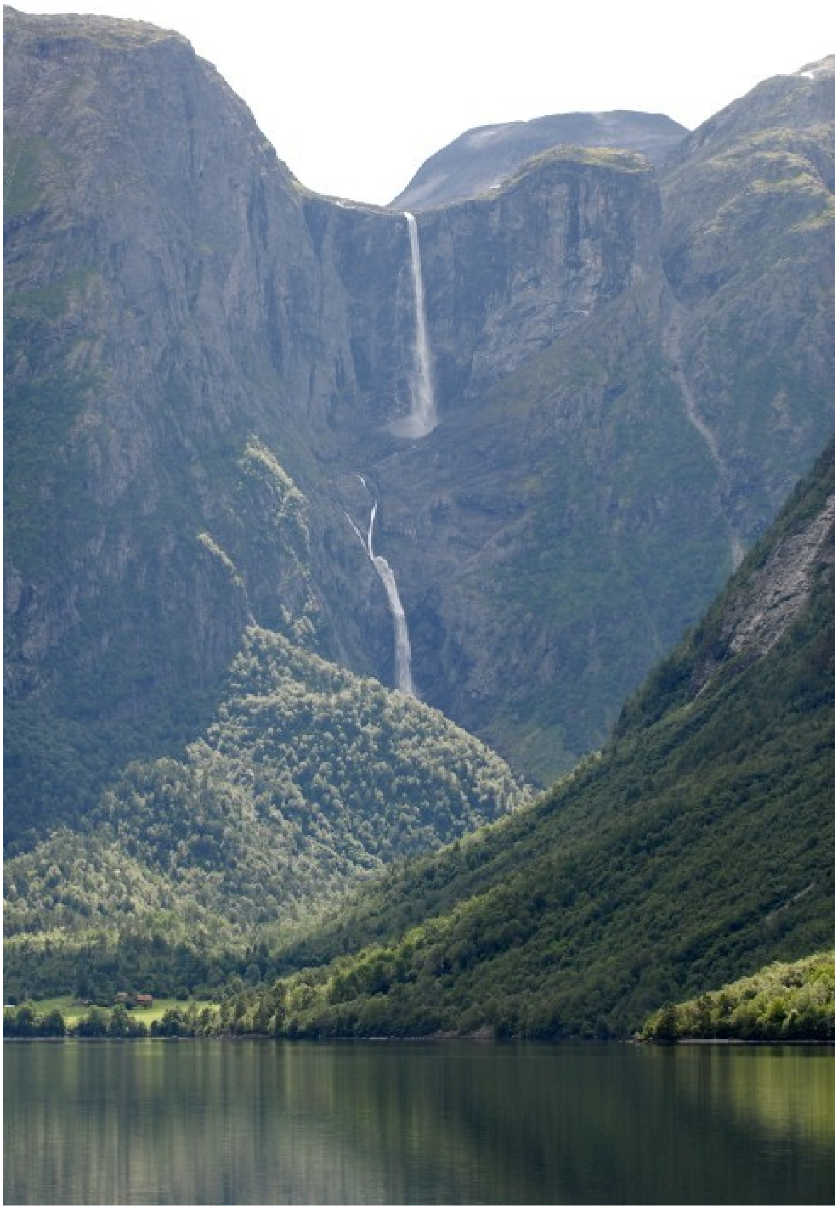


FIGURE 1.1: Mardalsfossen. Photo by Bjørn M. Øverås.

As mentioned, the hydropower development of Grytten was controversial mainly due to Mardalsfossen. One may wonder why both waterfalls were not equally controversial given the national importance of both. Several factors were involved. The grytten hydroelectric plant and Mongefossen are both located in the municipality of Rauma, the

FIGURE 1.2: Mongefossen. Photo by Andreas Normann, accessible from Rauma Folkebibliotek.

main beneficiary in terms of jobs and income from the electricity production. Mardalsfossen, on the contrary, was located in Nesset municipality by the town of Eikesdalen, which had already experienced loss of water flow due to a previous hydroelectric development known as Aura. In addition to local opposition in Mardalsfossen, the movement included a number of political and intellectual personalities. Professors Arne Næss and the environmental philosopher Sigmund Kvaløy Sætreng were important intellectuals in the movement. Other influential participants included the political leader Odd Einar Dørum of the Liberal Party of Norway (*Venstre*) and the organization Group for Nature and Environment Protection *Samarbeidsgruppe for Natur- og Miljøvern.* (SNM). The movie director Oddvar Einarson also played a critical role on the diffusion of the movement to a broader public through the movie *Kampen om Mardøla (1972).*

Although the so-called *mother of all Norwegian environmental campaigns* did not manage to stop the construction of Grytten, environmental associations were formed and proliferated after the campaign. The world's first environmental ministry was set up two years later and the first conservation plan was adopted after three years. Furthermore, the need for recreation, potable water, irrigation for cultivated land and the use of water as a recipient for waste became gradually more important, and contributed to the inclusion of environmental measures in new watercourses [Norwegian Environmental Agency, 1984]. Legislation also gradually changed in order to meet the growing environmental concerns. The possibility to revise licenses was introduced in 1959 through the watercourse law and the industry license law. The time horizon for the revision of licenses for water developments was changed to 50 years for power plants that had been given concessions with an indefinite time period. The concession term for revision was changed to 30 years for both definitive and indefinite licenses through the amendment of the watercourse law in 1992[5] [Det Kongelig Olje- og Energidepartement, 2012].

There was no national coordination with respect to the granting of concessions for hydroelectric developments until the proposition of *Master Plan number 63 (1984-85) on national management of watercourses* was presented to the Norwegian Parliament. Environmental interests were for the first time taken into account in order to prioritize (or to prevent) the hydropower projects for the subsequent consideration of a license [Norwegian Environmental Agency, 2013]. The Master Plan ranked hydroelectric projects in terms of groups of profitability, energy needs, the values of the watercourses, and the level of regional conflict. The projects with the highest level of conflict and/or costs in comparison with energy demand were not considered for a license. In order to categorize the projects economical evaluations were made. The appraisal method used can be considered as an emerging form of an environmental benefit-cost analysis (EBCA), although non-use values were only included as qualitative elements in the assessments. The responsibility of the Master Plan is now administrative and economic reports are not presented any more, although the evaluation is based upon previous knowledge.

The changes in the legal framework also reflect increased environmental concerns. The Master plan is currently guided by the *EU Water Framework Directive for Water Bodies*. Its objective is to achieve a *good ecological status* for water bodies by 2015 through the implementation of a national river basin management program. The program identifies the environmental impacts, what measures to apply and their implementation, and the ways in which they are to be monitored. That being said, the 2015 target does not need to be reached if improving ecological status of the water body entails extraordinarily greater costs compared to the environmental benefits. In this context, EBCA has been

[5] For the licenses given before the time of the amendment, the time would be 50 years from the time of the concession of the license and in any case 30 years after the time of the amendment in 1992.

proved to be a relevant decision-making tool to inform policy in light of the water directive [Hanley and Black, 2006; Molinos-Senante et al., 2011].

Nowadays, the situations has changed since the 1970s. There are higher environmental standards, moreover other important interests are involved in the allocation of natural resources such us tourism and recreational fishing. Raumavassdraget is the river located beside Grytten and is known for being a national salmon river. National salmon rivers usually attract fish enthusiasts from all over the country, and also from abroad. The income that licenses and accommodation provide is often of key importance for the local economies. Recreational fishing is generally of major economic importance in high income countries, and its growing demand often requires that public agencies address the conflict of interest between different interest groups [Tisdell, 2003].

The west coast of Norway is known to be a popular tourist destination in summer due to its spectacular nature. It is estimated that Trollstigen, one of the natural tourist attractions closest to the power plant, was visited by over half million people during the summer of last year [Smisethjell, 2014]. Total tourist consumption is estimated to amount to 25 billions NOK during summer 2013 [Innovasjon Norge, 2013]. Although domestic tourism still constitutes most of the tourist related revenues, international tourism is of high importance due to the generally higher daily consumption of internationals.

The electricity price in the Nordic electricity market in 2012 and 2014 were the lowest of the past 14 years[6] [Nord Pool Spot, 2015], and it is expected that that the low price situation continues at least until the electricity cables from Norway to England and Germany are in place [Montel Nyhetsbrev Norge, 2015]. Through the green certificate agreement that came into force in 2012, both Norway and Sweden committed themselves to the ambitious target of increasing their share of renewable electricity by 2020. In the Norwegian case, the increase of renewable electricity will lead to an electricity surplus for the coming years [Enova, 2014].

1.0.2 Research question, hypotheses and overview

This thesis aims at answering the following research questions:

> RQ1: *–Is it welfare enhancing to employ NVE's proposed minimum flow regime for Mongefossen from mid-June until mid-August?*

> RQ2: *–Which form of flow regulation yields the highest social surplus for Mongefossen and Mardalsfossen?*

[6] Adjusted for the Norwegian CPI.

The current water regime set by NVE –The Norwegian Water Resources and Energy Directorate– for Mardalsfossen waterfall states that a water flow of 2.5 m^3/s from the period of the 20th of June to the 30th of July and 2 m^3/s from the 1st of August to the 20th of August should be allowed to pass through the waterfall. This quantity is the particular *minimum flow* for Mardalsfossen, representing the 5th percentile of water flow (i.e. the water flow that is surpassed 95% of all days during the summer and winter half-years, respectively [NVE, 2012]). This type of flow regulation will be referred to in the shorthand form *minimum flow regime* or *MF regime* in this thesis. When only the period is referred independently of the flow rate, *minimum flow period* or *MF period.* When only the flow rate of 2-2.5 m^3/s is referred independently of the period, *minimum flow rate* or*MF rate* used For the concession reevaluation in 2020 of the Grytten power plant, NVE proposes to introduce a minimum water flow in Mongefossen as well [NVE, 2012]. It is not stated, however, what flow value the 5th percentile will correspond to in this case, or for what period this should be introduced. What it states is that the measure should cause up to 5% production loss in the power plant. Estimates of the production loss incurred by the NVE minimum flow regime in Mardalsfossen are on the same order (Case 1 in section 5.1). It therefore seems plausible to assume that the minimum flow and period in which this is to take place should resemble that of the NVE minimum flow regime for Mardalsfossen. Research question 1 (RQ1) presupposes this assumption.

Given the positive externalities of the water flow in Mongefossen and Mardalsfossen to for instance tourism, recreation, and non-use existence value, an important objective in this thesis is to evaluate whether the operational regimes can be altered in order to attain a higher social surplus, as expressed in research question 2 (RQ2). The effect of different flow rates and periods will be considered in 16 case-scenarios, nine for Mongefossen (Cases 1.0 to 1.8) and seven for Mardalsfossen (Cases 2.0 to 2.6) in section 5. The results of these will help to explore the following hypotheses:

> H1: – *Daytime/nighttime adjustment of the water flow decreases the cost incurred by Grytten power plant and is beneficial from a EBCA perspective.*
>
> H2: – *Upon increasing the water flow, the benefit from tourism will outweigh the costs incurred by Grytten power plant.*
>
> H3: – *Extending the period of minimum flow, in order to cover the peak tourist season* [7]*, outweighs the costs incurred by Grytten power plant.*

[7] High tourist season here refers to the period from the 1st of June until the 31st of August.

H4: – *Extending the period of minimum flow to cover the whole year can be justified by the increase in benefits from recreational fishing and willingness to pay for non-use values.*

H5: – *The present minimum flow regime is detrimental to a potential increase in the NPV.*

H6: – *When considering what type of regulation to implement, variables such as tourism, recreational fishing and electricity prices are relevant for decision-making.*

These will be discussed one after another in section 6. Finally, the results of these discussions will be used to draw conclusions in section 7 for RQ1 and RQ2.

1.0.3 Scope and Structure of the Thesis

This aster thesis provides an overview of the relevant factors necessary to be taken into consideration in the upcoming revision of Grytten power plant. The key parameters that are affected by the choices on regulation are identified, as well as their interrelation. Given than a marginal increase on flow corresponds to approximaly the same increase on tourism benefits *'waterfall experience'* for low flow rates, the potential increase in the Net Present Value (NPV) is evaluated, and other measures are considered in the event that this assumption does not hold. Investigations into the weaknesses of the current regulation –the minimum flow regime in Mardalsfossen– are made, and forms of regulation that hold the potential to increase welfare further are proposed for both waterfalls Mardalsfossen and Mongefossen. Given the complexity of the given task, assumptions have had to be made which should be the topic of further inquiry. In particular it would be instructive to conduct a study that identifies the marginal increase on *'waterfall experience'* or *willingness to pay for non-use values* in relation to the increment of the flow in a waterfall, in order to estimate the flow value that maximizes utility. Functions describing these relations would serve to better inform environmental policy-making. Such an investigation would however require access to data that were not available during the writing of this thesis –either because such data were not known to exist by the author, or because they were not openly published. Therefore, when a proposed solution is evaluated in this thesis to give a maximum social surplus, this is to be understood in comparison to the case-scenarios appraised here, under the given assumptions. The relevant underlying assumptions are presented and discussed in terms of possible shortcomings in sections 4 and 6. Since identification of the real utility functions for the most part fall outside the scope of this thesis, only first approaches are made with respect to these on the basis of data accessible to the author. On this note, a field trip to the north-west coast of Norway was conducted in which a significant amount of helpful data was gathered from representatives of different interests surrounding the waterfalls (see section 4.1). Hopefully this thesis has succeeded in laying out the groundwork for further inquiries by giving an overview of the important factors, and has pointed out some plausible solutions that enhance social welfare for the upcoming concession reevaluation.

Here follows an overview of the ensuing discussions:

> Section 2 presents the general conceptual framework for the environmental benefit-cost analysis.
>
> Section 3 discusses the terms in the equation for the benefit-cost rule.
>
> Section 4 presents the data and the assumptions.
>
> Section 5 presents the analysis of the different case-scenarios.
>
> Section 6 summarizes the results of the analysis, and discusses the findings.
>
> Section 7 answers the research questions, summarizes the findings of this article and identifies themes for further inquiry.
>
> Appendix A and B supply the background data for the analysis in section 5.
>
> Appendix C supplies some photographs from the field excursion to Åndalsnes, Molde and Eikesdal.

Chapter 2

Theoretical Framework

When appraising the project of a hydro power plant it is useful to apply the economic tool of benefit-cost analysis, since decisions that involve a change on the level of electricity production in a hydro-power station, may entail future consequences for the environment. Economic analysis typically seeks to economically evaluate environmental impacts that otherwise would be neglected by the private profit maximization function of hydro power plants. Private or commercial evaluations would not take into account external effects in their ordinary financial appraisal. Environmental damages – as reduction of biodiversity and water for recreational purposes – would be part of the negative externalities of running a hydropower plant. If the project evaluation pursues the goal of being welfare enhancing, externalities should be incorporated and become decision-making relevant along with ordinary inputs and outputs.

2.1 Net present value

The environmental benefit-cost analysis (EBCA) of this master thesis will incorporate both the negative and positive externalities that may arise as a consequence of electricity production and therefore net present value (NPV) will be treated from a social perspective. Monetary valuations will be attached to environmental goods and the project will be recommended to go ahead if NPV is still positive after correcting for market failure. Net benefits across individuals will be added at a point in time and then the sum of net benefits will be discounted. The form in which the social NPV (NPV_s) will be presented is intended to suit our case and the costs and benefits of environmental character will be separated –as often done in the literature[1]from the 'commercial' ones for the purpose of

[1]See for example [Perman, 2003] –.

clarity, since different methods are used to estimate them. Social NPV could be written as:

$$
\begin{aligned}
NPV_s &= \sum_{t=0}^{T} \frac{EB_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{EC_t}{(1+r)^t}, && \text{(2.1a)}\\
&= \sum_{t=0}^{T} \frac{B'_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C'_t}{(1+r)^t},\\
&= ENB_d - NC'_d, && \text{(2.1b)}
\end{aligned}
$$

where EB, EC, B' and C' denote environmental benefits, environmental costs, ordinary/commercial benefits and ordinary/commercial costs, respectively.In (2.1b) ENB_d represents the environmental discounted Net Benefits, assuming that when environmental impacts are taken into account then the benefits of releasing water offset the environmental costs. NC'_d represents the discounted Net Cost, assuming the consequences for the environment have not been taken into account. In this case, one assumes that commercial NC'_d of letting more water pass through the waterfall offsets benefits from the hydropower plant standpoint.

If $ENB > NC' = NPV_s$, then NPV_s is positive and the project should go ahead. In continuous time, the social NPV can also be written:

$$
\begin{aligned}
NPV_s &= \int_0^T ENB_t \mathrm{e}^{-rt} dt - \int_0^T NC'_t \mathrm{e}^{-rt} dt && \text{(2.2a)}\\
&= \int_0^T \mathrm{e}^{-rt} \big(ENB_t - NC'_t\big) dt && \text{(2.2b)}
\end{aligned}
$$

The consequences of increasing the water flow in *Mardalfossen* do not cease when the project is completed due to the fact that the consequences for the wilderness are long term. If we suppose than $T \to \infty$ and yearly costs and benefits are constant, the mathematical formula can be simplified:

$$
\begin{aligned}
NPV_s &= \int_0^\infty ENB_t e^{-rt} dt - \int_0^\infty NC'_t e^{-rt} dt\\
&= (ENB - NC') \int_0^\infty e^{-rt} dt\\
&= \frac{ENB - NC'}{r} && \text{(2.3)}
\end{aligned}
$$

2.2 Setting the social discount rate and the time period

The values calculated in the NPV are sensitive to how one weighs the consequences in the distant future. Since the lifespan of hydroelectric projects are long, one should take care to avoid choosing a discount rate that neglects the environmental impacts that one intends to include in the EBCA. Likewise, the time horizon chosen when calculating the social NPV of a project should extend to the period in which the environmental impacts cease to exist [Perman, 2003]. For instance, when appraising a hydroelectric project with a lifespan of 40 years, the time horizon should extend to include the period when the last negative (in this case) environmental impact ceases to exist. If the plant contaminated the water, damaging the fish population for 5 years after the project was decommissioned, the time orizon should be 45 years instead of 40.

A high discount rate disregards the consequences of the project for future generations and most literature is critic towards choosing high social discount rates where negative externalities for the environment are spread over time. Therefore, high social discount rates are usually avoided when an environmental valuation is involved [Stern, 2007]. Furthermore, some would claim that high discount rates are bad for the environment [Ackerman and Heinzerling, 2002]. Since determining the social discount rate is therefore not a trivial matter, the most relevant models discussed in the literature shall here be reviewed in order to identify the appropriate social discount rate. Understanding the reasoning behind the different approaches and their implications will be useful for the later sensitivity analysis.

The social discount rate, r, also called the consumption rate of interest, could be defined from both opportunity cost and consumption perspectives. The former is identified with consuming in a later period instead of investing the money in the capital market (for example the bond market or the share market) in a present period and enjoying of an additional consumption provided by interest yield in the later period. The latter is related to the minimum compensation needed for postponing present consumption for the future.

A common model used from the opportunity cost perspective is the Capital Pricing Mode, generated by Sharpe [1964] and Lintner [1965].

In Norway, the Green Paper of 1997 recommended to use the Capital Pricing Model (CAPM) to calculate the social discount rate [Ministry of Finance, 1997]. The CAPM determines what the expected return of an asset should yield given its risk profile. The risk is greater if the return associated with the asset is correlated with the return on the market portfolio, which is composed of all the assets of the economy. The higher the sensitivity of an asset is to the market risk, the higher return an investor will require.

The risk is considered as non-systematic when it can be diversified by holding different securities. On the other hand, the systematic risk cannot be diversified and therefore a risk premium is required. The idea behind using the CAMP for public projects is that the risk premium can be found by identifying the financial assets in the capital market which share a similar risk profile. The risk-adjusted opportunity cost of a public project should cover at least the risk-free rate of return and the associated premium risk. The specific risk premium should reflect the uncertainty of the economic outcome of the project. Thus, the systematic risk depends on the conjunction of the economy when the benefits and costs of the project accrue.

Although it may therefore seem simple to calculate the r of public projects theoretically, several complications may arise. The CAPM is valid for only one period and this simplification means that the discount rate adjustment model will often not be suitable to discount projects with a long time horizon Ministry of Finance [2012]. Contrary to the premises of the model, the interest rates, risk premiums and volatilities are not constant and vary over time along with business cycle fluctuations. Furthermore, for projects with a very long-term perspective there may be no other assets to which the maturity can be compared Ministry of Finance [2012]. Further complications that should be mentioned include the fact that the CAPM assumes that any project can be compared with an asset in the capital market, but in practice this is hard to achieve because not all wealth is tradeable and hence reflected in the market Ministry of Finance [2012].

From the consumption-based perspective, the required rate of return of the Ramsey equation, named after Ramsey [1928], has been the model commonly used. It has also been found to be more suitable for projects with consequences that spread over several periods. Furthermore, the variables provided in the equation allows for the addition of ethical considerations for future generations. The required rate of return of the Ramsey equation may be expressed as:

$$r = \rho + \eta g, \tag{2.4}$$

where ρ is defined as the utility discount rate or consumers rate of time preference, η is the elasticity of the marginal utility of consumption and g is the growth rate. The parameters ρ and η shall now be discussed in turn.

The consumer rate of time preference ρ is understood as impatience, i.e., the degree to which the utility of consumption is reduced upon delay into the future. There has been little agreement about its value: The prescriptive and descriptive approaches have argued for lower and higher values, respectively, relative to each other. There is no reason to believe that the divergences of opinions are going to arrive at a consensus because attaching different weight to the welfare of different groups and generations is related to ethical values and different perceptions of equity are difficult to reconcile.

Those who defend the descriptive approach argue that the value of ρ can be revealed from market behavior. For instance, with $\eta = 2$ and consumption growth $g = 2\%$, a 2% in ρ could be inferred when the market return of investment is 6% (Nordhaus 2007; Weitzman 2007).

The supporters of a rather prescriptive approach, endorse a value of ρ close to 0 based on ethical grounds [Stern, 2007; Cline, 1993; Grant and Quiggin, 2003] and argue that a value far from 0 discriminates future generations, since this fact that utility of the individual now being worth much less than the utility of future generations causes a discrimination hard to defend [Stern, 2007]. The reasoning that supports a nonexistent, or very small, ρ is already introduced by renowned economists such us Ramsey [1928], Pigou [1932] and Solow [1974]. According to Stern [2008] the only ethical reason to adopt a positive ρ would be the one illustrated by Beckerman and Hepburn [2007] based on the idea that one has stronger fellow feelings for those closer to us that the ones that will live in the future. Nevertheless, Stern [2008] argued that this type of reasoning derived from evolutionary biology of the survival of groups is ironical because its application in environmental issues would hinder the survival of the earth and thus the groups living on them [Stern, 2008].

The parameter ηg is related with the preference of consumption smoothing. When there is economic growth, consumption is expected to increase. However, when one is rich the utility of consuming is less than when one is poor. It is therefore assumed that continued growth results in an increasing declining rate.

In practice, when measures or long-time projects that affect future generations are considered, even the defenders of high social discount rate derived from opportunity cost, argue for a prescriptive approach [Harrison, 2010]. This view seems to have impacted the recommendations of European countries on the social discount rate applicable to benefit-cost analysis. They have followed a downturn variation from typically a 6-7% to a 3-4%. One example is the UK, where the HM Treasury recommended a discount rate of 6% in 1996 and decreased it to 3.5% in the later edition of the green book of 2003, where the value of ρ was set at 1.5%, η at 1 and g at 2%, [HM treasury, 2003].

Norwegian's public authorities also followed a downward tendency when recommending the use of social discount rates. Since the power plant is located in Norway, the risk-adjusted discount rate recommended by the Ministry of Finances Ministry of Finance [1997] will be used as guideline in this Master Thesis, and the different approaches presented that supported either higher or lower social discount rates will be used as foundation for its variation in the sensitivity analysis. The norwegian guidelines about benefit-cost analysis Ministry of Finance [1997] recommends a risk-adjusted discount rate of 4% (risk-free 2%), if systematic rate applicable, for effects in the first 40 years. From 40 to 75 the rate declines to 3%. Beyond 75 years, a rate of 2% is recommended.

Therefore, the discount rate used will be 4%, corresponding to a 30 years. Since the periods between concessions is set to be 30 years, the period used in calculating the NPV will also be 30 years unless the analysis shows otherwise in the event that fish related benefits are large in comparison to other benefits. the concession was first give to Grytten power plant in 1970 and the revision is taking place 50 years after in 2020 the revision of concessions was changed to 30 after the amendment of watercourse regulation low in 1992.

2.3 Addition of the Krutilla and Fisher variable

The Krutilla and Fisher variable (KAF) is a new variable that can be added to the benefit-cost analysis when environmental benefits (or costs) are appraised. It was introduced by Krutilla and Fisher [1975] and it is linked to the idea that the value of environmental services increase over time relative to ordinary inputs and outputs. Due to technical progress other ways to produce electricity than by hydropower are developed and become more effective. In addition, the use of other carriers than electricity are also explored, for instance, using heat pumps to warm up the houses instead of electricity. Hence, substitution possibilities are expected to increase over time as economical progress is made. Demand is also expected to rise along with economical growth, but the increase in demand may be met at decreasing costs over time.

Regarding environmental goods and services, however, Krutilla and Fisher (KAF) argue that economic growth usually increases the willingness to pay for wilderness benefits because technological progress will probably not increase substitution possibilities of environmental services over time. Assuming that preservation benefits grow over time, the KAF variable a can be incorporated in the EBCA – as shown in Perman [2003]– in the following way:

$$\begin{aligned} NPV_s &= \int_{t=0}^{T} (ENB\mathrm{e}^{at})\mathrm{e}^{-rt}dt - \int_{t=0}^{T} NC' e^{-rt}dt, \\ &= ENB \int_{t=0}^{T} \mathrm{e}^{-(r-a)t}dt - NC' \int_{t=0}^{t=T} \mathrm{e}^{-rt}dt, \end{aligned} \tag{2.5}$$

where T is the time horizon, and r is the social discount rate. The parameter a is the Krutilla-Fisher variable, whereby the value of environmental services increases over time. Solving (2.5) gives

$$NPV_s = \frac{ENB}{r-a}\left[1 - \mathrm{e}^{-(r-a)T}\right] - \frac{NC'}{r}\left[1 - \mathrm{e}^{-rT}\right]. \tag{2.6}$$

For a long time horizon $T \gg 1/(r-a) > 1/r$ the exponential functions become negligible giving the result

$$NPV_s = \frac{ENB}{(r-a)} - \frac{NC'}{r}. \tag{2.7}$$

2.3.1 Deciding KAF from an Optimality point of view

The optimal level of environmental services (Q^E) is found where the demand for environmental services (D^e)equals the supply for environmental services (S^e). In the case of Grytten, the environmetal services provided can be for instance basin restrictions or minimum water flows that mitigate the negative environmental impacts. It is assumed that it is costly for grytten to provide the environmental services.

When the concession was given in 1970, such environmental requirements were, for the most part, ignored in the evaluation of the project. Accordingly, electricity was produced until Grytten's marginal benefits (MB) were 0, and therefore the was no supply of environmental services, q_1, as shown in fig. 2.1 shows that when the environmental services are taken into consideration in the EBCA, even if only partially meaning that optimality is not reached, significant net benefits for society may result.

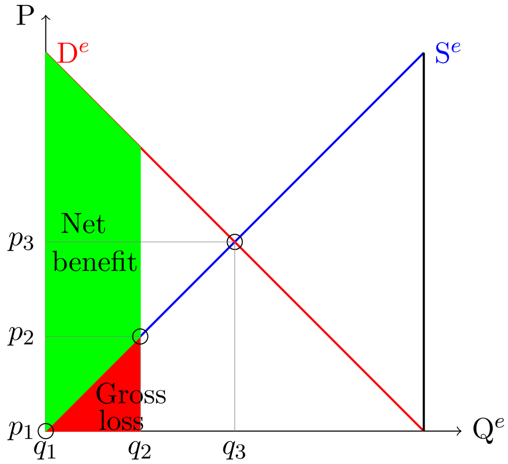


FIGURE 2.1: The parameter q_1 represents the quantity 0 of environmental services that Grytten provides when the demand for environmental services is not taken into account. Any higher quantity of environmental services than q_1 would entail a significant net benefit for society, as indicated at the quantity q_2. The optimal quantity of Q^e is found at q_3.

The addition of the KAF parameter, a, as discussed in Sec. 2.3, can also be justified from an optimality perspective. Factors like willingness to pay for environmental goods, change of technology and preferences may affect the supply for environmental services (S^e) and demand for environmental services (D^e) curves differently over time and hence, optimal quantities of electricity may vary as well.

If there is an increase in willingness to pay for environmental services and economical growth over time is assumed, the (D^e) would also increase. The size of this increment would depend on the elasticity of the demand. The discussion of whether the income elasticity for environmental goods is greater than 1 is related to the concept of "the environmental Kuznets curve". Despite being defined by [Grossman and Krueger, 1991], it was [Panayotou, 1993] who used that name for the U-shaped relationship between industrial pollution per capita and income. The inverted U indicates that pollution increases at early stages of economic development until it reaches a certain turning point, from which the pollution decreases with increasing income per capita. Yet, it is too daring to conclude that economic growth decreases pollution [Beckerman, 1972]. If environmental services were conceived as luxuries it would indeed suggest that the elasticity of demand is greater than 1 when a certain level of income is reached. Nevertheless, environmental goods vary a lot and not everyone perceives them in the same way. Some may be conceived as luxuries while others may be seen as a necessities [Hökby and Söderqvist, 2003]. Therefore, we cannot assume that the income elasticity is greater than unity.

Other critics argue that economic growth alone will not solve environmental problems because the relationship between income and type of emissions depends on many factors [Roca et al., 2001]. For example institutional, organizational and technology changes are important in this respect. Therefore the increase in income alone does not fully explain the U-inverted shape.

On the other hand, if the individual increasingly appreciates non-use environmental goods such as the experience of being in nature or enjoying a magnificent view, the willingness to pay increases for these and the (D^e) shifts to the right in fig 2.1. The reader who is interested in such occurrences may consider the work of Zandersen et al. [2007], in which benefit transfers were successfully validated for the first time for long periods. Zandersen et al. (Ibid.) test the benefit transfers of forest recreational values over a 20 year time horizon in 52 public forest in Denmark, through the application of the travel cost methods. Their results showed that preferences for characteristics of some forest attributes (non-timber benefit) had changed, being willingness to pay greater than increase in consumer price index.

Following the KAF argument, the (S^e) may increase to (S'^e) due to the influence in technological change over time. The (D^e) may increase to (D'^e) over time, because the relative value of environmental goods is going to increase, and hence the value of the environmental damages. The empirical evidence already mentioned about the positive (although lower than unity) elasticity of WTP, suggests that the increase in the MEC may be also triggered by a change of preferences over time and that growth in real income will increase willingness to pay for environmental services.

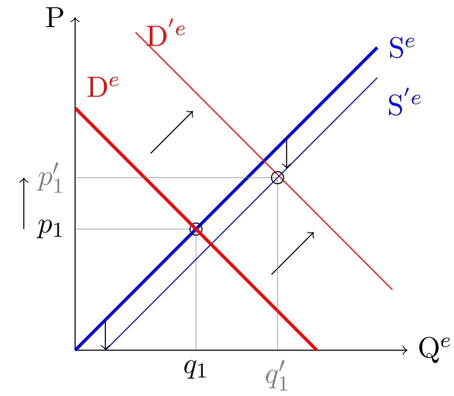


FIGURE 2.2: When the shift in D^e is greater than that of the S^e, the optimal quantity of environmental services will be increased from q_1 to q_1'. The price will increase from p_1 to p_1'.

Adding the KAF variable when the magnitude of the shift of the (D^e) is greater than that of the (S^e) over time, will make the price of the environmental services more expensive from p_1 to p_1' and will contribute in achieving a greater quantity of environmental services, from q_1 to q_1', as shown in fig. 2.2. Hence, in this case the KAF variable would be justified from the perspective of optimality.

By adding the KAF variable the price of the environmantl services increase. However, when the magnitude of the shift of the (D^e) is less or equal to that of the (S^e), the price of the environmental services, decreases from p_1 to p_1' according to fig. 2.3. The KAF is therefore not consistent in the case where the magnitude of the shift of(D^e) is less or equal to that of the (S^e) although it also implies in practice an increase of the quantity of environmental services,from as from $q1$ to $q1'$ as shown in fig. 2.3.

Since the addition of the KAF variable may not be consistent in all cases, the KAF is just going to be included in the sensitivity analysis, in order to see if any of the environmental measures appraisals that yields a negative NPV can become possitive by using the KAF variable and how the effect may vary in combination with different social discount rates. A cautious first estimate may be to choose a low KAF variable relative to our choice of r, i.e. as we shall see a choice of a= 0.005 seems to be a reasonable first guess for preliminary analysis.

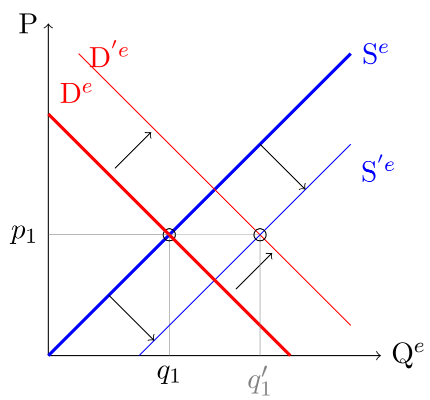


FIGURE 2.3: When magnitude of the increase in the supply from (S^e) to (S'^e) offsets that of the demand from (D^e) to (D'^{e}), the optimal quantity of environmental services will increase from q_1 to q_1'. The price p_1 will equal p_1'.

Chapter 3

Benefit-Cost rule

Our applied benefit-cost rule is inspired by Johansson and Kriström [2012], though modifications are made in order to fit our case. They develop an *ex ante* analysis through a general equilibrium model of a small open and economy, where the project is considered as small and the firm is profit maximizing. Each of the components of the benefit-cost rule will be first defined in this chapter and explained in detail in the follwing sections. As presented in the previous, the social NPV$_s$ may be expressed as:

$$NPV_s = ENB_d - NC'_d \tag{3.1}$$

where ENB$_d$ defines Environmental net benefits, which may be expressed as:

$$ENB_d = \int_{t=0}^{T} [WTP + Tourism + Fish] e^{-(r-a)t} dt \tag{3.2}$$

WTP refers the environmental benefits related from the aggregate willingness to pay for non-use values for having more water passing through the waterfalls. $Tourism$ denotes the tourist relatet benefits, by both national and international tourists, for visiting two of the highest waterfalls in Europe. $Fish$ denotes the fish benefits generated by an increase in the flow passing through the waterfall.

where NC' defines discounted Net costs, which may be expressed as:

$$NC'_d = \int_{t=0}^{T} LRe^{-rt} dt. \tag{3.3}$$

LR the loss of revenues of Grytten if a certain amount of water is released into the waterfall

3.1 Loss of revenues

In this thesis the prospect of allowing more water to flow from the reservoirs into the water falls, rather than be used for energy production in the Grytten power plant, is to be evaluated. It is however difficult to calculate the future loss of profits this may lead to because both the future loss of power and the spot prices are subject to stochastic variations and seasonality. Grytten power plant therefore faces a sophisticated dynamic profit maximization problem, the solution to which can only be obtained once all the sensitive inputs are known. Although some helpful information has been provided by the manager of maintenance in Grytten[1], some approximations and assumptions were inevitable in order to fill the informational gaps.

The model which will here be used for the calculation of loss of revenues and loss of power is based on [Johansson and Kriström, 2012]. However, an independent derivation from first principles [Giancoli, 2005, see e.g.] is here presented in order to obtain greater clarity regarding the physical processes involved and the relevant units, as well as to model the water-pumping at Mongevatn[2]. The loss of revenues of Grytten power plant per year, LR, which arises due to the loss of water from the magazines upon opening either of the two waterfalls, can be expressed in the following way:

$$LR = Pr^h \cdot LE, \tag{3.4a}$$

$$= Pr^h \cdot LP \cdot t, \tag{3.4b}$$

where Pr^h is the *high* or peak-load area price of Molde[3] of electricity which Grytten would produce for, since the maintenance manager noted than Grytten produces selectively at high prices[4], LE is the loss of energy that corresponds to the quantity of water which no longer is available for the production of electricity, and t defines the time duration that water is allowed to run through the waterfalls.

3.1.1 Loss of Power

Conservation of energy postulates that Potential energy (PE) is turned into Kinetic energy (KE) and friction (FE) [Giancoli, 2005, see]. If we simplify and assume that friction is negligible, then $\Delta KE + \Delta PE = 0$. When the water is at rest in the magazines

[1]On a tour of Grytten hydroelectric plant on the 9 th of March 2015, and subsequent email correspondence.

[2]Acknowledgement must be given to Ph.D. candidate Christopher A. Dirdal at the Department of Electronics and Telecommunications at the Norwegian University of Science and Technology who supplied helpful input for the subsequent model.

[3]The spot price that corresponds from 9 am to 8 pm.

[4]The use of peak-load prices instead of the average price will be discussed later on.

at the top of the mountain, the potential energy is maximal and the kinetic energy is zero.

By Newton's second law, one can write the Potential Energy as:

$$PE = m \cdot g \cdot h - FW \quad [J] \tag{3.5}$$

Where m represents mass in kg, $g \approx 9.81\text{m/s}^2$ is the acceleration of gravity, h is the height in meters and FW is the frictional work which shall here be assumed to be negligible[5]. The Power P [W] is the change of energy (here PE) per time t [s]:

$$P = \frac{dPE}{dt} \tag{3.6a}$$

$$= g \cdot h \cdot \frac{dm}{dt} \quad [W = J/s] \tag{3.6b}$$

While the derivative $\frac{dm}{dt}$ is expressed in the units of kg/s, the minimum water flow requirement given by the authorities is expressed in terms of the change in volume V, which we call the water flow f:

$$f = \frac{dV}{dt} \quad [\text{m}^3\text{s}]. \tag{3.7}$$

Since we need to know the change of mass per time expressed in kg. per second, we relate the quantities through the parameter known as the density of water ρ [kg/m^3]:

$$\frac{dm}{dt} = \rho \frac{dV}{dt}. \tag{3.8}$$

The density of water is roughly $\rho = 1000 \text{ kg/m}^3$ at 4°C. Hence the power may be expressed:

$$P = g \cdot h \cdot \rho \cdot \frac{dV}{dt} = gh\rho f \tag{3.9}$$

It is commonly assumed that a the turbine converts between 80% to 90% of Energy into electricity [Johansson and Kriström, 2012]. We will assume the efficiency η to be slightly higher, around $\eta = 95\%$, at the suggestion of the maintenance manager who explained that the turbines had recently been changed and that the tunnel had been polished and made smoother by covering it with three layers of paint. The resulting equation for the electrical power generated becomes:

$$P = \eta g h f \quad [W]. \tag{3.10}$$

[5]Great effort is placed into keeping the friction as low as possible in hydro-power plants.

3.2 Prices and the Electricity Certificate Market

In January 2012 Norway and Sweden established a common market for green electricity certificates where the goal was to increase their renewable electricity share by a total of 26.4 TWh by the end of 2020. The target of 26.4 TW represents an increase of about 10 % of current consumption in both countries [Hadeland Energi Strøm, 2015] and equals more than half of the total electricity usage in Norwegian households [Norway Exports, 2011]. This is seen as a significant step towards achieving the national Norwegian target of overall 67.5 % of renewable energy by 2020, under the Renewable Energy European Directive. [Eliston and Nilsson, 2013].

As illustrated in fig. 3.1, producers of electricity from renewable sources[6] are entitled to get a certificate from the Government for each Mega-watt-hour (MWh) of renewable electricity produced for a maximum of 15 years (number 1 in the fig.[7]). The producers can sell the certificates in an open market (number 2) to the suppliers[8], who have the obligation to buy an assigned quota of certified electricity on behalf of final consumers (number 4). Once the suppliers have bougtht the electricity certificates, financed by the households, they fulfill their quota and cancel their obligation (number 5). The proportion of the quota is set in comparison to total demand of electricity excluding certain power-intensive industries. The price of the certificate follows the market rules of supply and demand. In 2012, 2013, 2014 the quota was 3%, 4.9%, 6.9% respectively, achieving its maximum in 2020 with a quota of 18.3 % and lasting until 2035 [Stortinget, 2011, §17].

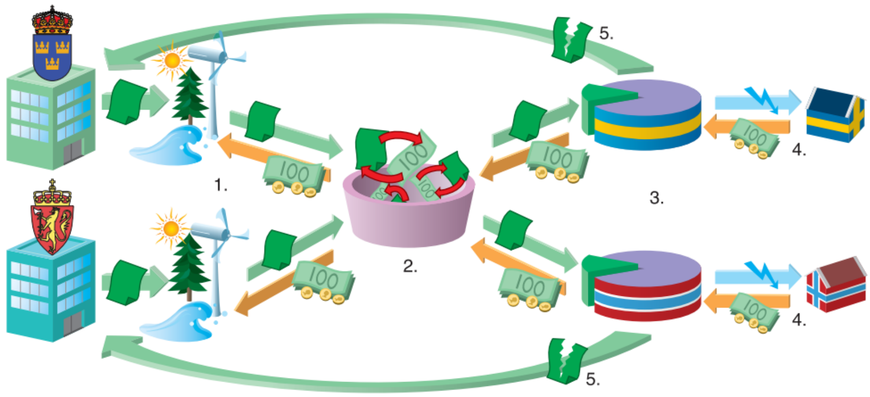


FIGURE 3.1: Regime of operation of green certificates[Eliston and Nilsson, 2013]

[6] Hydro, wind, solar, ocean, geothermal and bioenergy.

[7] Not all the conventional renewable sources of energy are endorsed by the certificate as stated in the Norwegian law about the Certificate Market, *Elsertifikatloven*.

[8] The certificates may also be sold to those consumers who self-supply and who buy electricity straight from the Nordic power exchange or through a bilateral agreement [Stortinget, 2011, §16] (number 3).

On the one hand, one can think that this measure makes the electricity prices increase for households because suppliers, which are obliged to buy a certain quota, pass the bill to customers. Each household in Norway can expect that between 1.7-2.1 øre/kWh (including taxes) of this year's electricity bill will correspond to the green certificate, [NVE, 2015a]. On the other hand, however, the profitability achieved by selling the green certificates is higher than without the scheme, where the amount of profitability depends on price and quota. The extra income for renewable electricity producers attracts further investments and hence increases the production of total electricity, which means higher supply, and therefore lower prices (demand ceteris paribus). In that way, the drop in electricity prices would outweigh the cost of the scheme payed by the customers.

However, there are other indicators that could soften the decrease in prices caused by the Electricity Certificate Market. Autum last year there was given green light to construct new capacity lines to Germany and UK [næringsliv DN, 2015].

The cable to UK will be the world's longest power cable from UK to Norway with a capacity of 1400 MW. Statnett and the British National Grid signed cooperation agreement in March 2015. The investment shared by 50% each will cost 1.5-2 billion euros and it will go from Kvilldal in Rogaland, Norway to Blyth in UK. It will also be the first direct link between the two countries [næringsliv DN, 2015].

Since electricity prices in both Germany and Britain are higher that in the nordic countries, it is expected that exports will significantly outweigh the imports on the first years [Montel Nyhetsbrev Norge, 2015]. Therefore, a price increase in the Nordic market – compared to not having the cables– may be expected the first years after the cables are in place [Montel Nyhetsbrev Norge, 2015]. Nevertheless, the question of whether or not the increasing effect in prices is large enough to outhweiht the decrease effect in prices from the Electricity Certificate Market, will have to wait to be answered at least 5 more years. The reason is that there is uncertainty about when the cables will start working, since both of two british and german cables have been posponed to 2021 and 2020 respectively.

By the moment, the market believes in future low nordic electricity prices for at least the coming 5 years, as reflected in the forward prices for 2020 [Group, 2015]

3.2.1 Other price drivers in the Nordic Electricity Market

If this thesis is to assume that the prices will continue low, it is also important to understand what other drivers than the Electricity Certificate Market are that influences both the supply an the demand curve.

Factors affecting each of the main Nordic energy sources (mainly hydro, nuclear and fossil power, in given order) will be the ones incluencing the future supply curve.

The total energy production in the Nordic region in 2013 was 383 TWh as shown in fig. 3.2. Hydropower was the main source of power production with 203 TWh accounting for a 53% of total power production, where Norway and Sweden were the main contributors with 62% and 32% of total installed capacity, respectively. The second largest source of energy production was nuclear with 86 TWh accounting for 22.5% of production, where Sweden and Finland are the only producers with 78% and 22% of installed capacity, respectively. Fossil power generation holds the third position with 12.3%, followed by wind 6.3% and biomass 6%, [Nordic Energy Regulators (NordReg), 2014].

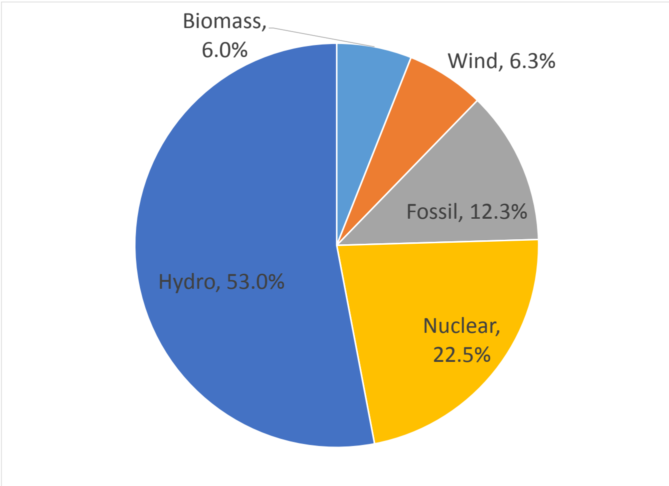


FIGURE 3.2: Power generation according to power source in Nordic Market, 2013 [Nordic Energy Regulators (NordReg), 2014]

Owing to their high share of production in the Nordic electricity market, the development of the Norwegian and the Swedish hydroelectric market will be of significant importance for the future development of prices. It is characteristically cheaper than electricity from thermal plants and at the same time it is able to increment energy availability by regulating power at a low cost with a short-term notice thanks to their capacity of water storage. Nevertheless, it is not free from drawbacks. Their regulating capacity can however be reduced by low levels of precipitations and for instance a dry year would likely cause an increase in prices. In the case of Norwegian hydro energy, a high production of 142 TWh was achieved in 2000, while the production was as low as 106 TWh in 2003 [Det kongelig olje- og energidepartement, 2013]. This difference in the precipitation level will affect consumer electricity prices, typically varying from an average of 20.000 (including cable rent and taxes) to 16.000 NOK per year [Olje- og energidepartementet, 2014].

Despite the need for importing electricity rises in dry seasons, the exchange capacity is however not unlimited. For example the capacity between Norway and neighboring countries is limited to 5400 MW (compared to an average of total production capacity of 31.000 MW [Det kongelig olje- og energidepartement, 2013]) and an increase in the area price typically arises due to congestion in the electricity line.

Biopower, gas and coal, and other fossil power have the highest marginal costs. When dry years occur and hydroelectricity production cannot handle a sudden change in supply/demand both the prices of fossil fuels and CO2 quotas become relevant for price determination despite their modest share in production compared to hydropower and nuclear. In addition, the European electricity market is dominated by thermal power and prices affect indirectly by the exchange of electricity with the Nordic countries [Johansson and Kriström, 2012].

Nuclear power future development can also influence future electricity prices. Dangerous incidents with nuclear power, such as the one caused by a major earthquake in Japan on 11 March 2011 to the the three Fukushima Daiichi reactors, can potentially create political will to drastically reduce/limit its production. According to the report Nordic Energy Regulators (NordReg) [2014] an increase in average nuclear availability had a dampening effect on prices from 2012 to 2013, where the availability increased from 77 percent to 80 percent. Their stable production profile make them less expensive and thus suitable for base load production than fossil power plants.

New power lines and major electricity changes in the countries surrounding the Nordic market are also relevant factors for the determination of future prices. The Nordic power market has reduced its dependence upon Russia over time, while increasingly becoming dependent upon Germany: The Nordic electricity market imported 11.5 TWh from Russia and 1 TWh from Germany in 2005, while in 2013 the Nordic countries imported more from Germany than from Russia (6.8 TWh as compared to 4.8 TWh [Nordic Energy Regulators (NordReg), 2014]).

On the side of the demand there may be factors that affect both the short and the long run prices. With regards to the short run, the demand typically fluctuates daily, weekly, and seasonally. First, there is an increase in consumption when people go to work and when they come back from it and use domestic services at home. Secondly, the demand also rises during the week, since the activity level is higher from Monday to Friday than during the weekend because of business activities. Third, the little need for using air conditioning in summer combined with an increase of the widespread electricity use for heating purposes in winter approximately rises by double the consumption in the coldest winter months bye2008.

With regards to the long run prices, the economic activity level abroad plays an important role on the demand. Power-intensive industry is still important in Norway [Det kongelig olje- og energidepartement, 2013] and a period of economic growth would increase the demand for normal goods and hence Norwegian exports. An increase in Norwegian industry production would require a higher consumption of electricity. Nevertheless, the electricity consumption (including the industry) has not increased over the last 15 years. Rather, quite stable development has been witnessed, with a net total consumption of 110 494 GWh in 2000 to 109 269 GWh in 2013, see fig. 3.3.

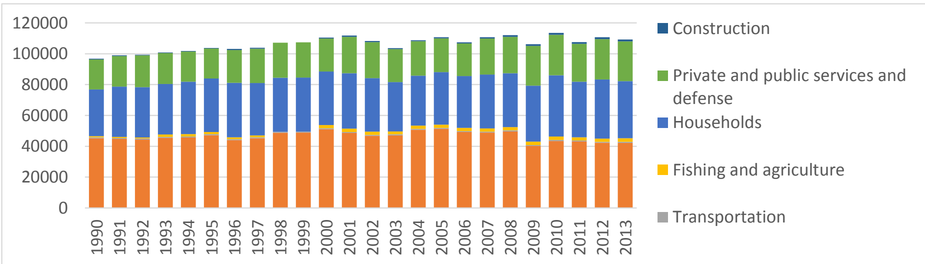


FIGURE 3.3: Net domestic electricity consumption in Norway (GWh), [SSB, 2015a]

With the rise of environmental concerns, such as those caused by climate change, a more environmentally friendly structuring of energy consumption has been promoted over the recent years, as well as the development of more energy efficient technology. Legislation has reflected this concern, both on national and international levels. For instance, *the European energy directive* targets a 20% increase in energy efficiency for all member countries [EU, 2012], while *the energy labeling directive of household goods* set requirements to the main actors of the manufacturing and supplying chain so that the consumers can be sufficiently informed about the most energy efficient products, [EU, 2012]. In Norway, for example, the technical building regulation Kommunal- og moderniseringsdepartementet [2010] set limits on the total net energy consumption from fossil fuels sources.

In addition to the above measures, Norway allocate a high amount of resources to support investments that focus on new cost effective energy solutions. The Energy fund allocated 3060 million NOK between 2012 and 2013 through the Norwegian National Energy Agency called Enova. In the annual report for 2013, Enova states that energy efficiency is on demand in construction and rehabilitation of buildings and that there is a strong enthusiasm for low energy houses despite low energy prices [Enova, 2014]. According to the SSB analysist Ann Christin Bøeng [2011], energy efficiency has contributed to reduce energy use in Norway by 18 percent from 1990 to 2009. In fact, electric power consumption per household in Norway has followed a downward tendency since 2004, as shown in fig. 3.4.

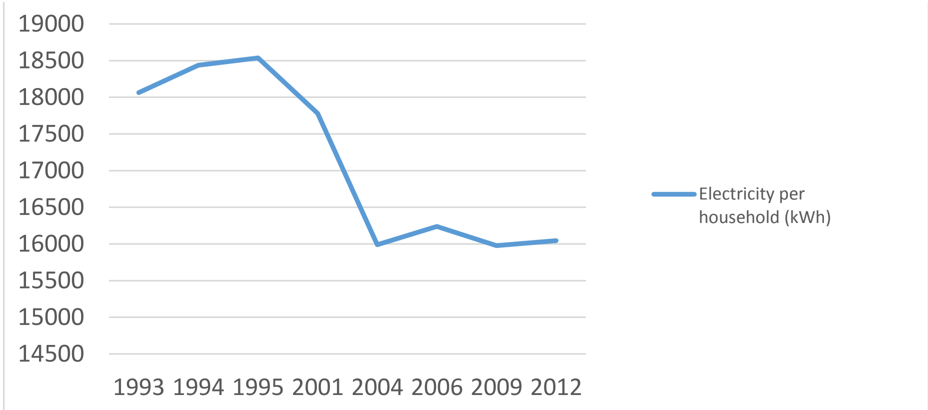


FIGURE 3.4: Electricity consumption per household in Norway (kWh) [SSB, 2015b].

Although electricity is the most common carrier of energy in Norway, accounting for around 77 percent in households and services [Bøeng and Holstad, 2013], there are other environmentally-friendly energy carriers which have increased their usage over the past years. While in 2013 the energy consumption decreased a 1.7% from the previous year (making a total of 215 TWh) due to the decrease in consumption of both electricity, biofuel and oil products, there were other forms of energy other than electricity that increased. These were gass and district heat [SSB, 2015c]. The heat power plants are environmentally friendly since they use waste as their main source for heat prouduciton. Although their total energy share is still small (4.3TWh in 2010 [Det kongelig olje- og energidepartement, 2013] it has approximately tripled since 2000 and it is established (or under development) in the major cities of Norway.

3.2.2 Effect on prices

Empirical evidence suggests that the short-run price elasticity of the demand for electricity is very low [Faruqui and George, 2002; Yusta and Dominguez, 2002]. So as illustrated in fig. 3.5, an increase in supply in the coming years from S to S^{el}, may have a large impact on price (from p^1 to p^{el}), due to the steep demand curve.

The development of the demand of electricity will also play an important role for the determination of the prices in the coming years. The utilization of new technologies for efficiency, energy recovery, the use of other energy carriers than electricity and a relatively lower population growth projection by 2020 compared to the increase of supply (7.9% and 10% respectively [SSB, 2015d]) may shift the demand curve to the left, but the effect is unclear since lower electricity prices may dampen energy saving investments and shift the curve towards the opposite direction.

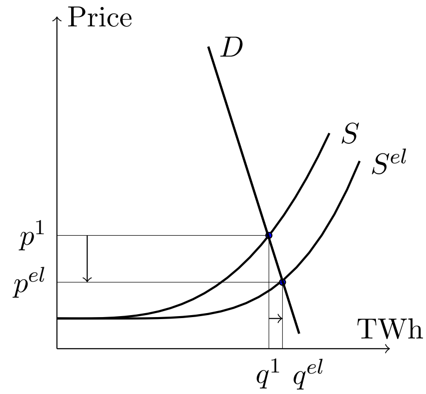


FIGURE 3.5: Increase in supply from S to S^{el} stimulated by the electricity certificates, leading to a decrease in price from from p^1 to p^{el} and quantity of electricity (TWh) from q^1 to q^{el}.

3.3 WTP for environmental services

There is an array of functions than environmental goods can provide and that are included in the individual utility function. Taking a river as an example, one of the ways that it can be valued is through direct consumption of the fish. Since fish is a commodity bought and sold in the marketplace it should be easy to attach value according to the observed price. Nevertheless, the economics of environmental evaluation has in the past twenty-five years recognized the possibility that individuals may derive value from a natural resource without intending to make use of it [Perman, 2003]. The total economic value (TEV) cannot be reduced to direct consumption and we distinguish between use values and non-use values. The former category can further be divided into consumption – as in the case of the fish – and non-consumption values. In the former category the commodity – in this case the fish – is utilized in the act of using them, whereas the non-consumption values, the satisfaction is derived from an activity that does not entail the destruction of the good. Recreational activities such us canoeing, kayaking and hiking are suitable examples.

Non-use values do not necessarily imply the physical interaction with the good. In the case of the two waterfalls Mardalsfossen and Mongefossen, their scenic beauty can be one of the most important sources of value, and welfare could be derived from documentaries, pictures, reports etc. The utility can also be derived for the simple fact of knowing that Norway has one of the highest waterfall in Europe (existent value) or that future generations are going to be able to enjoy it (bequest value).

Since there is no objective empirical way in which to attach monetary value to nonmarket goods, several stated preference methods and revealed preference methods have been developed. According to Mitchell and Carson [2013] contingent valuation is considered to be the most promising method to estimate non-use values, whereas indirect methods derived from revealed preferences approaches are more suitable for use values of public goods. Since we are especially interested in the non-use values of the two waterfalls, we therefore see contingent valuation (CV) as the appropriate method. This method measures the WTP (or willingness-to-accept, WTA) for the change in utility upon an improvement in an environmental good (or the compensation in lieu

Conducting a CV would typically involve identifying the population of interest and taking a representative sample of households. However, since there is no origanl economic estudy conducted to capture the non-use value in the case of the waterfalls of Grytten, this Masther thesis enonomists rely often on benefit transfers. Benefit transfer is the procedure of applying estimated values or findings from previous studies to similar changes in environmental quality [Navrud and Bergland, 2004]. Rosenberger and Loomis [2003, p.445] claims that benefit transfer "describe the use of information from previous research to inform decisions".

Benefit transfers, also called, value transfers [Navrud and Bergland, 2004, see] are convenient both from an economic and time-saving point of view and its practical feature has made it subject of a growing literature, see for example [Desvousges et al., 1998; Brouwer, 2000; Navrud and Ready, 2007]. The errors that arise from applying value transfers may vary a lot from one validity test to another since the they entail both spatial and temporal differences. However, in the absence of original data about WTP for non-use values in the case of Mardalsfossen and Mongefossen, value transfer can be useful as a proxy for decision-making [Bickel et al., 2005]. Since in our valuation of benefits of incresing the water flow in both Mardalsfossen and Mongefossen rely on several estimators apart from WTP, one can consider that the level of accuracy provided by the benefit transfer should be relatively lower as if the benefits of the proposal of increased waterflow would be measured with just one estimate.

As suggested in Ready et al. [2004] simple unit transfers approaches can probably perform as well in terms of accuracy. As pointet out in Navrud and Bergland [2004] the value of the site-study or group of studies can be transferred if one assumes that the well-being experienced by an individual at the study-site will be equivalent to an average individual in the policy-site.

The environmental goods are very heterogeneous and the willingness to pay can be very different from country to country, as well as socioeconomic characteristics of population. Therefore, one should be specially coutious in unit value international transfer if the income level from the study-site is differs from the policy-site [Navrud and Bergland, 2004; Bickel et al., 2005]. Other critics suggest that international benefit transfer may not be applicable even when the income level are similar (or have been adjusted). Ready et al. [2004] measured specific health impacts related to air and water qualiity throuhg simultaneous contingent evaluations in five European countries. Average errors of 38% in the transference International unit values (38%) could not be explained by differences in income, demographic measures and other adjustments, since they had been taken into consideration. It turned out the the willingness to pay for a given health problem was consistently higher in the two countries (Spain and Portugal) where the income was the lowest.Ready et al. [2004] underlines that unic problems can arise when benefit transfer happends between two countries. The difference in currencies cannot be simply solved by a market exchange rate conversion. Further, the differences in preferences do not need to be related to observable differences in demographics and can derive from shared experiences, culture and costumes. As long as the WTP was related to the health status or the demographic differences an adjustment could be made, but errors would arise from underlying non-quantitative differences in preferances.

In order to avoid potencial problems from international value transfer this Thesis is going to focus on transferring values from hydroelectric projects that happened in Norway. The data upon the analysis will be based is explained in further detail in section 4.6.

3.4 Fish

According to [NVE, 2012] the regulation of the watercourses can have an effect on the water temperature, water quality and ice conditions. In the report, the population of fish affected by the hydroelectric development is the one of the river Rauma. Since the water used from the basins is transfered to the turbines located by Rauma River, the negative effect of the plant is not due to little water flow, but to a change in temperature. According to the report a total of 50 populations of anadromous fish, of which 34 are salmon, are lost or threatened where the watercourse regulation has been a decesive factor. Nevertheless, the loss of fish is often caused by a combination of several factors apart of those from the power plant. Other causes that determined the loss were acidification and/or the presence of the salmon parasite *Gyrodactylus salaris*. This is the case of Raumavassdrag, where the parasite is found to be the main cause of its *very poor* ecological condition. In 1980 the Gyrodactylus salaris was first found around the area of Rauma and the parasite spread rapidly around the different lakes and rivers of the area [9]. The parasites live under the skin of the fish in fresh water. It is considered to be one of the biggest threats of the Norwegian salmon especie and it is estimated that it has costs until today a the loss of revenues amounting from three to four billions NOK [Miljødirektoratet, 2014]. In 1993 the region went through a treatment of rotenone

[9]Rauma area is formed by the main river, Raumavassdraget and other 5 smaller called Henselva, Innfjordelva, Måna, Skorga og Breivikelva

/footnoteColourless insectiside which originates naturally from seeds and stems of several plants which also erradicates all the fish of the water. There was new treatment involving a full-scale treatment of 2 rounds in 2013 and 2014. According to the envionmental director Ellen Hambro, the goal is to set up a treatment which lasts the sufficient time and with the right amount of rotanone concentrations in order to remove the parasite for good[Miljødirektoratet, 2014]. The treatment strategy has been significantly changed after the evaluation of the measures target to erradicate the parasite carried by a group of experts appointed in 2008. The autoctone especia of Raumavassdraget has been kept in a genebank and the introduction of new salmon eggs has started.

It is difficult to know to what degree more water released into the waterfalls is going to affect the benefits from fish. When the release of flow amounts to a small reduction on energy production, it can be appropriate to assume a linear relationship between the loss of production and the acquired benefits for fishing.

3.5 Tourism

Tourism can include a wide spectrum of activities motivated by business travel, leisure, religion, family, environment among others. Therefore, it could cover from conventions, pilgrimages, vacationers to also sightseers, like in the case of Mongefossen and Mardalsfossen, that come to experience nature. Crick [1989] suggests that there are no successful general theory on tourism because of its difficulty to cope all its complex and dynamic aspects. Instead, our approach is going to be case-specific based, in order to evaluate the potential growth on tourism in the case of Grytten's waterfalls.

The tourism related benefits do not target the same type of benefits from the waterfalls as the WTP. The later targets the non-use value of the waterfall, the intrinsic value of its existence, witout implying that the person will interact with the place where the waterfall is located. Tourism, however, is focused on the use non-consumption value of the waterfalls. There is no value for tourists unless they can experience the view (or have an excursion) to the waterfall.

Chapter 4

Data and assumptions

4.1 Data collection on a field trip to Åndalsnes

A substantial amount of the data given in this section was collected during interviews on an excursion by the author to Molde, Åndalsnes and Eikesdal between the 8th-10th of March 2015. Meetings were held with the following people who each represent separate interests in the debate surrounding the waterfalls Mardalsfossen and Mongefossen:

1. Torunn Dyrkorn, marketing chief in *Visit Molde* tourist center.
2. Are Sæther, maintenance manager at Grytten power plant.
3. Vidar Skiri, director of Rauma river-owner's association and official expert on fishery in regulated watercourses.
4. Marit Wadsten, Lecturer at Volda University College who is currently writing a book on the environmental activism that was set up against the construction of Grytten power plant ("Mardøla-aksjonen").

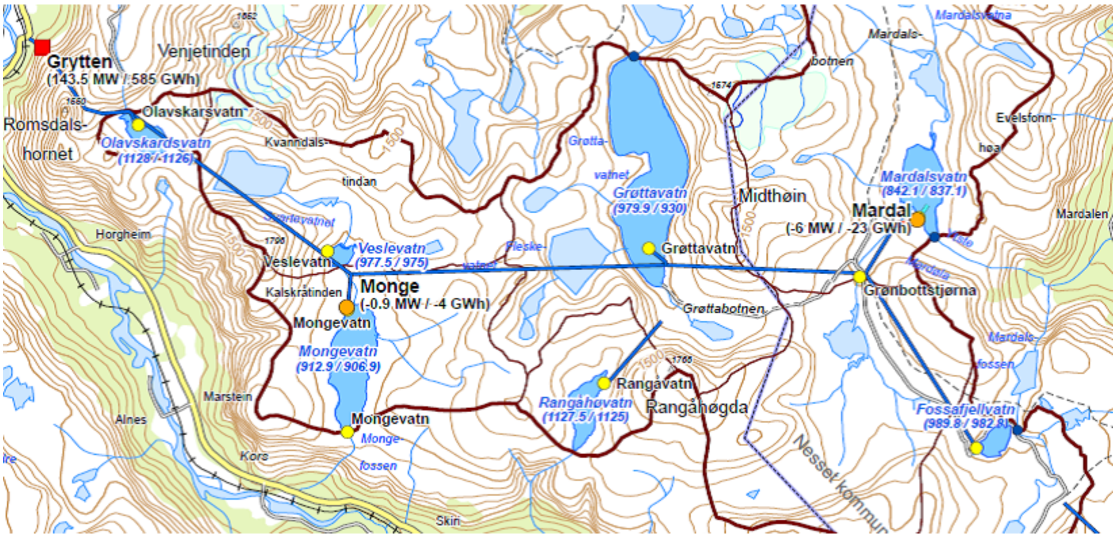
Some additional information and photographs from this excursion are added in appendix C. As far as possible the author has sought to rely on data from openly published sources, but when such data is not available the relevant interviews will be used as primary sources for the following analysis.

4.2 Grytten power plant

Grytten power plant lies in the municipality of Rauma in the county of Møre and Romsdal, nearby the town of Åndalsnes. It is owned 88 percent by Statkraft and 12 percent by Tafjord Kraft [Statkraft, 2015], and the average electricity production of the las 8 years is 547,29GWh, according to the maintenance manager of the plant. Its drainage basin covers 50-100 km^2 of river and 10-20 km^2 of lake area [NVE, 2012]. Water is collected into a channel inside the mountain that connects several of the lakes (blue straight lines in fig. 4.1a, also visible in the model displayed in fig. 4.1c), which then is finally discharged into the Rauma river (on the left side of fig. 4.1a) after having been channeled through the turbine for energy production. Water is also collected from watercourses located in the neighboring municipality called Nesset (on the right hand side of fig. 4.1a, the land separated by the blue border). Here the water is transferred from the river system at Eikesdal to the power plant. The water intakes into the channel system (marked with yellow circles) are located at Sandgrovvatn, Bruå, Fossafjellvatn, Mardalsvatn, Grønbottstjørna, Rangå Mongevatn, Veslevatn and Olavskardsvatn, when moving from right to left on the map. Part of the water collected at Bruå is transferred by a tunnel to the river Østre Mardøla which leads to the lake Fossafjellvatn and finally to Grøttavatn. The lake is regulated by a dam (blue circle in fig. 4.1a, and also visible in fig. 4.1b), which causes a low waterflow level at the lower part of Østre Mardøla (also called Søndre Mardøla). Since Mardalsfossen collects water from the low part of Østre Mardøla, which leads to Mardalsjøna, the low waterflow is a result of the dam at Fossafjellvatn.

Considering the other interesting waterfall in the context of this thesis, Mongefossen, one sees in fig. 4.1a and fig. 4.1c that its water comes from the lake Mongevatn, which also is regulated by a dam. The main reservoir for water storage in the Grytten power plant is the lake Grøttavatn. Unlike Mardalsvatn, Mongevatn is at a lower altitude than the reservoir Grøttavatn, meaning that water must first be pumped up from Mongevatn to Grøttavatn for use in the power production. The water intake and pump are marked by an orange circle in fig. 4.1a. The electricity used by the pump at Mongevatn decreases the overall electricity production by 4 GWh yearly. For purposes of calculating the energy production it should be noted that it is the altitude of Grøttavatn, rather than the height of either Mardalsvatn or Mongevatn, that is relevant.

At the moment there is seldom any water flow out of Mongefossen. This only occurs when there is so much rainfall that the water level in Mongevatn exceeds the dam capacity. For the revision of the concession in 2020, NVE currently recommends changing the current practice to allow for a minimum water flow of 2.0-2.5m ^{3}/s [NVE, 2012].



(A) Source: Statkraft

(B) Source: By author

(C) Source: By author

FIGURE 4.1: (a) Map over the network of lakes connected to Grytten Hydroelectric power plant. (b) Model of Mardalsfossen. (c) Model of Mongefossen.

4.2.1 Minimum flow and possibility of adjustment

Manøvrerings reglementet by the Ministry of Oil and Energy on the 28th of September 1990, required that a flow of water corresponding to 2.5 m^3/s and 2.0 m^3/s be let out of the Mardalsfossen waterfall during two separate periods in the summer. That is, from the 20th of June until the 30th of July, Statkraft is committed to let 2.5 m^3/s through Mardalsfossen and if there is not enough water Fossafjellvatn (which at the same time receives water from from Bruåa), water from Sandgrovvatn has to be released. From the 1st of August until the 20th of August less water is required, 2 m^3 /s, and if there is not enough water from Fossafjellvatn, Statkraft does not have to let water run from Sandgrovvatn [Det Kongelige Olje- og Energidepartement, 1990]. Therefore, during 1.08-20.08 there can be considerably less water flow than 2.0 m^3/s being let through Mardalsfossen: Compare for instance figures 4.2a and 4.2b where the former was taken at the inauguration of Antony Gormley statue *Another Time* in august 2014 and the latter was taken in June earlier that year. Therefore, the possibility of a dry waterfall in August will be taken into account in the analysis on Mardalsfossen.

(A) (B)

FIGURE 4.2: (a) Mardalsfossen waterfall in August 2014 at the inauguration of Antony Gormley statue *Another Time*, with a water flow considerably smaller than the NVE minimum requirement of 2 m^3/s. (b) Mardalsfossen earlier that year, prior to the erection of the statue, with a water flow of roughly 2.5 m^3/s.

In August 2014 during the Eikesfjord town summer festival, the mayor of Nesset municipality contacted NVE to ask for an increase of the waterflow in the waterfall Mardalsfossen, for the occasion of a concert on the 9th of August in its vicinity with Henning Sommero and John Pål Inderberg. At that part of the year there was less water flow than the minimum of 2.0 m^3/s. NVE agreed to the mayor's request, and it is estimated[1] that there was between 2.5 - 3 m^3/s of water flow in Mardalsfossen under the concert, (see fig. 4.3b for a photo taken under the event). The agreement between Nesset's mayor and NVE has reminded the local population that the concession regulations are not written in stone, and that they are subject to political pressure. In the context of this master thesis, the fact that the water flow can be regulated on a seemingly hourly

[1]Estimated by the tourist information office in Molde

basis is relevant for the ensuing analysis in section 5. In a meeting with the maintenance manager of Grytten hydroelectric plant on the 9th of March 2015, it was confirmed to the author that such a *dynamic regulation* is technically possible, although the current system is not designed for it. In that way it may for instance be feasible to have a lower water flow during the day when there is more visitors to the waterfalls and a lower flow at nights, so as to not incur any additional costs to the power plant.

(A) By Bjørn Magne Øverås. (B) By Bjørn Magne Øverås.

FIGURE 4.3: (a) The dam which regulates water flow from the lake Fossafjellvatn into the Mardøla river, which leads to Mardalsfossen waterfall. (b) Mardalsfossen under the Eikesdal town festival concert by Henning Sommero and John Pål Inderberg on the 9th of August 2014. The water flow was estimated to be around 2.5 m^3/s -3.0 m^3/s.

With the possibility of increasing the water flow in Mardalsfossen above the minimum flow (2-2.5 m^3/s), it seems likely that the tourist related benefits and willingness to pay for non-use values of the waterfall also increases. The question, however, is whether or not the increase in value would be substantial in comparison to the loss in revenue for Grytten power plant. By comparing the appearance of Mardalsfossen before the regulation in fig. 4.4a to its appearance under minimum water flow in fig. 4.4b, it seems that the appearance of the waterfall under minimum water flow is comparable, although visibly smaller, to that prior to regulation. It is also possible that the same will be the case in Mongefossen for NVE's proposed minimum water flow for 2020. In the catalog published for the installation of Antony Gormley's statue Andr [2014] *Another Time* in Mardalsfossen, it was claimed that the discharge in figure 4.4a reached 45-50 m^3/s (during the time of flooding, before the construction of Grytten). Although it is likely that this given estimate is subject to some degree of speculation, given that no exact measurements of the flow existed at the time, the willingness to pay for a full restoration

(A) (B)

FIGURE 4.4: (a) Mardalsfossen before the introduction of water regulation. (b) Mardalsfossen at the minimum water flow.

of Mardalsfossen will likely be far smaller than an order of magnitude greater than in the situation with minimum water flow. Rather, we may assume that the willingness to pay will resemble that which is known from economic theory for a general good: When the quantity offered to the buyer is small, the price by which it is valued is comparatively higher than when quantity of the good is large, given that the elasticity of demand is positive (as illustrated in fig. 4.5). The question remains as to what amount of flow should be considered *high flow* compared to the minimum flow (MF) and whether the amount of water flow at Mongefossen and Mardalsfossen should be comparable. In order to perform the EBCA with flow rates greater than the minimum flow, some assumptions must be made that are open to discussion (as will be further discussed in section 6). For one, given that the value of water flow saturates at some maximum value upon increasing the water flow, it will be assumed that the minimum flow already captures a considerable amount of this maximum value. This seems plausible given the large numbers of tourists that visit Mardalsfossen every summer. Secondly, *high flow* rates will here refer to rates greater or equal to 3 m^3/s in Mardalsfossen and 4 m^3/s in Mongefossen, as shown in fig. 4.5. In the figure, the value v_{high} corresponds with a greater water flow in Mongefossen than in Mardalsfossen in order to reflect the aesthetic differences between them: Mardalsfossen is generally considered to have a more spectacular fall, having a long vertical drop while at Mongefossen the water descends like a pony tale. It may therefore need more water than in Mardalsfossen to look as spectacular. Figure 4.6 shows Mongefossen before and after the regulation. After the regulation Mongefossen has been left dry, except in the case of flooding. Hence it seems plausible to assume that the value of the flow increases rapidly for low flow levels in line with what one may expect of an economic good, as illustrated in figure 4.5. Although the value of the minimum flow (MF in figure 4.5) will in reality be a litter lower in Mongefossen than in Mongefossen, it will be assumed that this difference is negligible. This difference will after all be much smaller than the difference $v_{\text{high}} - v_{\text{MF}}$.

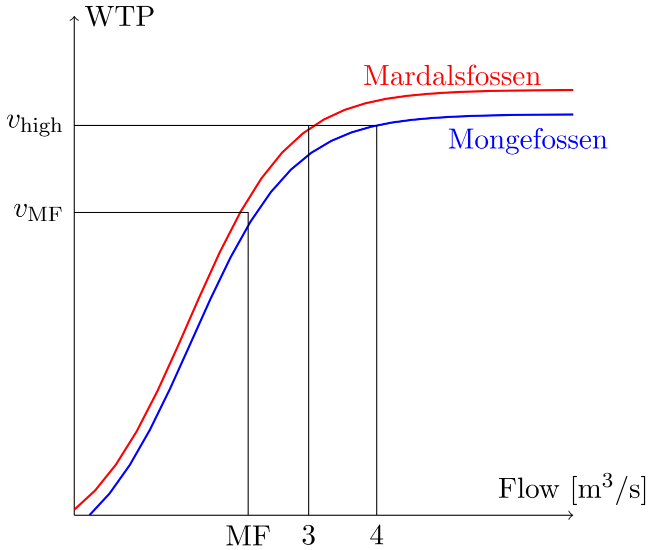


FIGURE 4.5: *High flow* refer to rates greater or equal to 3 m^3/s in Mardalsfossen and 4 m^3/s in Mongefossen. The value v_{high} corresponds with a greater rate defined as high flow for Mongefossen than in Mardalsfossen. It reflects the aesthetic differences between them. The minimum flow, MF, captures a considerable part of total value.

4.3 Prices

The environmental measures of releasing more water into the waterfall entails a reduction in the electricity production of Grytten power plant. When the overall market supply of electricity decreases, less quantity is offered for every price range and the supply curve shown in figure 4.7 shifts to the left from S to S'. The price will then increase from P to P'. Yet, the analysis assumes no increase in price despite the decrease in energy production for two reasons. Firstly, most of the environmental measures that are going to be evaluated in the analysis represent a small loss of energy production compared to the average yearly energy production of the power plant. Secondly, Grytten's total yearly production is small compared with total supply sincce it amounts to 547 290 MWh, and the total electricity production by hydropower developments in Norway amounts to 131 400 000 MWh [NVE, 2015b]. Since the total yearly production of the Grytten power plant represents less than 0.5% of the total hydroelectric production, this thesis assumes

(A) With permission from Rauma folkebibliotek, by Andreas Nordmann

(B) Thomas Rødstøl, June 2010.

FIGURE 4.6: (a) Mongefossen prior to regulation. (b) Mongefossen in June 2010.

that the total effect on the supply curve is very small. Therefore the shift of the supply curve in figure 4.7 is so small (S") that the change on price (P") is negligible.

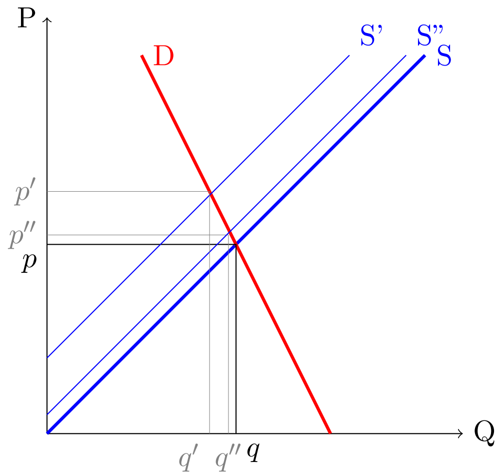
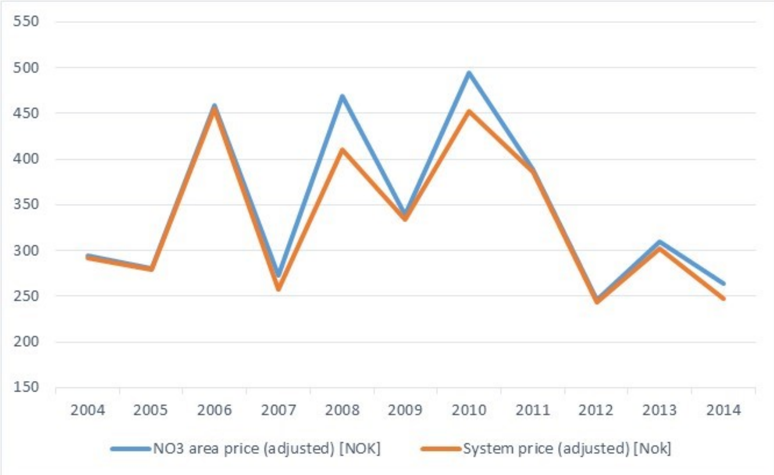


FIGURE 4.7: We assume that increase on price from p to p'' is negligible since the change of the supply curve S to S" is very small.

The Maintenance Manager of the plant noted that the Grytten usually produces during periods of high prices in the market[2]. Since it has several basins and a good capacity to store water, the plant does not need to produce all the time. This is useful because it gives regulating power to the Norwegian electricity market and facilitates the balance

[2]With a yearly energy production of 547.29 GWh and capacity of 143.5 MW the minimum yearly production hours amounts to 3'813.87 hrs; i.e., 44% of the year.

between supply and consumption of electricity. Since the water that may be allowed to run into the two waterfalls could have been instead stored until later periods for when the production of water was desired, it seems appropriate to work here with yearly averages of electricity prices and loss of energy. Grytten power plant may benefit from peak-load prices and therefore incurre in higher loss of revenues from the application of the environmental measure than that of a hydropower plant which production varies according to the flows of water running.



(A) NO3 area price and System price(adjusted)

FIGURE 4.8: The electricity price of the area of molde follows the system price.

Since the market expects low prices due to the Electricity Certificate Market – as explained in the theory –, last year seems to be a price that reflects low expectations, and hence, will be used as the base case in the analysis. The 2014 average system price is one of the lowest electricity price of the last 14 years. The on price that is slightly lower is the one of 2012 when adjusted for the CPI, as seen in fig. 4.8. Using the price of last year seems also to be in line with that expected by the market, since the forward prices given by 5-years (ENOYR 20) maturity period, do not either show higher prices than that choosen as an the base case estimate to use in the analysis [Group, 2015].

However, instead of using the 2014 system average price, 247.7 NOK (or 29.61 Euro/MWh) NOK/MWh, the area price of Molde is preferred in this case, amounting to 263.57 NOK/MWh (or 29.61Eur/MWh) . The reason is that Molde is the area where the power plant is located. Due to power congestions with the power lines, a different price may arise. As we can se in fig. 4.8, Molde price has usually been slightly higher than the system price, based on different local supply and demand conditions. The presence of the most important aluminium plant in Europe – as mentioned in section 3.2 – may be one of the factors causing an increase in the demand.

For calculating the Molde peakload prices and the Molde offpeak average prices, this thesis takes percentage variation of peakload and offpeak system prices with respect to their average and applies the same variation to the Molde area average price.

Although the variation between peakload prices and offpeak prices may not be exactly be the same, it should approximate. For both system price and Molde area price, the difference beetween peakload prices and offpeak prices are due to the rush hour and lifestyle habits. Since Molde's population will presumably follow similar behavioral patterns than the rest of the population in the Nordic countries, the difference in the percentage of variation from average prices to peakprices and offprices respectively may be negligible.

According to Statnett, the prices of the nordic electricity market will rise about 0.03-0.06 NOK/kWh 30-60 NOK/MWh when the cables of Great Britain and Germany are in place, compared to the price if the cables were not buil [Montel Nyhetsbrev Norge, 2015].

As upper bound for the sentitivity analysis, this thesis will use this forecast, increasinig Molde 2014 area price (NO3) by 45 NOK[3] to obtain the Molde Area price. It will be used as a high estimator. The peakload and offpeak prices will be the result of applying the same proportional increase of 4.5% for peakload prices and the decrease of 5.7% for offpeak prices

Table 4.1: Price estimates used in the analysis

Molde average [NOK/MWh]	263.57
P^h [NOK/MWh]	278.5935
P^L [NOK/MWh]	251.7094
P high estimate	308.57

4.4 Recreational fishing

Before the Norwegian authorities decided whether or not to invest in the rotanon treatment and include it the national budget, related fish evaluations were conducted that assessed the economical activity from recreational activities connected with the salmon in Rauma. According to Rødstøl and Gerhardsen [1983] the economic activity around fishery amounts to 17 546 390 indexed to 2014 prices, where it includes the sale of fishing cards and the rent of the cabins from the fish owners. Economic activity derived from housing and trade in Rauma was also part of the report. 25% of the activity on Raumavassdraget is assumed to influence the activity of the other

[3]mean between 30 and 60 NOK.

smaller rivers of Rauma area, the indexed assessment in 2014 prices amounts to a total of 21 932 987 NOK. The kilos of salmon fished in Raumavassdraget amounted 3182 [Miljødirectoratet/Lakseregister, n.d.].

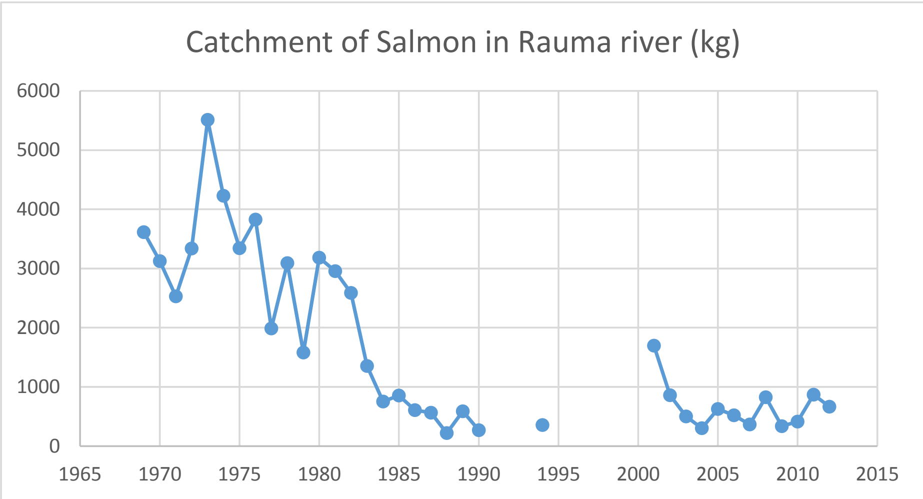


FIGURE 4.9: Decreasing catchment of salmon in Rauma river (kg)

When appraising each of the environmental measures that will be undertaken in section 5, this thesis will take as our base case 10% of total impact for yearly average energy production of the waterplant as shown in table reflabeltablefishestim. The estimator used for the worst-case scenario sensitivity analysis is 5%.

TABLE 4.2: Fish estimates used in the analysis for total impact on fish at average electricity production.

Estimates fish	
Low	Base
5%	10%

As fig. shows, the number of catchs of salmon dropped dramatically since 1981. In 1993 the region went through a treatment of rotenone /footnoteColourless insectiside which originates naturally from seeds and stems of several plants which also erradicates all the fish of the water. Except from a low number in 1994 (355kg), there is no record of catchment from 1991 to 2001. Although it seems that that the catchment had picked up in 2001 (1608 kg), the parasites had been found again in Rauma 1996 and the population descended rapidly again. There was a new try involving a full-scale treatment of 2 rounds in 2013 and 2014. According to the envionmental director Ellen Hambro, the goal is to set up a treatment which during the sufficient time and with the right amount of rotanone concentrations that removes the parasite for good[Miljødirektoratet, 2014]. The treatment strategia has been significantly changed after the evaluation of the measures target to erradicate the parasite carried by a group of experts appointed in 2008. The autoctone especia of Raumavassdraget has been kept in a geneticbank.

4.5 Tourism

Tourism is divided between benefits from cruise tourism and other tourism. It is assumed in the analysis that the tourism for one waterfall does not impact the other, because the two waterfalls are accessed through two different fjords. Although belonging to the same hydropower plant, the car road from one point to the other goes around Isfjorden by Åndalsnes and Langfjorden, as shown in the map fig. 4.10. In the same figure one can see that Mardalsfossen is found by Eikesdalen next to Eikesdalsvatnet and it is accessed mainly from Eresfjor. Mongefossen is located in Rauma Municipality, around 20 km away from the nearest town Åndalsness by Romsdalsfjorden following the E136 from Åndalsnes between Trollveggen and Verma.

The waterfalls are located nearby the western cost of Norway, which is known to be a popular destination for cruises in the summer season. At the same time ,they are difficultly accessible by foot, because in the case of Mongefossen it is located far from any population. Mardalsfossen is close to Eikesdalen but the valley, which only have some dozens of citizens, is far from Eresfjord unless it is accessed by car. Therefore, the tourism will be divided in the analysis by tourists who hire package holidays through a cruise and tourists who do not hire package holidays and that they drive to see the waterfall. The assumptions will be adjusted to the specific characteristics of Mongefossen and Mardalsfossen areas.

4.5.1 Cruise tourists

In the case of Mongefossen, if more water was released into the waterfall, one could assume that it will increase the number of cruises that come to visit it. Nevertheless it is not clear (in the short-run at least) because the area is already very attractive for cruises. The waterfall is located next to *Raumabane* railway line which is already considered to be one of the most beautiful in the country [NSB, 2014]. There are other important attractions to see as Trollvegen and Kylling bridge and therefore to predict how much the number of cruises would increase, would be subjected to a very high degree of uncertainty. Instead, it is more likely that the same number of cruises stay longer in the port for that the passenger can visit the waterfall. According the Molde tourist office, the passengers take the *Raumabane* train to the local stop of Bjorli and ususally come back by take bus. If the Mongefossen waterfall was not dry. It could

FIGURE 4.10

be seen from the the railway. Since the buss has more flexibility than the train, the tourists could stop by the waterfall on the way back and make a trip up to Mongefossen. We assume for our base case estimator than the cruises could be stationed for 1 and a half hours more. It is assumed 1 hour for the sensitivity analysis and the worst case scenrario, 2 hours for hour high estimator.

According to the list of cruises of 2015 Molde og Romsdal Havn IKS [2015] that are planed to arrive to Åndalsnes 14 cruises in June, 14 more in July and 7 in August. Therefore, during the high tourist season the number of cruise ships that go to Åndalsnes (in the vecinity of mongefossen) amount to 35. During the MF period, the number of cruises amount to 25. In winter they increase to 45, although in practice they amount to 38, since the average capacity is also smaller [Molde og Romsdal Havn IKS, 2015].

During the high season (from the 1st to the 31 of August), the vessels have a capacity of 1500-2500 passangers excluding crew on average and they are operated by well-known companies such as Aida cruises, Costa cruises and MSC cruises among others. The estimate used as the base case is 2000 passengers. As a low and high estimator it will be used 1500 and 2500 respectively.

Tourists that traveled in package trips (cruise) used in summer 2013 2625 NOK per day, according to Innovasjon Norge [2013]. From this total, 1500 NOK were used for the the package trip and 1125 NOK was used for other expenses, as food and souvenirs. In the case of the cruises of Mongefossen, however, the 1125 NOK per day would be used to buy food or souvenirs outside the boat. Since the expenses go on top of the accommodation, we assume that they would mainly take place on the day-time. It is expected that the cruise ships inÅndalsnes would spend 1.5 hours -medium case estimator- longer on port so that the tourists could visit Mongefossen.

The estimators are summarized in table 4.3

TABLE 4.3: Mongefossen cruise tourism money consumption

Estimate	**Time spent [hrs]**	**Day-time con-sumption**	**Money per tourist [NOK]**	**Passengers per boat**	**N. cruises MF period**	**N. cruises summer period**
Low	1.00	1125	93.75	1500	25	35
Base	1.50	1125	140.63	2000	25	35
High	2.00	1125	187.50	2500	25	35

In order to calculate how the environmental measure would benefit the *cuise* tourism in Mardalsfossen we assume that if the waterfall is not dry the place reunites the necessary conditions to attract a high amount of cruises. According to the technical report Geir Gaarder [2010], the nature of the area is of national value since it is part of Eikesdalsvatnet conservation area for bein covered by old humid deciduous forest with hazel woods and elms and other deciduous trees as pine, birch, aspen willow and rowan. There is also a high concentration of red-listed species (34 listet so far from the red list of 2006) and the area is popular also for mushroom entusiasts. Apart from the nature, there is path of about 1300 meters long from the toll that leads right up to Mardalsfossen. The tourist is guided by some information panels and a restaurant by the parking lot is opened in summer. By the feet of the waterfall there is a statue called *another time* made by the artist Antony Gormley. Although there are currently no cruises coming to Eresfjord, there is a pilot project planned for summer 2016 when 3 cruises will by Eresfjorden an which will have Mardalsfossen as their main attraction along with the magnificent mountain scenary of Aursjøven, which opens in June. If the project succeeds the number of cruises will increase. Having as a reference 25 cruises from the neighboring fjord located nearby Mongefossen we could assume a base case estimate that amounts to 15 ships. Since the area isvless known that Åndalsnes one could expect that the number of vessels is also less. Likewise, the size of the vessels will be lower than the average of the vessels in Åndalsnes high-season which will correspond to the small vessels that land in Åndalsnes in August, of around 600 passengers excluding crew, as as estimated by the tourist office.

For Mardalsfossen we take into account the 24 hours consumption including accommodation as a base for our calculation, which amounts to 2625 NOK. In Mongefossen accomodation was not included because it is assumed that if the waterfall is dry, the cruises are going to come anyway to visit other interesting turist attractions of the area. However, the success of the project of the cruises in Eresfjord depends mainly on Mardalsfossen and therefore the tourist would not pay for the trip (including accomodation) at all if it was not for this. As our base case estimator we assume that total expenses are used in connexion with Mardalsfossen as it is assumed 1/3 day (24hours) and 2/3 (24hours). The nationality of the tourists that more often hire package holidays is correlated with the distance from where the tourist come from [Innovasjon Norge, 2013]. In that way 78% of the citizens from Xina, and 73% for the rest of Asia, 40% of South-Europeans, 35% of Americans take package holidays (against 10% of Norwegians). That means that most of the tourists that hire cruises to the West coast are foreigners and they usually spend a higher amount of money than the tourist in non-package holidays according to Innovasjon Norge [2013]. Among the foreigners 75% of them plan to experience nature in their holidays against 43% of the Norwegian according to [Innovasjon Norge, 2013]. In table 4.4

Table 4.4: Mardalsfossen cruise tourism money consumption

Estimate	**Time spent [days]**	**Day-time consumption**	**Money per tourist [NOK]**	**Passengers per boat**	**N. cruises MF period**	**N. cruises summer period**
Low	0.33	2625	875	500	15	21
Base	0.50	2625	1313	600	15	21
High	0.67	2625	1750	700	15	21

4.5.2 Other tourism

In order to calculate the number of tourists that do not hire a package holiday and drive to take a trip up to the waterfall it will be used the existent data of tourism in the minimum flow period in Mardalsfossen as a proxy for estimating the number of non-package tourists for Mongefossen during 20th of June until the 20th of August.

They are both of difficult access by foot from other urban centers and the waterfalls are of national importance . There was a toll located before the path that goes up to the waterfall and that allows for cars to park. The total toll collected in 2014 amounted to 80.000 NOK from charging 30 NOK per vehicle [4]. Assuming 4 persons per car it would amount to 10.667 tourists. Taking as reference 4 persons per car giving a total of 10.667 as our base case estimator it is assumed 8000 tourists for the low estimator and 13.333 tourist for the high estimator corresponding for 3 and 5 people per vehicle respectively. The numbers used are in line of a conservative approach since the number of people could be higher. It is technically possible to sneak from paying the toll and it does not take much longer time to park the car a before the toll and walk from there to the waterfall. The guest book is found on the way up to Mardalsfossen and the tourists can freely choose to stop and register themselves. A total of 4000 registered in 2014. The number was significantly higher during the minimum flow period and reduced to not more that some dozens during other periods where there was not minimum flow.

When extrapolating the number of *non-cruise* tourists that are likely to come if the minimum water flow is also present in other periods we can use the distribution of vessels during different periods as a proxy. The number of vessels that land on Åndalsness port depend of the the availability of seasonality and the weather. It is much more pleasant to travel by boat on the warm months of June, July and August than for example on colder months as November. The tourists have also higher availability from job in that months. If the measure of the minimum water flow is extended to the whole June, July and August (instead of the from the 20th of June until the 20th of August) we will assume that 10.667 people (data from Mardalsfossen) will visit Mongefossen during 20th of June until the 20th of August. There are 25 vessels that come to port during the 20th of June until the 20th of August. There are 10 more from the 1st until the 20 of June and from the 21st until the 31 of August. This represents that from June until August will be an increment of 40% with respect to the period of the minimum water flow, from 20th July until 20th of August. Likewise to calculate the number of tourists from the 1st of June until the 31 of August we increment 10.667 people by 40%, which amounts to 14.934 tourists. Since the number of vessels of the whole year is 45, which is 80% more than the number of vessels in the minimum flow period 20June -20August, the increment of 80% is taken to calculate the total number of tourists per year, which amounts to 23.999, and 80% more than 10.667. It is followed the same procedure for the low and high estimate. The different estimators are summarized in table 4.5

Traveller's expenses of non-package holidays amounts to 1175 NOK per day (excluding business trips) [Innovasjon Norge, 2013]. Expenses per day incurred in accommodation, transport and other consumption which amounts per person to 375 NOK, 200 NOK and

[4]Information provided by Marit Wadsten

TABLE 4.5: Number of 'other' tourists for Mongefossen and Mardalsfossen.

Estimates	**Period**		
	20.06-20.08	01.06-31.08	All year
Low	8 000	11 200	12 160
Base	10 667	14 934	16 214
High	13 333	18 666	20 266

600 NOK respectively. As suggested in the survey [Innovasjon Norge, 2013] the non-package turists are the ones with a lower daily travel expenses but who tend to spend most nights compared to tourist who hire package holidays. It is likely that tourist would like to visit the area and spend the night in Åndalsnes but we are going to be conservative in our estimators and assume a 1/2 of the day as medium estimator used in our base case, 1/3 of the day and 3/4 for the low and high estimators. The summarize table with the estimators previously presented can be found in table 4.6

TABLE 4.6: 'Other tourism' money consumption per visit to Mardalsfossen and Mongefossen.

Estimates	**Time spent [days]**	**Day consumption [NOK]**	**Benefits per tourist [NOK]**
Low	0.33	1175	392
Base	0.50	1175	588
High	0.67	1175	783

4.6 WTP

As mentioned in subsection 3.3 it will be done a value transfer of the annual environmental costs of the Sauda project based on the results of the contingent Valuation study [Bickel et al., 2005; Navrud, 1994]which were also summarized in Navrud [2001] . The average electricity production was projected to increase 1.3TWh annually (from 1TWh) and augment the capacity by 500MW. There was one upgrading projects and other 6 diversion projects. In order to capture the non-use values a representative sample 300 households (of a total of 316.000) of Rogaland and Hordaland were interviwed. The total WTP for the non-use values was a result of multiplying the WTP/households/year by the total population of the two counties, which amounted to 316.137 households.

Other diversion projects without waterfalls showed a much lower willingness to pay although the impacts were much higher. For example in the diversion project 2, which covered the upper Åbø watershed and Lake Sandvatn the water flow of 16.7 km of river was going to be reduced 71-80%.The large reductions in water flow was going to reduce the aestheic quality of the agricultural landscape with existent 10 cultural objects, of which 12.5 % were older than 1537 and the days recreational activities for swimming and hiking were going to be of *much lower* quality. However the WTP amounted to 9.03 NOK [5] as shown in [Navrud, 2001], which is much lower than WTP estimated in the other 2 waterfalls.

The waterfall of Langfossen was a part of the diversion project 4 covering Lower Åbø and it is characterized for beeing of national value as shown in figure 4.11. As described in the table of impacts developed in Bickel et al. [2005, p.161] the impacts of the parts of the area which was of regional-national value were described as small and no impacts were expected on geologically important structures. In 15.6/13.1 km of river the water flow was going to be reduce up to 60% but Langfossen water flow was going to be preserved in summer and the impacts were considered as small. The willingness to pay from the households of the county -capturing the non-use values- were the highest of the 7 projects, amounting to 33.24 NOK -also adjusted by CPI.

FIGURE 4.11: Langfossen

The second highest estimate was for diversion plan 1, which covered the rivers of Maldal and Sageelv. In that case just 1.7 km of river was going to be affected, and the the flow was only going to be reduced up to 10 %. The waterflow Sagfossen and Maldalsfossen were of large and medium local value but the impacts were estimated to be high. The willingness to pay from the households of the county amounted to 21.32 NOK -also adjusted to 2014 prices-. and the WTP of Sauda households was a little higher, since Sagfossen could be seen by the community and the use value (non-consumption) was higher from the community that from the county, amounting to 25.71. Yet, we are

[5] 0.72 ECU with a exchange rate of 8.3 as presented in Bickel et al. [2005] and adjusted by the Norwegian CPI [SSB, 2015e]to 2014 prices.

interested to capture the non-use values as through the WTP and the use-value of the experience through the estimator of the tourism.

Since Mongefossen and Mardalsfossen are of national interest we will use its estimate of 33.24 NOK as a value transfer for both Mongefossen and Mardalsfossen. Note that the WTP an important water is high despite the level of impact is low. Note that the flow in summer was going to be preserved so at least part of the willingness to pay was to avoid negative impacts in winter. This may be because the non-use values and the use-values (non-consumption) differ on the way of valuing the waterfall on different seasons. The use values although non-consumptive differ from the non-use values for example in valuing the waterfall in winter. Tourists extract the use (non-consumptive) value of the waterfall by doing excursions or sightseeing, which the conditions are much better in summer than in winter. On the contrary, the willingness-to-pay for its existence would likely have similar values in winter than in summer. The WTP for avoiding small impacts in Langfossen amounts to 33.24 NOK, which in the worst case it would represent a 40% decrease in water on winter season. On that case we can assume that the WTP for incresing the water flow to 2-2.5 m^3/s (MF) on Mongefossen/Mardalsfossen is at least(or higher) than 33.24 NOK. As shown in fig. 4.12 and previous presented in subsection 5.10 we assume that the WTP increases rapidly on low level and slows down on high levels of flow. Therefore we assume that since $\delta WTP2$ Langfossen amounts to 33.24 NOK/household/year in order to avoid small impacts, the willingness to pay to reach the Minimum flow in Mardalsfossen and Mongefossen has to be equal or more $\delta WTP1$.

In the contingent valuation of the Sauda project the quantity of households used to calculate the total WTP comprised the both the county where the community of Sauda (Rogaland) and the neighboring county Hordaland. The total households were 316.137. In the case of Mardalsfossen and Mongefossen the county of Møre og Romsdal (114,651) along with the neighboring counties Sogn og Fjordane (46,330) and Sør-Trøndelag (149,276) will be used as the base case estimate. The number of households in the year 2014 amounted to 310,257 [SSB, 2014]. Since both Mongefossen and Mardalsfossen are higher than Langfossen [SSB, 2013; NVE, 2009] one may also argue to include a wider area. When there are an important environmental goods one can also understand them as of global interest and include more countries in calculating the WTP than the one where the environmental goods is found. This is the example of Delphi stated-preference exercise as presented by Navrud and Strand [2013]; Strand et al. [2014] where environmental valuation experts from different countries were asked to predict the WTP for the amazon forest preservation among their own countries' citizens. In the case of Mardalsfossen and Mongefossen, although in much lower scale, it will be also included the number of households of Oppland -the neighboring county to the south of Møre og Romsdal, 87,416 households- in the high estimate. The total number of households included in our analysis will for the base case estimate 310,257 households, corresponding to Sogn og Fjordane, Møre og Romsdal and Sør-Trøndelag. Finally 397,673 for the high case estimate, corresponding to Sogn og Fjordane, Møre og Romsdal, Sør-Trøndelag and Oppland. The estimators are summarized in table 4.7

TABLE 4.7: Willingness to pay (WTP) price estimates.

Estimate [NOK]	**Number of households**		
	Low	Base	High
33.24	114 651	310 257	397 673

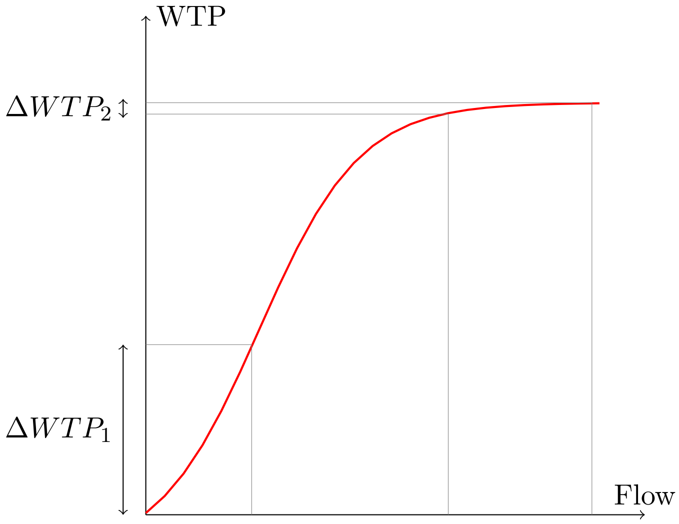


FIGURE 4.12: The WTP 1 for achieving a MF in Mardalsfossen and Mongefossen whould be equal or greater than the WTP2 in langfossen to avoid a decrease in flow from its maximum.

Chapter 5

Analysis

The EBCA is performed using a NPV of thirty periods – each period of one year –, since we assume that the conclusions of this master thesis concerning the measures adopted in both of the waterfalls will be applied for the revision and therefore unchanged for 30 years, which is the time frame stipulated by law[1]. Firstly, in order to answer the research question –*Is it welfare enhancing to employ NVE's proposed minimum flow regime for Mongefossen from mid-June until mid-August?*, the EBCA of Case 1 is performed. After this, Cases 1.1 to 1.8 are developed for Mongefossen to evaluate if one may implement better environmental solutions than the minimum flow regime tested in Case 1, as asked in the second research question –*Which form of flow regulation yields the highest social surplus for Mongefossen and Mardalsfossen?* Likewise the second research question is addressed for the context of Mardalsfossen in Cases 2 to 2.6. Note that this section aims to merely present the methodology and reasoning behind each case-scenario – the discussions regarding the results are thoroughly treated in chapter 6. Cases 1 and 2 are the 'base'-cases to which all the other cases are compared. Since Cases 1.1 to 1.8 and 2.1 to 2.6 are all variations of Cases 1 and 2, a fruitful approach may be to jump to chapter 6 once having understood Cases 1 and 2 here, and then refer back to each of the other cases when their results are discussed.

In Case 1.1 the EBCA is performed exploring the possibility of having a daytime/nighttime adjustment of the water flow, i.e., to keep the same minimum rate of flow in the daytime while decreasing the amount of flow during nighttime. Hypothesis one is thereby tested, which states that daytime/nighttime adjustment decreases costs and therefore increases the NPV. In Case 1.2 the EBCA is performed for the same period suggested by NVE, but with increased flow. The second hypothesis is therefore tested, which estates that higher amounts of flow increases the NPV, mainly due to the increase of benefits

[1] Unless the decision needs to be changed because it was found harmful the general interests of society.

from tourism. In Case 1.3 the daytime/nighttime water flow adjustment is used to increase the flow at daytime instead of keeping the same minimum of flow as in Case 1.1. After that, Case 1.4 and 1.5 explore the possibility of extending the period of flow to the whole year. Special attention is given to evaluate if the increase on fish benefits and WTP for non-use values outweigh the costs of the power plant, as claimed by hypothesis 4. Case 1.6 to 1.8 are developed to tests hypothesis 3, which estates that extending on the water MF period from two months to three aiming to cover the high tourist season outweighs the costs of from loss of energy.

Following the cases on Mongefossen, this analysis switches focus to Mardalsfossen. Case 2 analyzes the same regime of minimum flow currently applied for Mardalsfossen by NVE (excluding the practices regarding dry seasons discussed below). Case 2.1 analyzes the economic implications of not reaching the minimum flow in August due to dry seasons: The present regime of minimum flow (MF) in Mardalsfossen allows Grytten to not let water flow via Mardalsfossen in the event that the immediate basin connected to the waterfall is dry. As explained in 5.10, between mid-June through to July Grytten would be required to supply water from a second basin called Sandgrovvatn in the event that Mardalsfossen's immediate basin was dry. Cases 2.2 to 2.4 focus on the environmental benefits that arise as a result of the development of cruise tourism, i.e. allowing more water to flow via the waterfalls. Here this will sometimes be referred to in the shorthand form 'the environmental benefits of tourism', although this is somewhat misleading. The consequences to such benefits in the event that such cruise tourism fails on account of low flow in August will also be discussed. Other solutions for Mardalsfossen are also explored, particularly in case 2.5 and 2.6, in pursuit of answering the second research question.

Finally, the different categories of environmental benefits and costs are first presented for period 0 before performing the NPV for the 30 periods. The intention of doing this is to know how the proportion of each category of environmental benefits and costs are going to be decision-making relevant for choosing the solution that gives the highest NPV. This method of presenting is especially relevant in order to test hypothesis 6, which claims that the increase in tourism and recreational fish values combined with low electricity prices triggered by the electricity certificate market are decisive for the EBCA. Furthermore it is useful to know what effect the KAF variable plays when the sensitivity analysis is performed, and what the effect of the social discounting rate is.

The development of Case 1 is presented in detail to facilitate understanding the methodology and assumptions, while the remaining cases are described very briefly – avoiding unnecessary repetitions. For instance, the different steps taken will not be explained if it is apparent that they are equal for the previous cases. Low, base case and high estimates are applied in each of the cases according to the criteria explained in the data chapter 4.

5.1 Mongefossen case 1 NVE

The EBCA is first conducted on the environmental measure that NVE will consider in the revision of the concession in 2020 as explained in chapter 1. The base case estimates for the tourism and WTP are used since we are considering minimum flow, consisting of $2.0m^3/s$ and $2.5m^3/s$ during the period 20.06-30.07 and 01.08-20.08 respectively. The seasonal influx of cruise tourists during these two months is captured by the quantity of cruise vessels that are planned to arrive at the two ports nearby Mongefossen, as described in section 4.5.1. Other tourism is captured by the base case estimates of tourists in Mardalsfossen during the same period at minimum flow rate, as presented in 4.5.2. A sensitivity analysis is performed using the high and low estimates in order to test the sensitivity of the different inputs on the EBCA.

5.1.1 Loss of revenues for period zero

The loss of revenue depends on the amount of water that is released into the waterfall, the period of time in which this is allowed to happen, the energy price and the efficiency of the turbine. In order to calculate this loss the following declaration of terms is made.

LP	–	Loss of power [W]
t	–	hours of water flow
P^h	–	Energy price [NOK/MWh]
η	–	Conversion efficiency of turbine
LR	–	Loss of Revenue [NOK].

The loss of revenue equals the product of the conversion efficiency η, the loss of power LP and the peak load energy price P^h along with the appropriate unit conversions – without taking the pump into consideration:

$$\begin{aligned} LR &= \frac{LP[\text{J/s}] \cdot t[h] \cdot 3600 \text{ s/h}}{3600 \text{ J/Wh}} \cdot \frac{1 \text{ MWh}}{10^6 \text{ Wh}} P^h[\text{NOK/MWh}] \\ &= \frac{LP \cdot t}{10^6} \cdot P_r \quad [\text{NOK}] \end{aligned} \tag{5.1}$$

Inserting for LP found in section **??** gives

$$LR = \frac{\eta \cdot g \cdot h \cdot \rho \cdot f \cdot t}{10^6} \cdot P^h \quad \text{[NOK]} \tag{5.2}$$

5.1.2 Loss of revenues taking the pump into account period zero

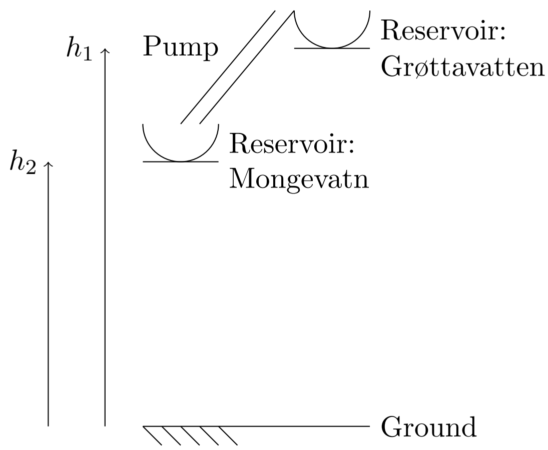


FIGURE 5.1: Model of Mongefossen

As illustrated in fig. 5.1 the height h_2 of the water from Mongevatn by Mongefossen is 913 meters above see level, which is lower than h_1. Grøttavatn is the main reservoir to which the water from Mongevatn is pumped and has a height of 980 meters above see level [vann-nett, 2015a,b]. With the need to pump water from Mongevant to Grøttavatten the potential power that may be harvested from the water is on the one hand greater by the increased potential energy at a higher height h_1 while on the other hand is diminished by the amount of power consumed by the pump. Taking into account these elements we express:

$$LP = g \cdot h_1 \cdot \rho \cdot f_1 - LP_{\text{pump}}(f_2), \tag{5.3}$$

Where $LP_{\text{pump}}(f2)$ represents the loss of power by the consumption of the pump, and it is a function of the water flow f_2 that is to be pumped up, instead of let out into the water fall. The pumping process is essentially the inverse of the generation of power in the turbines – electrical energy is used to pump water upwards by a turbine. The same model for loss of power as derived in Sec. **??** applies for the loss of power of the pump:

$$LP_{pump}(f_2) = g\Delta h \rho f_2 \tag{5.4}$$

$$= \alpha \cdot f_2 \tag{5.5}$$

Where Δh defines the difference between h_1 and h_2 (67m), f_2 defines the flow that is pumped and α defines a constant of the flow. If there is no flow being pumped, the power is zero.

In general, one cannot assume that the flow rate of the pump will equal the flow rate chosen for the water outlet into the waterfall, i.e., $f_2 \neq f_1$. For technical or economic reasons it is conceivable that a lower flow rate $f_2 < f_1$ may be pumped over a longer time interval t_2 [hrs] instead of the time interval Δt_1 [hrs] in which water is allowed to flow into the waterfall:

However, since we are ultimately interested in the energy consumption, and not the power consumption in itself, the distinction between $P(f_{\text{pump}})$ and $P(f)$ does not matter. The quantity of water pumped must be the same independently of the flow and time. Hence the energy consumption is the same by virtue of our simple model (5.4):

$$E = \alpha P_{\text{pump}}(f_2)t_2[\text{hrs}] \cdot 3600\text{s/hrs} = \alpha f_2 t_2 \tag{5.6}$$

$$= \alpha P(f_1)t_1[\text{hrs}] \cdot 3600\text{s/hrs} = \alpha f_1 t_1 \tag{5.7}$$

$$= f_1 t_1 = f_2 t_2 \tag{5.8}$$

The corresponding loss in revenue –without taking into account that the pump of electricity may be done at other price that P_r^h– LR from (5.3) and (5.4) may be expressed

$$LR = \eta \cdot \frac{g \cdot (h_2 - \Delta h) \cdot \rho \cdot f \cdot t}{10^6} \cdot P_r \tag{5.9a}$$

$$= \eta \cdot \frac{g \cdot h_1 \cdot \rho \cdot f \cdot t}{10^6} \cdot P_r, \tag{5.9b}$$

where $h_2 = h_1 + \Delta h$ has been used in arriving at (5.9b). According to (5.9) the cost of pumping water a height Δh is exactly matched by the increased profit of releasing the water from the new height h_2. This is clearly only the case when losses, e.g. due to friction, have been neglected. However, if we take into consideration that the power production takes place at peakload hours and pumping takes place during offpeak hours – corresponding to the periods of high (P_r^h [NOK/MWh]) and low energy prices (P_r^l [NOK/MWh) respectively the loss of revenues equation be expressed as:

$$LR = \left(\frac{\eta \cdot h_1 \cdot g \cdot \rho \cdot f \cdot t}{10^6} \cdot P_r^h\right) - \left(\frac{\eta \cdot \Delta h \cdot g \cdot \rho \cdot f \cdot t}{10^6} \cdot P_r^l\right) \tag{5.10}$$

$$= \frac{\eta \cdot g \cdot \rho \cdot f \cdot t}{10^6}\left[h_1 \cdot P_r^h - \Delta h \cdot P_r^l\right]. \tag{5.11}$$

We use the data presented in section 4 and apply the formula 5.11 for calculating the loss of revenues, as presented in table 5.5. Therefore the loss of revenues that will represent for Grytten will be:

$$LR = \frac{0.95 \cdot 9.81 \cdot 1000 \cdot \big(2.5 \cdot 984 + 480 \cdot 2\big)}{10^6} \cdot \Big[980 \cdot 378.59 - 67 \cdot 251.71\Big] \qquad (5.12)$$
$$= 8164416.64 \text{NOK}.$$

Where $(t_a \cdot f_a) + (t_b \cdot f_b) = t \cdot f$.

As shown in table 5.5 the proportional loss of energy would be LE 31,235.24 MWh if we did not take the LE of the pump. However, the total LE would result in LE 29,099.77 (LEwithout pump $- LEpump = 31,235.24 - 2,135.47 MWh$) since 2,135.47 MWh of energy E would be used on pumping the water up to Grøttavatn if the water had not been released. The $LEpump$ saves a 6.8% of $LE_{withoutpump}$ but the effective saving in LR would be a little lower, 6.18 % (from dividing LR_{pump} 537 517.92 by $LR_{withoutpump}$8 701 933.46) since it would be cheaper to pump the water at night at price $P_r^L = 251.71$ than at day-time, when the production of electricity takes place and the price is higher $P_r^h = 278.59$. The total LE which amounts to LE 29 099.77 MWh would represent a 5.32% of total energy E, since the average total E production of the last 8 years amounted to 547,290 MWh. The amount of hours in which the water is released into the waterfall at different flow rates f_a and f_b is t_a ($41 days \cdot 24 hrs$) and t_b ($41 days \cdot 24 hrs$) is.

As explained in section 4.3 it is taken the yearly average of Molde Norwegian area 2014, which amounts to 263.57 NOK/MWh. The yearly average price Pr^h, is the result of increasing the average price by 5.7 percent. The percentage of increment corresponds to the average daily difference of the peakload prices with respect to average daily prices from the 1st of January 2014 until the 31 December 2014 as published in elspot market. The average off-peak price compared to average yearly prices from the period of the 1st of January 2014 until the 31 December 2014 as published in elspot market is 4.5 percent lower than average price. Applying the decrease the yearly average off-peak price for Molde, Pr^L, amounts to 251.7 NOK.

The total hours that Grytten is in operation also reflects that they do not have to produce all the time and that they can choose to produce in peakload hours. The maximal average power production of Grytten power plant amounts to 143.5 MW [2] and the yearly energy production amounts to 547.29 GWh [3] . To calculate the number of hours H per year in which the hydroelectric plant is in operation we take into account

[2] According to Statkraft's map over the Grytten Power plant.
[3] As provided the the representative of Statkraft.

that if we let the 143.5MW of power run for one hour it amounts to 143.5 MWh of energy. So if we divide the yearly energy production by the energy production in one hour at the maximum power rate:

$$H = \frac{547.29 \text{ MWh/ year}}{143.5\text{MWh/ hrs}} = 3,813.87 \text{ hrs/year} \tag{5.13}$$

This amount of hours represent that it is full opeation 43 percent of the year, which it is consistent with the assumption of peakload average prices.

TABLE 5.1: Case 1 baseline data for calculating loss of revenue

Parameter	**Value**
η [%]	0.95
g [m/s^2]	9.81
h_1 [m]	980
h_2 [m]	913
ρ [kg/m^3]	1000
f_a	2.5 m^3/s
f_b	2 m^3/s
t_a [hrs]	984
t_b [hrs]	480
P^h [NOK/MWh]	278.59
P^L [NOK/MWh]	251.71
LE excl. pumping energy [MWh]	31 235.23
Pumping energy [MWh]	2 135.47
Pump consumption [%]	0.068
LE of yearly production [%]	0.053
LR excl. pumping costs [NOK]	8 701 933.46
Pumping Costs [NOK]	537 517.54
Pump cost share [%]	0.0618
Yearly Total LR [NOK]	**8 164 415.92**

5.1.3 Benefits from cruise tourism for period zero

The results presented can be found at table 5.6 along with the base case estimates, which assumptions were previously commented at 4.5. The tourist that hire a package holiday on a cruise where accommodation is included spend on average 1125 NOK for food souvenirs and other expenses apart from the package price in which the accommodation on the ship is included. Since this expenses go on top accommodation we assume that they would take place on the day-time. The expenses would amount to 93.75 NOK/hour from dividing 1125 NOK/day-time by 12 hours. Assuming the ship would let them be on the area 1 and a half hours total expenses per tourist per day would amount to 140.63

Table 5.2: Case 1, environmental benefits of tourism.

Tourism	
Cruise tourism	
Package holiday cruise [NOK/day]	1125
Visiting waterfall [hrs/day]	1.5
Number of cruises 2015	25
Number passengers [per cruise]	2000
Total cruise tourism [NOK]	**7 031 250.00**
Other tourism	
Total toll [NOK]	80 000
Toll price [NOK]	30
Passengers/car	4
Total visitors	10 666.67
Expenses per pers. [NOK/day]	1175
Time per visit [day per pers.]	0.50
Total other tourism [NOK]	**6 266 666.67**
Total tourism	**13 297 916.67**

NOK. The number of cruises from the 20 th of June until the 20th of August is planned to be 35 and the capacity of the each cruise is around 2000 people on average. Total benefit from the environmental measure would be the result of multiplying 140.63·35·2000 which amounts to 7 031 250 NOK.

5.1.4 Benefits from other tourism for period zero

As discussed in section 4.5 we would use the tourism of Mardalsfossen in summer season as a reference for calculating the amount tourists that shall not hire a package holiday and that they would drive to the area (non-package tourists). The main data and results applying the base case estimates of section 4.5 can be found in table 5.6. The total toll collected in one year was 80.000 NOK and assuming 4 passenger per car it would amount to approximately 10 667 tourists. Assuming that the visitors spend half a day on the trip to the waterfall, where total expenses per day are estimated to be 1175 NOK/person (from 375 NOK accommodation + 200 transport + 600 NOK) the expenses/person/visit would amount to $1175 \cdot 0.5 = 587.5$. The benefits of the environmental measure would amount to a total of 6 266 667 NOK from tourist without package holiday. Benefits from total tourism (both from package and not package) would amount to 13 297 917 NOK which which is greater that costs suffered from Grytten (8 164 416) if the environmental measure takes place.

5.1.5 Benefits for fish period zero

The benefits would amount to 0 for the first 10 years, since it is the time estimated for the restoration of the salmon population. Nevertheless, it is presented in section 4.4 the NPV of the benefit for the recreational fish values due to the the environmental measure on the year eleven, since it would take 10 years for the fish population to be restored. It would amount to 116 619 NOK on year 11, which amounts to the NPV of 84,248 NOK. The 116 619 NOK is the result of multiplying the percentage of total impact of the hydroelectric plant, 10 percent by the percentage of decrease on energy (E) that the measure represents for the firm, in that case, 5.32 percent and by the total value of the population of fish given by the report, which amounts 21 932 987 NOK. The data and results shown in table 5.7 would be taken into consideration when discounting the environmental benefits from year eleven until 50.

TABLE 5.3: Case 1, environmental benefits of fish.

Fish	
Report [NOK]	21 932 987.06
LE of yearly production [%]	0.0532
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	116 619.12
NPV of benefit for period 11	**75 753.56**

5.1.6 Benefit of WTP for period zero

In order to calculate the willingness to pay for the environmental measure we use the base case estimates discussed in 4.6. The data as well as the results are summarized in table 5.8. The total WTP is the result of multiplying the total amount of WTP 33.24 NOK/year/household multiplied by the number of households. The population of the county Møre og Romsdal and the neighboring counties Sogn og Fjordane and Sør-Trøndelag amount to a total of 310 257 households. Therefore total WTP amounts to 10 311 475 NOK.

TABLE 5.4: Case 1, environmental benefits of willingness to pay.

WTP	
WTP/household/year[NOK]	33.24
Total households	310257
Total WTP [NOK]	**10 311 475.29**

5.1.7 EBCA

The net present value NPV_s is calculated by (2.6) assuming a T=30. We take into account that the fish population is assumed negligible for the first ten years in the following manner: The benefit of fish in the 11th period (116 619 NOK as listed in table 5.7) is included in the total environmental benefits ENB from year 1, and then the net present value of the fish benefits $FENB$ over the ten first years are subtracted from this. Expressed mathematically,

$$NPV_s = \frac{\overbrace{ENB}^{\text{Incl. } FENB}}{r-a}\left[1-\mathrm{e}^{-30(r-a)}\right] - \frac{NC'}{r}\left[1-\mathrm{e}^{-30r}\right] \underbrace{- \frac{FENB}{r-a}\left[1-\mathrm{e}^{-10(r-a)}\right]}_{\text{Correction}}. \tag{5.14}$$

Inserting numbers from tables 5.1, 5.2, 5.3 and 5.4 with $r = 0.04$ and $a = 0$ gives

$$\begin{aligned} NPV_s = {} & \frac{13'297'916.67 + \overbrace{116'619}^{FENB} + 10'311'475.29}{r-a}\left[1-\mathrm{e}^{-30(r-a)}\right] \\ & - \frac{8'164'415.92}{r}\left[1-\mathrm{e}^{-30r}\right] - \underbrace{\frac{116'619}{r-a}\left[1-\mathrm{e}^{-10(r-a)}\right]}_{\text{Correction}} \\ & = \underline{270'902'144.60}. \end{aligned} \tag{5.15}$$

The resulting EBCA is positive, amounting to 270 902 145 NOK.

5.1.8 Sensitivity analysis

The sensitivity analysis is performed using the high and low parameters presented in section 4 in order to test the sensitivity of the inputs on the ECBA. Both the results and the parameters used summarized in table 5.2.

Based on the forecast found in 4.3 the high estimator taken as a upper bound is 45 NOK higher than Molde prices, amounting to $P_r^h h$ 326.16 as a high price and 294.68 NOK as$P_r^h L$ as a low price. The variation on output is 24 352 202.6 NOK, since the NPV decreases by a 9% from 270 902 150 NOK to 246 549 947 NOK. The price has to increase to 808 NOK so that the NPV is approximately 0.

If all of the low estimates were used at the same time, the NPV decreases to 51 922 724 NOK. By performing the sensitivity analysis with the low estimate that has the highest impact on output after the social discount rate - time per visit-, the NPV decreases to 234 408 958NOK, as shown also in Figure 5.2. If the EBCA is performed with the social discount rate of 6% instead of 4%, the result of the EBCA still amounts to 215 611 064 NOK. With a low social discount rate of 2%, the NPV amounts to 350 003 560 NOK. If the KAF variable is used, the NPV increases and the percentage of increase varies using different social discount rates. If r=2% and KAF 0.5% the NPV increases to 387 908 485 NOK, which represents and increase of 10.8%. If r=4% is used in combination with KAF, the NPV increases to 297 050 620 NOK, which represents and slightly lower increase of 9.7%. If r=6% is used in combination with KAF, NPV increases to 387 908 485 NOK, representing an increase of 8.6%.

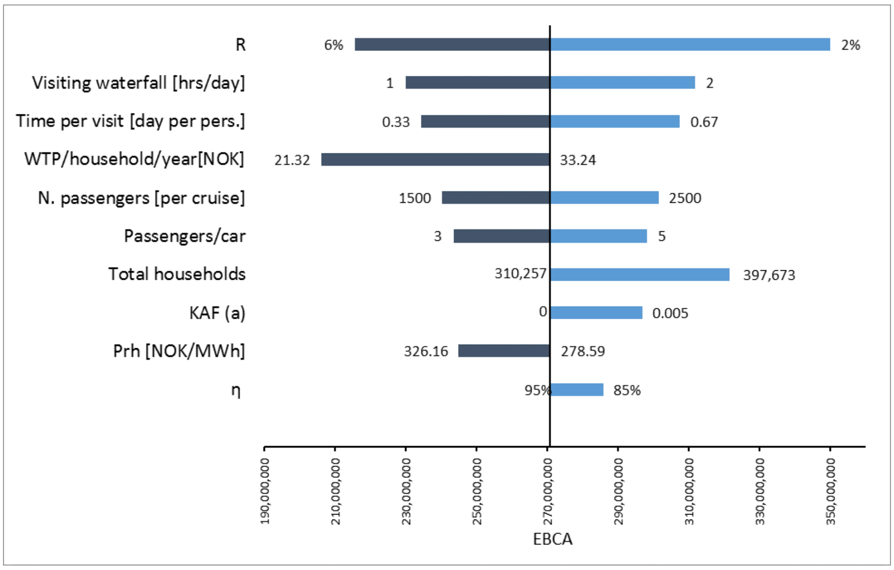


FIGURE 5.2: The Y axis represents the NPV from the EBCA using the base case estimators and amounts to 270 902 150 NOK. The X axis shows the variation on the output (EBCA) if the analysis operated with the low and the high estimates instead of the base Case estimates. The numbers beside each extreme of the bars are the low and high estimates.

5.2 Case 1.1 low cost adjustment

The possibility of daily adjustment is used to keep the same rate of minimum flow at day-time and decrease to the minimum of 1 m^3/s at nighttime. The LR therefore decreases to 5 829 679 NOK as presented in table A.1 and the NPV increases to 311 382 583 NOK, since the loss of energy decreases to 3.80%. The flow $t \cdot f$ is calculated by multiplying $t_a * f_a + t_b * f_b$. Where t_a = 492 hrs, f_a = 3.5m^3/s, t_b = 240 hrs and f_b 3m^3/s. So $t * f$= (2.5+1)*41 days*12 hrs + (2+1)*20 days*12hrs since the flow of 2.5

m$^3/s$ on day-time (from 8am to 20pm) and 1 m$^3/s$ at night-time (here from 20pm to 8am) equals to an average of 3.5 m$^3/s$ per 12 hours. Likewise, the period in August of 2.0 m$^3/s$ on day-time (from 8am to 20pm) and 1 m$^3/s$ at night-time (here from 20pm to 8am), which equals to an average of 3 m$^3/s$ per 12 hours.

The rest of the benefits are expected to otherwise follow case 1, since the tourism should not be affected by a decrease of flow at nigh-time, where there is hardly any tourist. The benefits of the fish decreases slightly to 54 091 NOK, as shown in A.2. Yet, although it is assumed the same WTP since the base case estimate works as a minimum -as explained in 4.6- the WTP could also decrease due to the overall decrease in flow, and therefore total NPV.

5.3 Case 1.2 period NVE high flow

The operations follows the same logic as in 5.1 the possibility of releasing a higher flow than the minimum flow for the same time period is evaluated. As presented in 5.10 the high flow is considered to be 4 m$^3/s$ for Mongefossen and the period extends from 20th June until 30 of July. Since there is a higher probability than the high flow attracts more tourism and the WTP rises, the high estimate for WTP and tourism will be used as discussed in 4.

The Loss of revenues increases to 13 979 772 NOK since a high flow running the whole day increases the loss of energy of yearly production to 9.104%. Yet, the increase in loss of energy is outweighed mainly by the increase on cruise tourism and other tourism, which amounts to 11 718 750 NOK and 10 444 444 NOK respectively. The WTP increases to 13 216 770 NOK and the fish related benefits increase to 129 711 NOK. The final NPV amounts to 375 707 176 NOK. The results are presented in detail in tables A.3 and A.4.

5.4 Case 1.3 period NVE high flow adjusted

The operations follows the same logic as in the previous case but the daily adjustment is used to increase the flow at day-time instead of keeping the minimum flow. The high flow of 4 m$^3/s$ will be decreased at night to 1m^3/s, as presented in 4.2.1. In that way the high flow at day-time will be capture by the high estimate for tourism presented in section 4.5. The base case estimate will be used for WTP instead of the high estimate, as presented in 4.6 since the decrease on flow at night may have a negative impact on WTP despite the positive impact on high flow at daytime.

The results are presented in detail in tables A.5 and A.6. The Loss of revenues amount to 8 737 357 NOK and both the benefits from cruise tourism and other tourism remain the same as in the previous case, amounting to 11 718 750 NOK and 10 444 444 NOK respectively. The benefits from fish amount to 81 070 NOK. The final NPV amounts to 415 845 981 NOK.

5.5 Case 1.4 the 'pristine nature' view

The Mongefossen model is applied as in the main case 5.1 but the degree of flow and the period is modified in order to evaluate the 'pristine nature' view. The 'pristine nature' view tries to capture the interests of one of the main groups involved in the regulation of the hydroelectric plant and also find out if it is justified from a EBCA perspective to release water during longer periods than high season due to possible benefits on fish. The one who embodies the 'pristine nature' view' would like a high flow during the whole year, it does not matter whether he or she is going to visit the waterfall, but would be satisfied by knowing that the impressive waterfall is finally free from human intervention. Since it is unknown how much water could be released if the flow was free, the high flow of 4 m^3/s will be assumed as defined in section 4.2.1. The high estimates found in section 4.5 for number of people per boat and passengers will be used when measuring the tourist on high season, since the high flow is supposed to be more spectacular that the flow at minimum flow rate. Yet, the number of tourists that come during the whole year are not going to be much greater than the number coming in high season. The high case estimate will be used for WTP instead of the base case estimate, as presented in 4.6.

The NPV of the EBCA turns to be negative and amounts to - 630 907 880 NOK. The negative result is a consequence of a high Loss of revenues amounting to 83 649 454 NOK, since the the loss of energy of yearly production is 54.477%. As discussed in section 4.5.2 it is used the tourism of Mardalsfossen during the minimum flow period as a reference for calculating the amount tourists that do not hire a package holiday during the minimum flow period. In order to calculate the distribution of the non-package tourists during the whole year the distribution of cruises to Åndalsnes during the one year period is used. The benefits of the environmental measure amounts to a total of 15 875 556 NOK for tourist without package holiday. Benefits from cruise tourism amounts to 17 812 500 NOK. The loss of revenues is around ten times higher than previous case but the tourism is less than double. The benefits of the environmental measure for the fish population can not outweigh the costs either, since although they increase around 5 times more -amounting 776 142 NOK- the total proportion of benefits from fish compared to any other category is still very small. The amount of WTP is greater than in the previous case since the high estimate is used. It amounts to 13 216 770 NOK.

The results from the calculation of loss of revenues are presented in more detail in table A.7. The benefits from tourism, fish and WTP are found in table A.8.

5.6 Case 1.5 the 'pristine view modified'

Since the result of the previous case is negative, in the 'pristine view modified' the flow period of flow comprises the whole year but the flow is reduced to the minimum flow. Given that the flow is minimum the base case estimates are used. The high estimate will be used for WTP since the period of the flow comprises the whole year. The justification for such assumption is presented in section 4.6.

The NPV of the EBCA is still negative and amounts to -161 515 371 NOK as shown in table A.9 . The loss of revenues decreases to 42 999 257 NOK but it is still high, because of the high level of loss of yearly which represents the 28%. The benefits from cruise tourism, other tourism fish and WTP are found in table A.10 and they amount to 10 687 500 NOK, 9 525 333 NOK, 398 969 NOK and 13 216 770 NOK respectively. The results related to tourism are similar but slightly smaller than in a shorter period as in case 1.2. This can sound counter-intuitive but it is due to the little influx of tourists in winter time and the use of the base case estimates due to the minimum flow.

With a lower social discount rate of 2%, the NPV amounts to -207 596 695 NOK which is actually lower than our actual result. The NPV increases to -129 204 162 NOK with a higher social discount rate of 6% is used. If the KAF variable is used, the NPV increases. The percentage of increase varies using different social discount rates. If r=2% and KAF 0.5% the NPV increases to -153 307 469NOK, which represents an increase of 26.15%. If r=4% is used in combination with KAF, the NPV increases to -124 083 001 NOK, which represents an increase of 23.18%. If r=6% is used with KAF, NPV increases to 102 812 965NOK, representing an increase of 20.43%.

5.7 Case 1.6 the 'tourist' view

The Mongefossen model Case 1 is applied and the degree of flow used is the minimum flow but the period is modified in order to evaluate the 'tourist' view. The 'tourist' view tries to capture the interests of the tourist office which would like that the minimum water flow would be extended to at least the three month of high season June, July and August.

The base case estimates for tourism and WTP will be used, as presented in section 4.5 and 4.6 respectively. Although the flow is not high the benefits of releasing more water increases due to a higher transit of tourist that in the minimum flow period. Therefore, the result of the EBCA is not just positive but greater than case one, amounting to 304 225 662 NOK. The increase in NPV happens in spite of the loss of revenues increases from 8 164 416 NOK -in case one- to 11 602 065 NOK. The main drivers of this increase are benefits from cruise tourism and other tourism amounts to 9 843 750 NOK and 8 773 333 NOK respectively, which almost reaches the benefits from tourism of the whole year. The benefits from fish amounts to (NPV year eleven) 107 650 NOK and the WTP is the same as in case one, 10 311 475 NOK. The results are found in more detail in tables A.11 and A.12.

5.8 Case 1.7 the 'demanding tourist view'

The 'tourist' view tries to capture the interests of the tourist office which would like that the period in which the water is released covers the whole summer and at the same the experience of the tourists is increased through a high water flow. The high water flow for Mongefossen is defined as 4 m^3/s in section 4.2.1. The high estimates found in section 4.5 for number of people per boat and passengers will be used when measuring the tourist on high season, since the high flow is supposed to be more spectacular that the flow at minimum flow rate. The high case estimate will be used for WTP instead of the base case estimate, as presented in 4.6.

Although the flow increases and hence the loss of revenues -which almost doubles- from 11 602 065 NOK to 20 855 069 NOK compared to the previous case. Yet, the increase in cruise tourism and other tourism outweighs the costs. They amount to 16 406 250 NOK and 14 622 222 NOK respectively. The effect of the high flow is similar to case 1.2. The benefits from fish amount to 193 504 NOK and WTP amounts to 13 216 770 NOK. The are found in more detail in tables A.13 and A.14.

The NPV amounts to 411 378 672 NOK. This is the highest NPV seen so far without using daily regulation. The ratio of cost-benefits is 47%, which is greater than the ratio in case 1, which was 34.5%. When using the high estimate of prices the NPV decreases to 349 173 760 NOK. The decrease in NPV applying the high estimate for peak-load price is 15%. When performing the EBCA in the worst case scenario -using all of the low estimates- the NPV becomes negative, amounting to -114 426 126 NOK.

5.9 Case 1.8 the 'demanding tourist view' adjusted

Since the result of the daily adjustment (or regulation) had a positive effect on the NPV in case 1.3 it is expected to also have a successful effect during the whole summer, where at day-time the flow is increased to 4 m^3/s and decreased to $1m^3$/s at night, as presented in section 4.2.1. The NVP turns indeed higher than with out regulation, amounting to 496 219 799 NOK. The reason is the significant decrease on loss of revenues – despite the decrease on WTP –, keeping the high benefits from tourism from the previous case, amounting to -16 406 250 NOK- for cruise tourism and -14 622 222- for other tourism. The benefits on fish are also low compared to the rest of categories of environmental benefits and costs, amounting to 120,940NOK.

When performing the worst case scenario -using all of the low estimates- the NPV is still positive and greater than Case 1 and Case 1.7, amounting to 12 452 791 NOK. The ratio of cost-benefits is 31%, which is lower than the ratio in case 1.7, which was 47%. By using the high estimate of prices the NPV decreases to 457 341 738 NOK. The decrease in NPV applying the high estimate for peak-load price is 7.80%. The maximum peak-load price that gives a NPV of approxiamtely 0 amounts to 885.7 NOK.

The results from the calculation of loss of revenues are presented in more detail in table A.15. The benefits from tourism, fish and WTP are found in table A.16.

5.10 Mardalsfossen case 2 NVE minimum flow

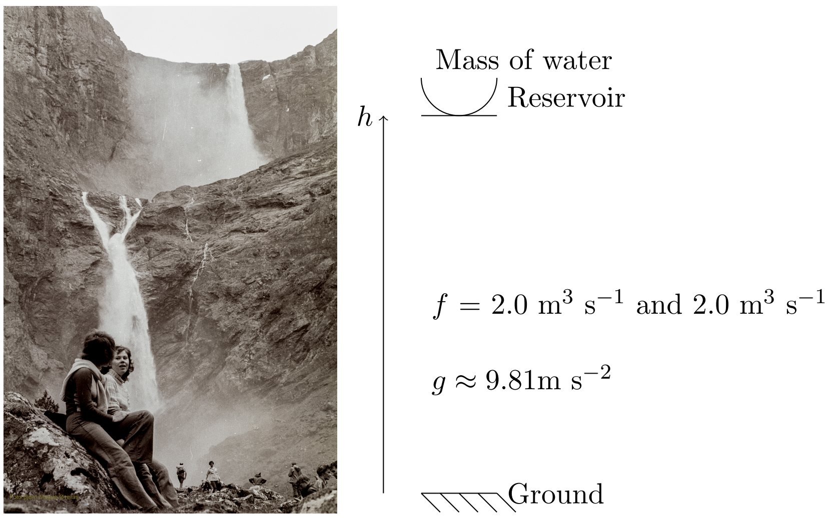
The loss of revenues follows section 5.1.1, since the Mardalsfossen model has no pump as one can see in figure 5.3. In that figure (b) a minimum flow requirement of 2.5 m^3/s was established for the period 20.06 -30.07 and a minimum flow of 2.0 m^3/s for the period 01.08–20.08 according to the water regulation the 28th of September 1990 [Det Kongelige Olje- og Energidepartement, 1990]. In Grytten power plant the water from the waterfall goes directly to the main basin, Grøttavatn. From there the water slides down to the turbines. Height h would in fact not be measured from the top o the waterfall but from the main basin, which is 980 meters over see level [vann-nett, 2015a].

Since different case-scenarios are evaluated regarding Mardalsfossen it is adequate to compare their results with the present state of Mardalsfossen. Therefore the analysis starts by performing the EBCA of Mardalsfossen with minimum flow from the 20th of June until the 20th of August. As explained in detail in section , the present regime allows in practice to release less water in August than the minimum flow rate. Yet in this case it is assumed that the levels of 2.5 m^3/s and $2m^3$/s are actually reached.

The loss of revenues amount to 8 701 933 NOK. Since there are currently no ships docking in Eresfjord, the port of access to Mardalsfossen, the environmental benefits from cruise tourists amounts to 0. However, there is data about other tourism, which the environmental benefits amounts to 6 266 667 NOK and the WTP for non-use values amounts to 10 311 475 NOK. The WTP for non-use values is benefit that gives the highest value, followed by other tourism. The environmental benefits from fish are also modest in Mardalsfossen, amounting to 81 313 NOK.

The ratio benefits-cost is 52%. When taking the high estimate for peak-load prices the NPV decreases from the total NPV of 138 753 655 NOK to 112 798 191 NOK, which represents a decrease of 18.7%. The peak-load price that gives approximately a NPV of 0 amounts to 532.9 NOK. The NPV decreases to 57 480 828 NOK using low estimates for benefits combined with the high price estimate.

The tables of loss of revenues and environmental benefits are found in tables 5.5 and Y respectively.



(A) (B)

FIGURE 5.3: (a) Photo of Mardalsfossen by Bjørn Magne Øverås (1972). (b) Model

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5.11 Mardalsfossen case 2.1: Dry season

It is relevant to find out how much money the hydropower plant saves if the waterfall is mostly dry in August. It is assumed there is not enough water from Fossafjellvatn and Bruå and they do not have to release water from the other basin, Sandgrovvatn, the waterfall is going to be dry and release on average 0.5 m^3/s in August. The loss of revenues descends to 6 869 947 NOK which represents a 4.5% loss of yearly energy

Table 5.5: Case 2 baseline data for calculating loss of revenue

Parameter	Value
η [%]	0.95
g [m/s^2]	9.81
h_1 [m]	980
ρ [kg/m^3]	1000
f_a	2.5 m^3/s
f_b	2 m^3/s
t_a [hrs]	984
t_b [hrs]	480
P^h [NOK/MWh]	278.59
LE [MWh]	31235.24
LE of yearly production [%]	0.0571
LR [NOK]	8701933.46
Yearly Total LR [NOK]	**8701933.46**

Table 5.6: Case 2, environmental benefits of tourism.

Tourism	
Cruise tourism	
Package holiday cruise [NOK/day]	2625
Visiting waterfall [hrs/day]	0.5
Number of cruises 2015	0
Number passengers [per cruise]	600
Total cruise tourism [NOK]	**0.00**
Other tourism	
Total toll [NOK]	80000
Toll price [NOK]	30
Passengers/car	4
Total visitors	10666.67
Expenses per pers. [NOK/day]	1175
Time per visit [day per pers.]	0.50
Total other tourism [NOK]	**6266666.67**
Total tourism	**6266666.67**

Table 5.7: Case 2, environmental benefits of fish.

Fish	
Report [NOK]	21932987.06
LE of yearly production [%]	0.0571
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	125177.15
NPV of benefit for period 11	**81312.69**

production 1.2% less than when the waterfall is not dry and reaches the minimum flow. The environmental benefits on fish decreases to 64.194 but its impact is not very

TABLE 5.8: Case 2, environmental benefits of willingness to pay.

WTP	
WTP/household/year[NOK]	33.24
Total households	310257
Total WTP [NOK]	**10311475.29**

meaningful on the NPV. The WTP amounts to 10 311 475, although in reality can decrease. The estimate of WTP per household represents the quantity of money that the households would at least pay for the minimum flow (minimum) as it is today, covering the possibility of being dry in August. The NPV increases to 170 515 525 NOK due to the decrease on costs. The tables with the loss of revenues and environmental benefits are presented in tables B.1 and B.2 respectively.

5.12 Mardalsfossen case 2.2: NVE minium flow cruise tourism succeeds

So far it has not been any cruise ships docking in Eresfjord but a pilot program of three ships has been launched for the next year to visit Mardalsfossen and if successful the number will increase. If the the minimum flow is reached in August and the development of cruise tourism succeeds, the NPV increases to 345.119739 despite the increase of costs compared to the previous case. This is because the environmental benefits from cruise tourism are even greater than other tourism, amounting to 11 812 500 NOK. The rest of benefits and costs would equal those of case 2. It is much beneficial that Grytten bears the costs of reaching the minimum flow in winter, which can entail a maximum increase in loss of revenues of 1 831 986 NOK, than to loose the potential benefits of cruise tourism. The reader is referred to tables B.3 and B.4 for more detail.

5.13 Mardalsfossen case 2.3: If dry and cruise tourism succeeds

Supposing that the minimum flow is reached it is important to notice the difference in cost from the previous case and the increase in cruise tourism. Since it is assumed than the scenic beauty of the waterfall varies significantly at low rates it is likely than development of cruise tourism is jeopardized if the waterfall is dry. If so the results equals the ones of case 2.1. If it was dry but it the project succeed anyway the NPV increases to 376 881 610 NOK. The NPV is slightly higher than in the previous case since the costs are kept low at 6 869 947 NOK. The benefits and costs equals case 2.1

but with the exception of the development of cruise tourism, which results equals the previous case 2.2.

5.14 Mardalsfossen case 2.4: If dry and cruise tourism fails in August

If the the development of cruise tourism did not fail entirely but partially, and the ships don't come in August during the minimum flow period, the NPV decreases to 335 608 393 NOK. The decrease is due to a decrease of environmental benefits from cruise tourism. While in the previous case cruise tourism amounts to 11 812 500 now it descends to 9 450 000 NOK. The rest of cost and environmental benefits equal the previous case. The number of cruises descends from 15 -which it is the base case- to 12. This is because as explained in section 4 the distribution of cruises in Åndalsnes. The 20% of the cruises that arrive to port during the minimum flow period do it during the 1st of August until the 20th. Therefore, the number of cruises that are estimate to arrive in at Eresfjorden during the minimum flow period established by NVE is 20% less than the total number of cruises during the minimum flow period -15-, that is 12. The reader is referred to B.7 and B.8 for a more detailed presentation of the results.

Since the NPV is higher when the cruise tourism is included and the benefits of tourism increase more than costs, it is interesting to see if the cruise companies would be willing to pay to Grytten plant the difference in costs that the plant would save if the waterfall was dry in August. This compensation would be in exchange of that the MF was reached. Although the probabilities are unknown it is still interesting to simulate with an example whether the tourist vessels would be willing to pay the difference of 1 831 986 NOK given that there is not always dry. The amount is the difference of LR between case 2.3 and 2.2. Applying the Bayes' Decision Rule the cruise company should choose the alternative that gives the highest expected payoff [4]. The expected payoff is a product of multiplying each payoff by the prior probability of the corresponding state of nature and then summing these products. If dry in August and the cruise tourism does not succeed the cruise company will earn 0 NOK. It is assumed in the simulation that there is a high chance that if dry in August the whole cruise operation fails, and the probability given is a 60%. If dry in August and the cruise tourism fails partially the cruises will still come during the period of MF except in the August period and the probability given is moderate, 30%. The payoff equals the benefits from cruise tourism in case 2.4, which amounts to 9 450 000 NOK . If it is dry in August and the cruise tourism still succeeds the probability is low, 10%, and the payoff amounts to 11 812 500 NOK -as in case 2.2.

[4]assuming the tourist cruise company is risk neutral

If it is not dry the probabilities that the cruise trip succeeds are high , 90%, and the cruise revenues amount to 11 812 500 NOK -as in case 2.2. If not dry the probability that the cruise tourism fails and the revenues are 0 is low, 10%.

The expected payoff for the cruise company if it turns out that the waterfall is dry is $0 \cdot 0.6 + 9450000 \cdot 0.3 + 0.1 \cdot 11812500 = 4,016,250$. If the waterfall is not dry the expected payoff is 11 812 500 $\cdot 0.9 + 0.1 \cdot 0 =$ 10631250 NOK. If the waterfall was always dry the cruise company would be willing to pay up to 6 615 000 NOK, which is much greater that the costs that Grytten would bear as a maximum to reach the MF. Nevertheless, the first basin connected to Mardalsfossen is not always dry. In that case the probability of being dry should be more than 27.7% so that the cruise company would be willing to cover the 1 832 355 NOK.

5.15 Mardalsfossen case 2.5: Low cost high flow adjustment

The current minimum flow regime in Mongefossen that enables the hydroelectric plant not to reach the minimum flow in August can jeopardize the development of cruise tourism. The maximum costs that the electric company can save are very small -1,831,986 NOK- compared to the potential losses from cruise tourism -11,812,500 NOK-.

Since the EBCA performed in Mongefossen showed us the benefits of daily adjustment, it is evaluated the possibility of adjustment during the period of minimum flow defined by NVE in order to keep the low costs that the dry waterfall in August yields and the high flow -that equals 3 m^3/s or more at day-time and 0.5 at night- which increases the number of tourists. The costs equals case 2.1, amounting to 6 869 947 NOK. The environmental benefits of cruise tourism are 18 375 000 NOK, other tourism 10 444 444 NOK , fish 64 194 NOK and WTP 10 311 475 NOK. The NPV amounts to 564 515 817 NOK. The high flow can even exceed the 3 m^3/s at day-time (3.19m^3/s for f_a and 0.5 for f_b). The hours t_a and t_b amounts to 732 each of them, since the 61 days corresponding to the 2 months of the NVE minimum flow period is multiplied by 12 hours.

The ratio cost-benefits is 23.8%, which is low compared to case 2. If the high estimate for peak-load prices is used the NPV decreases to 544 024 661 NOK, which represents a decrease on NPV of 3.63%. The price that yields an approximate 0 NPV amounts to 1589 NOK. When performing the EBCA on the worst case scenario with low estimates for benefits and high price estimate, the NPV amounts to 167 826 424 NOK.

For a detailed results the reader is referred to B.9 for costs and B.10 for environmental benefits.

5.16 Mardalsfossen case 2.6: Summer period adjustment

Besides the increase in the NPV as a consequence of the daily adjustment of the flow the cases of Mongefossen also showd the increase in the NPV as a consequence of extending the period of minimum flow set by NVE to also cover the whole months of June and August and then capture the high touristic season.

The NPV is the highest both in for Mongefossen and Mardalsfossen, amounting to 707 330 543 NOK. The loss of revenues increases to 10 248 610 NOK, but the increase in environmental benefits from tourism -both cruise and other- is even higher, amounting to 25 725 000 NOK and 14 622 222 NOK respectively. The fish benefits increase to 95 765 NOK but the share of benefits is low compare to the rest of categories. The WTP amounts to 10 311 475 NOK.

The ratio cost-benefits is 20%, which is lower than the ratio in case 2. If the high estimate for peak-load prices is used the NPV decreases to 676 761 769 NOK, which represents a decrease on NPV of 4.33%. The price that yields an approximate 0 NPV amounts to 1379.2 NOK. When performing the EBCA on the worst case scenario with low estimates for benefits and high price estimate, the NPV amounts to 175 874 198 NOK. The amount is also the highest of all the cases.

The results are gathered in detail in tables B.11 and B.12.

Chapter 6

Summary of results and discussion

This section will consider the results of the previous analysis, the validity of their underlying assumptions and the conclusions that may be drawn from them, in order to answer the two research questions posed in section 1.0.2. This will be done by discussing each of the outlined hypotheses of this thesis to Mongefossen and Mardalsfossen. Given the similarity between the models used for Mongefossen and Mardalsfossen, we will avoid repeating the same analysis for both waterfalls unnecessarily. The proposed solutions for the waterfalls given here will again be summarized in the conclusion of the next section.

A summary of the results from the previous section is found in Tables 6.1 and 6.2, and are also visualized by the graphs in Figures 6.1 for Mongefossen and 6.2 for Mardalsfossen. The NVE proposed minimum flow (MF) operational regime for Mardalsfossen and Mongefossen (Case 1 and 2 in the previous section) will serve as the base cases for which the other cases are compared. Therefore, the term 'NVE period' is here taken to imply the period used in Case 1 and 2 (20th of June until the 20th of August), and the term 'NVE minimum' flow is taken to imply the water flow used in these cases (2.5 m^3/s between 20th of June until the 30th July, and 2 m^3/s between the 1st - 20th of August). The term 'regulated' will often here refer specifically to the practice of adjusting water flow in the waterfalls during daytime/nighttime, as discussed in Cases 1.1, 1.3, 1.8, 2.5 and 2.6, and not primarily in the common sense of 'regulated watercourses'.

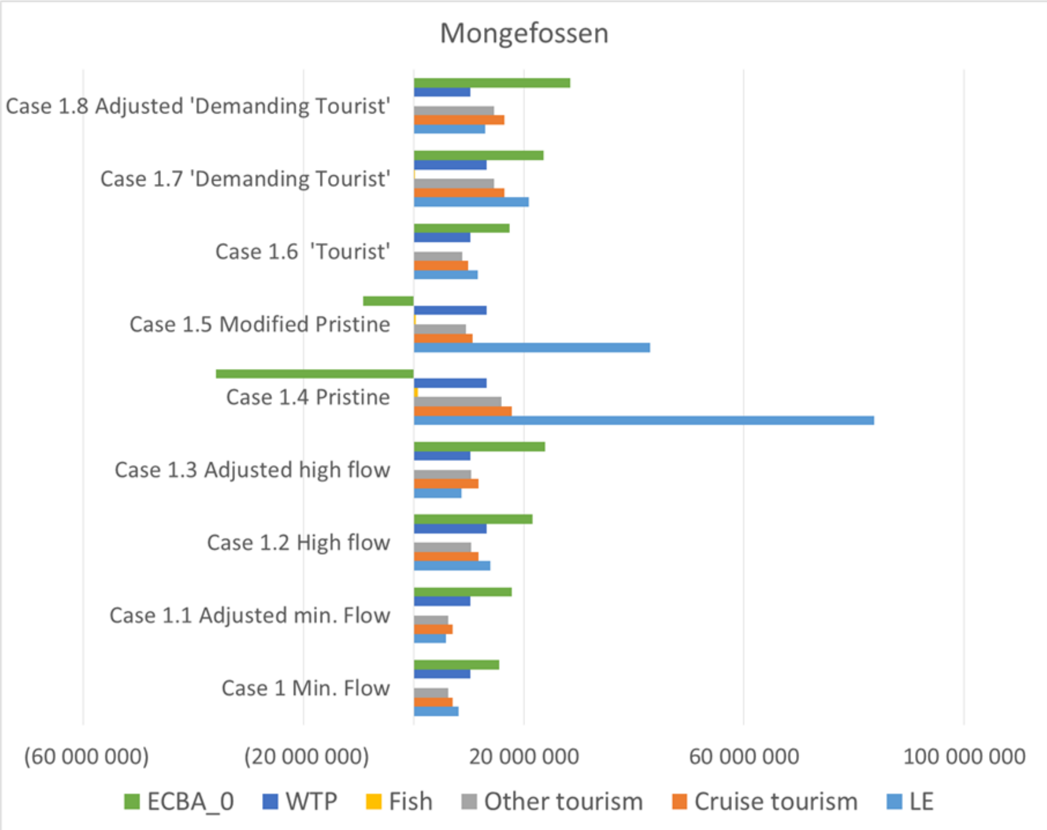


Figure 6.1: Visualizing the results of the EBCA for Mongefossen (numberical values found in Table 6.1)

6.1 Mongefossen: Research question 1

> RQ1: *–Is it profitable from the perspective of a EBCA to employ NVE's proposed minimum flow regulation for Mongefossen from mid-June until mid-August?*

As discussed in section 4, there is today no water flow out of Mongefossen waterfall except when the dam capacity in Mongevatn is exceeded. If, as discussed in Case 1 in section 5.1, NVE's proposal of allowing a minimum flow from mid-June until mid-August were to be adopted today, this would amount to a positive NPV of 270 902 150 NOK, versus a cost of 8 164 416 NOK. Furthermore, the NPV remains positive even when considering extreme scenarios in the sensitivity analysis of section 5.1.8). For Case 1 the loss of water flow amounts to a low share in the yearly production, of 5.32%. The corresponding low share of total revenue occurs even without daytime/nighttime adjustment of the water flow, owing to the relatively limited proposed flow period. The environmental benefits of WTP for non-use values alone are large enough to cover the loss of revenues of the electric company. Therefore, even without any tourism at all, the measure should be carried out since it would be welfare enhancing with a positive NPV.

However, tourism as a whole is even greater than the WTP, and even greater than the costs. The ratio of costs to benefits is 34.4%. This ratio is lower than in the case of high flow in the same period (Case 1.2), the period covering summer with the same amount of minimum flow and high flow (Case 1.6 and 1.7), and the period covering the whole year (Case 1.4 and 1.5). However, significant reductions in the cost/benefit ratio are encountered in the cases that consider daytime/nighttime regulation. Correspondingly, NVE's proposed MF regime for Mongefossen does not yield the highest NPV among the cases considered. In the following sections, the second research question RQ2: – *Which form of flow regulation yields the highest social surplus for Mongefossen and Mardalsfossen?*, will therefore be considered by examining the research hypotheses one after the other.

TABLE 6.1: Overview of costs and benefits for Mongefossen. These numbers are visualized in Fig. 6.1.

Case	Description	LR	Cruise tour.	Other tour.
1	Min. flow	8 164 416	7 031 250	6 266 667
1.1	Adj. min. flow	5 829 679	7 031 250	6 266 667
1.2	High flow	13 979 772	11 718 750	10 444 444
1.3	Adj. high flow	8 737 357	11 718 750	10 444 444
1.4	Pristine	83 649 454	17 812 500	15 875 556
1.5	Mod. pristine	42 999 257	10 687 500	9 525 333
1.6	'Tourist'	11 602 065	9 843 750	8 773 333
1.7	'Dem. tourist'	20 855 069	16 406 250	14 622 222
1.8	Adj. 'dem tourist'	13 034 418	16 406 250	14 622 222

Case	Fish	WTP	ECBA_0	ECBA	Cost/Benefit
1	75 754	10 311 475	15 520 730	270 902 150	0.34
1.1	54 091	10 311 475	17 833 803	311 382 583	0.25
1.2	129 711	13 216 770	21 529 904	375 707 176	0.39
1.3	81 070	10 311 475	23 818 382	415 845 981	0.27
1.4	776 142	13 216 770	-35 968 487	-630 907 880	1.75
1.5	398 969	13 216 770	-9 170 685	-161 515 371	1.27
1.6	107 650	10 311 475	17 434 144	304 225 662	0.40
1.7	193 504	13 216 770	23 583 676	411 378 672	0.47
1.8	120 940	10 311 475	28 426 469	496 219 799	0.31

6.1.1 The effect of using daily flow regulation: hypothesis 1

H1: – *Daytime/nighttime adjustment of the water flow decreases the cost incurred by Grytten power plant and is beneficial from a EBCA perspective.*

In Case 1.1 the daytime flow is kept equal, whereas the nighttime flow is reduced. Hence daytime/nighttime adjustment of the water flow allows to decrease costs from 8 164 416 NOK in Case 1, to 5 829 679 NOK. Correspondingly the NPV is increased from 270

902 150 NOK to 311 382 583 NOK. These numbers assume that the WTP remains unaltered. The fact that the nightly adjustment in this case leads to less water flow on average than in Case 1 may call this assumption into question. On the other hand, the value of WTP/household/year used in the calculation of WTP represents a lower bound estimate of the actual quantity of money that households would be willing to pay for the minimum flow regulation of today. Since this estimate takes into account the possibility of drought in August (as discussed in further detail in section 4.6), it could therefore also be the case that the WTP/household/year may be higher than the estimate used here. Further inquiry should be focused at studying the behavior of WTP/household/year when compared with the amount of water flow, as well as with seasonality. In the current analysis it has seemed plausible to keep WTP unaltered. The behavior of WTP is nevertheless not decision-making relevant at present, since several of the other case-scenarios considered give a higher NPV, of which the main contributor is tourism related revenue. Furthermore, tourism will not likely be affected by the nighttime regulation, since there will hardly be any tourists present then. So to summarize, when the benefits are mainly driven by tourism the measure of reducing the overall flow by nighttime adjustment should be considered reasonable, whereas there may exist some uncertainty if the benefits are mainly dependent on the WTP/household/year values used here.

Rather than merely reduce the nighttime flow, a much more effective measure is to simultaneously increase the daytime flow above the minimum water flow. As may be noted from Case 1.3 this has two positive effects with respect to Case 1.

- Firstly, the greater water flow in the daytime lends itself to a greater tourist experience, since the perceived magnificence of the waterfall is likely directly related with the amount of water flow (at least when the flow is modest initially).
- Secondly, given that the daytime increase and the nighttime reduction in flow partially cancel each other out, the increase in cost to Grytten power plant should be comparatively small.

It is found that the NPV increases from 270 902 150NOK in Case 1 to 415 845 981 NOK in Case 1.3. While the costs to Grytten merely increase by 572 942 NOK, tourism experiences a comparatively much larger increase of 8 865 278 NOK. The ratio of cost to benefits is also reduced from 34.4% to 26.8%, while the WTP is left unchanged. Here it seems reasonable to assume that any negative effect on WTP from the nighttime reduction is compensated by a positive effect on WTP for the increase in daytime flow.

The benefits of recreational fishing increases only slightly since the increase of yearly energy loss is low – from 5.32% to 5.69%. This means that less water is discharged from the turbine into river Rauma, thereby causing less problems for the fish population. One may wonder if fish conditions really do improve given that more variation on the flow rates can be thought detrimental to the fish population. However, as discussed in [NVE, 2012], the potential problems to aquatic life occur locally where the water is discharged, and neither of the waterfalls discharge directly into the national salmon river Raumavassdraget. Unlike run-of-the-river hydroelectric plants that must continually produce, Grytten is a power plant with a good storage capacity thereby allowing the plant to selectively produce at daytime for peak-load prices. Therefore, varying the flow rates between day and night will not automatically lead to fluctuating production. However, with an increase in the total amount of water allowed to flow through the waterfalls, the annual production will decrease, meaning that less water is discharged into Rauma directly in total.

Before moving on, some comments should be made regarding the choice of the particular nighttime flow rates used in the analysis (1 m^3/s and 0.5 m^3/s in Mongefossen and Mardalsfossen respectively). On the one extreme, one could have considered having zero water flow during the nighttime in order to minimize costs to Grytten power plant. This option is however perceived to potentially carry negative consequences especially towards tourism and WTP. A waterfall that is shut on and off stands in danger of loosing its appearance of untouched nature, and the value of the waterfalls as tourist experiences may decrease as a result. Also, completely shutting off the waterfalls at night may reduce the WTP since this practice may cast doubts on whether such a regulation any longer can be considered to be an 'environmental' measure. On the other extreme one could have the same nighttime flow as the daytime flow, the possibility of which is already considered in other cases where they have been shown to generally give smaller NPVs. Therefore, it seems plausible to operate with a flow rate somewhere between these extremes. It also seems plausible to differentiate the nighttime flow values between the rivers. On the one hand their different daytime flow rates imply having also different nighttime flow rates, if the latter are supposed to minimize the incurred costs on the Grytten power plant. Furthermore, Mongefossen is to some extent more accessible to the general public during night time: It can be seen both from the road E136 and the railway. Future inquiry should aim at identifying the optimum daytime and nighttime flow rates in a more rigorous manner.

6.1.2 High flow: hypothesis 2

> H2: – *Upon increasing waterflow, the benefit from tourism will outweigh the costs incurred by Grytten power plant.*

To test the hypothesis H2, continuous high water flows of $\geq$ 4 m^3/s in Mongefossen and $\geq$ 3 m^3/s in Mardalsfossen are assumed in Case 1.2 from the 20th of June until the 30th of July, in order to justify using high estimates for the tourism benefits. The purpose in doing so is not to imply that the high values of tourism that are assumed are necessarily to be expected in reality, but rather to get an idea of what the picture would look like from a EBCA standpoint in the event of a significant rise in tourism. As has been discussed in section 1.0.3, the anticipation of the amount and value of tourism in relation to the water flow in the waterfalls requires data unavailable to the author, and except for some simple first approaches made in the analysis, lies outside the scope of this thesis. The following reasoning underlies the use of the high tourism estimates in Case 2.1: It is assumed that the increase in utility caused by a marginal increase of flow is at least equal (or higher) than the increase of flow at low flow rates, before stabilizing once higher flow is reached (as explained before in section 4). The values used in the present master thesis are chosen on the basis of the current tourism numbers under the conditions of minimum flow in Mardalsfossen: Since there are thousands of tourists visiting Mardalsfossen at minimum flow from 2 to 2.5 m^3/s it is assumed that the minimum flow rate already captures a significant amount of tourist flow value.

With the above mentioned flow rates, costs are increased by approximately 70%, from 8 164 416 NOK in Case 1 to 13 979 772 NOK in Case 2. The increase in total tourism is 8 865 278 NOK (67%), thereby outweighing the costs. Since, as discussed in 4.6, it seems plausible to include a larger geographical area in the calculation of WTP for especially high water flow, the WTP is also assumed to increase in Case 1.2. This increase amounts to 2 905 294 NOK which represents a more moderate increase of 28.18%. Even if one should question this assumption, the NPV would still experience an increase if the WTP was left equal to that of Case 1. The NPV with a high WTP increases from 270 902 150 NOK to 375 707 176 NOK although the cost to benefits ratio increases correspondingly from 34,4 % in case 1 to 39.3 % in case 1.2. Similarly, the NPV increases in Case 1.7 where high flow is considered for a longer time period together with an increase in the cost benefits ratio: The NPV increases from 304 225 662 NOK to 411 378 672 NOK and the share of costs increases from approximately from 40% to 47%.

The high flow regime yields a higher NPV than with minimum flow, however it is not greater than that which employs a daytime/nighttime adjustment of the water flow (Case 1.3). A daytime/nighttime adjustment should therefore be considered unless this is deemed undesirable due to e.g. welfare considerations or fish population considerations (although the latter of these seems unlikely, as mentioned in relation to hypotheses H1 above).

6.1.3 Increasing the MF period to the whole high tourist season: hypothesis 3

H3: – *Extending the period of minimum flow, in order to cover the high tourist season, outweighs the costs incurred by Grytten power plant.*

Extending the minimum flow period set by NVE –from mid-June until Mid-August– to cover the whole of June and August as well, increases the benefits of tourism for minimum flow, high flow and daytime/nighttime adjustment (Cases 1.6-1.8). The influx of tourists is still high in June and August, thereby the benefit of tourism in Cases 1.6, 1.7 and 1.8, increases by 40% compared to Case 1, 1.2, and 1.3, respectively. If one compares the costs of Case 1 with those in Case 1.6 where there is NVE minimum flow for the whole summer period[1] the NPV increases by 33 323 512 NOK, although the cost to benefits ratio increases from 34.4% to 40%. Likewise, the NPV of the high flow in the NVE period evaluated in Case 1.2 and the NVE period high flow regulated in case 1.3, increase 35 671 497 and 80 373 818 NOK respectively. Further research should be focused on estimating if periods covering also September and May yield a higher NPV. Choosing to evaluate extending the period to three months instead of two was especially appealing because of its significant increase on tourists compared to a moderate decrease on costs.

In the analysis, the distribution of cruise arrivals planned for Åndalsnes through the year 2015 was used under the assumption that one may expect a similar distribution in the years to come. The number of tourists increase in summer compared with other months because of weather conditions and the tourist availability to travel, and therefore the distribution of cruise ships is expected to be independent of the flow rate. In order to calculate the tourism value designated as 'other tourism', data were taken from the toll booth leading up to Mardalsfossen in order to know the number of vehiches that pass during the minimum flow period, and then these numbers were weighted according to the distribution of cruise ships visiting Åndalsnes when extending the period of water flow. I.e., for the whole summer in Case 1.6 an increase of 40% has been assumed by considering the number of cruise ships outside the minimum flow period. A similar approach has been applied in Cases 1.7 and 1.8 in order to calculate the cruise tourism influx variation throughout the year: The number of cruise visitors in the NVE minimum flow period was weighted according to the number of cruise ships outside this period. The benefits of 'other tourism' for Mongefossen are assumed equal to Mardalsfossen, because it is assumed that the number of tourists that come by car to take a trip up to the waterfall will be comparable. This because both waterfalls are named among the highest and

[1]Understanding the whole summer period from the 1st of June until the 31st of August

most important in the country [SSB, 2013]. Yet, one could argue that Mardalsfossen has a higher potential for tourism due to its controversial history as explained in section 3.2. At the same time, however, the tourist development could be considered as incipient: A permanent exhibition of the history surrounding Mardalsfossen is projected in Eikesdalen, facilities such as a new path up to the waterfall was recently constructed (2012), an art statue was inaugurated last year (but is planned to be removed again eventually), a cruise project in Eresfjord is planned for the summer 2016, and the toll – used to estimate the quantity of cars – can be easily avoided. Since these factors suggest that the amount of 'other tourism' in Mardalsfossen can still grow, it seems reasonable that the values of 'other tourism' can at present be assumed equal for Mongefossen. It may be necessary to make an initial investment in Mongefossen to construct a path that enables to go up to the waterfall. Despite this, the conditions of the land around the waterfall could not be judged upon the authors visit to the waterfall since the waterfall can only be seen in times of flooding. Therefore, further study should be focused on this matter in future EBCA.

The parameters used to estimate the environmental benefits from 'cruise tourism' in Mongefossen are different from those used for in Mardalsfossen. Every year there are many cruises docking in the town of Åndalsness, which is nearby Mongefossen. The tourists usually take the train from Åndalsness to the first local stop in Bjorli. The railway is considered to be one of the most beautiful railways in terms of spectacular nature in the country [NSB, 2014], from which Mongefossen can be seen. The idea considered here is that the bus-ride back could take them to Mongefossen so that the tourists could take the walk up. The waterfall adds more value to Åndalsnes as a cruise destination, and it is therefore assumed that cruise ships could be docked in the port a while longer. The number of cruises are not assumed to increase – at least at the beginning – because the waterfall will likely be considered as one nature attraction among many others in the region. Another approach is to calculate the amount of money the attraction of Mongefossen would add to the train ticket, but since the waterfall will be one attraction among many it is difficult to isolate its effect.

6.1.4 Longer periods than high tourist season: Hypothesis 4

> H4: – *Extending the period of minimum flow to cover the whole year can be justified by the increase in benefits from recreational fishing and willingness to pay for non-use values.*

In Cases 1.4 and 1.5 the possibility of extending the period of water flow to a full year was evaluated, thereby aiming to capture the high estimated values on recreational fishing and WTP for the existence of waterfalls free from human intervention. However, more significant benefits on the value of fish would have been attained if the the river Rauma (national salmon river) had been directly connected with the waterfalls. This is however not the case.

When extending the period of water flow to a whole year, the proportion of loss of revenues increases dramatically as may be seen in figure 6.1. The losses increase by a factor of 10 in comparison to Case 1, while the benefits of tourism remain comparable to that of the high flow scenario in Cases 1.7 and 1.8. The costs are halved in Case 1.5 relative to Case 1.4, but the cost to benefits ratio is still high and the NPV becomes negative. The benefits in terms of WTP increases but not enough to outweigh the costs. The estimate used corresponds to the same base case estimate used in the rest of the cases, 33.2 NOK per household, and the increase on WTP from Case 1 to Cases 1.4 and 1.5 is due to including the numbers of households of one more counties, from 310 257 households to 397 673. The reasoning behind this is that when there is high flow, or when there is flow during the whole year, the waterfall may be of higher importance to people living in the area and therefore one may assume that more households can be included in the calculation. Nevertheless, there are no straightforward answers regarding how much more population should be included. The real question here is whether the WTP taken from the value transfer in Langfossen, used in the analysis for our estimate, was low compared to the actual WTP and how it would increase if the period of time in which the water is released was extended to the whole year. Given the complexity of the mater, a conservative approach has been chosen in order to calculate the increase of the WTP, where it has been assumed that the minimum flow captures a considerable amount of the maximum WTP. If the assumption does not hold then the results are inconclusive. However, if the WTP was to outweigh the costs, the WTP should increase significantly, around 270% and 70% in Case 1.4 and 1.5 respectively.

For the small reductions in energy production in the other case appraisals, it is appropriate to assume a linear relationship between the loss of production and the acquired benefits for fishing. However, when the measure entails a high decrease on yearly electricity production of 54% and 28%, as in case 1.4 and 1.5 respectively, the linear assumptions does not necessarily hold. However, even if these decreases in the yearly production corresponded to an increase of benefits on fish of 100%, the maximum benefits on fish would amount 2 193 298 NOK, which is significant in comparison to the costs incurred in either of the two cases. One can possibly argue that the data used to calculate the fish benefits, which stem from a recreational fish report from 1983, underestimate the benefits despite adjusting for the Norwegian consumer price index. On the other hand, the report reflects the values from when the recreational fish activities were at their highest. Shortly afterwards the salmon population dropped dramatically due to the parasite *Gyrodactylus salaris*, as explained in more detail in section 4.4. In addition to this, even if a higher value could be conceived, since the influence of the power plant – the key parameter in the analysis – is assumed low, this means that the nature of the analysis would not change substantially. There are several reasons why we may expect this:

- As earlier mentioned, the waterfalls are not directly connected to Rauma river.
- The power plant is situated quite close to the sea. When the young salmons are close to the sea they are less impacted by the temperature variation caused by the discharged water of the power plant.
- The production capacity of Grytten is modest when compared to the largest facilities in Norway. The 36 hydro power plants that constitute 40% of the national production all have a greater capacity than 200MW [Det kongelig olje- og energidepartement, 2013]. Grytten, on the other hand, has a capacity of around 143.5 MW [Statkraft Energi AS Eiendomsforvalning (PGPP), 2009]. Thereby the total water released after the electricity production is low in comparison to other power plants. Furthermore, the number of hours in which the plant is in operation are also low -estimated to be 43% of the year in the analysis.
- There is hardly any fish population in the river at the moment and its full recovery is expected to take about 10 years.
- At the moment the influence of the the parasite is comparatively higher than any influence the power plant has.
- Although hopefully small, there remains some degree of uncertainty of whether the fish population values from 1980 are going to be recovered after the rotenone treatment.

6.2 Mardalsfossen

Case 2 demonstrates how the measure of MF applied by NVE in 1990 is welfare enhancing, amounting to a NPV of 138 753 655 NOK. Nevertheless, the NPV is the lowest of all the cases evaluated for Mardalsfossen, the main reason being the absence of cruise tourism. The fact that the NPV of Case 2 is also smaller than in Case 1, is because so far there has not been any cruise arriving at Eresfjord, in vicinity of Mardalsfossen. The results of the analysis for Mardalsfossen are listed in Table 6.2.

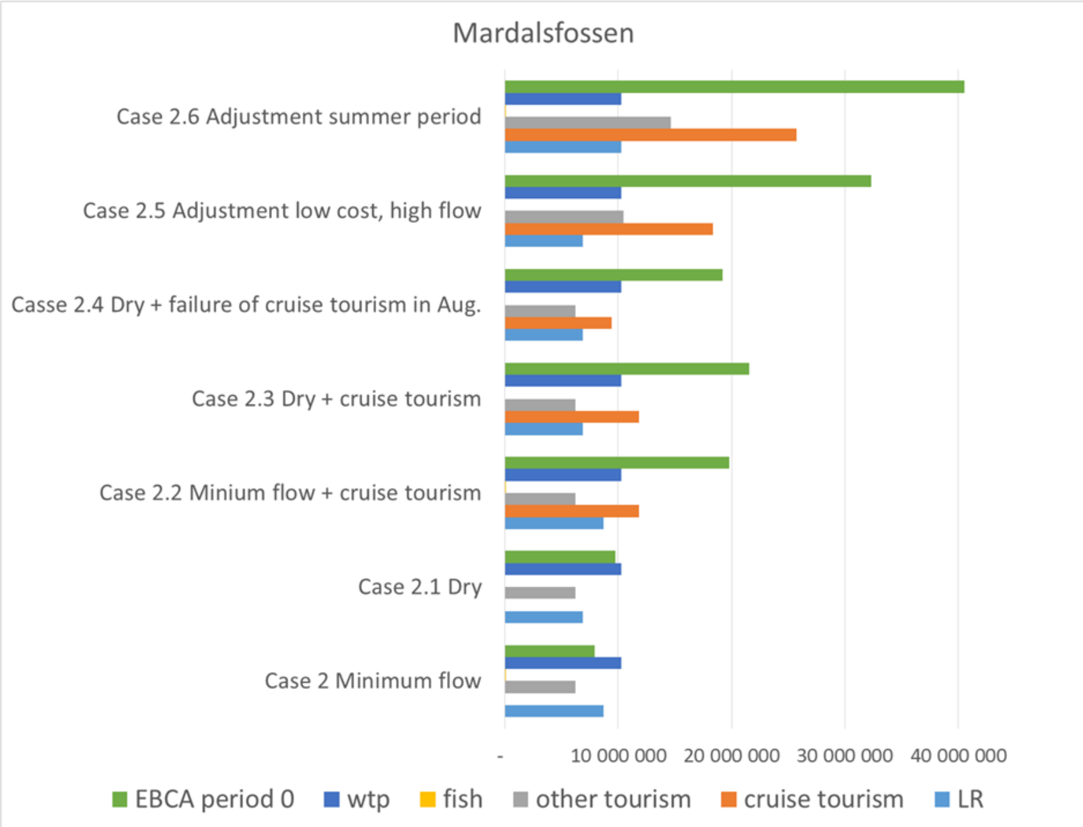


Figure 6.2: Visualizing the results of the EBCA for Mardalsfossen (numberical values found in Table 6.2)

It should be noted that the costs of releasing water via Mardalsfossen are comparatively higher than that of releasing the same amount via Mongefossen. The reason for this is that the water flowing into Mardalsfossen is located at a higher altitude than the main basin, Grøttevatn, where the water is stored until used for energy production (from there it runs through the main channel down to the turbines for electricity production, when needed – as explained in section 5.10). The basin of Mongefossen, however, is situated at a lower altitude than the main basin Grøttevatn, and must be pumped up for use in electricity production. Yet, the energy consumed by the pump when pumping water up to Grøttavatn is not large in comparison to the energy that the water produces, amounting to 6.84%. In practice the amount is equivalent to a lesser amount, 6.18%, since the water is pumped at night at off-peak prices. The loss of energy from the pumping may however be a little underestimated due to a presumed lower efficiency for up-pumping compared with the production of energy in the turbines, but the needed correction is likely to be insignificant.

Although the NPV of Mardalsfossen in Case 2, is lower than in the parallel situation of Case 1, the NPV changes substantially when we include 'cruise tourism', as seen in Case 2.2. The 'cruise tourism' in Mardalsfossen then amounts to 11 812 500 NOK, which

Table 6.2: Overview of costs and benefits for Mardalsfossen. These numbers are visualized in Fig. 6.2.

Case	Description	LR	Cruise tour.	Other tour.
2	Min. flow	8 701 933	0	6 266 667
2.1	Dry	6 869 947	0	6 266 667
2.2	Min. flow + cruise	8 701 933	11 812 500	6 266 667
2.3	Dry + cruise	6 869 947	11 812 500	6 266 667
2.4	Dry + failure cruise Aug.	6 869 947	9 450 000	6 266 667
2.5	Adj. low cost high flow	6 869 947	18 375 000	10 444 444
2.6	Adj. summer period	10 248 610	25 725 000	14 622 222

Case	Fish	WTP	$EBCA_0$	EBCA
2	81 313	10 311 475	7 957 521	138 753 655
2.1	64 194	10 311 475	9 772 389	170 515 525
2.2	81 313	10 311 475	19 770 021	345 119 739
2.3	64 194	10 311 475	21 584 889	376 881 610
2.4	64 194	10 311 475	19 222 389	335 608 393
2.5	64 194	10 311 475	32 325 166	564 515 817
2.6	95 765	10 311 475	40 505 853	707 330 543

is 4 781 250 NOK greater than that of 'cruise tourism' under the same MF regime in Mongefossen Case 1, representing a increase of 68%. The reason for this is that the 'cruise tourism' benefits are of different amount in both waterfalls. There is a pilot project of three cruises coming to Eresfjorden next summer, for which Mardalsfossen is the main attraction. In the case of Mongefossen, this is only one of many natural attractions in the area, and therefore the benefits are lower than in Mardalsfossen. If the experience of the tourists is Mardalsfossen is satisfactory, the number of cruises will increase. The Cases 2.2 to 2.6 presupposes that cruise tourism either succeeds or partially succeeds. The NPV of Case 2.2 is 206 366 084 NOK higher than in Case 2, corresponding to an increase of approximately 150%.

The size of the ships in Mardalsfossen is estimated to be smaller than in Mongefossen, but the benefits are, however, much greater. The reason for this is, on the one hand, that the time used by tourists visiting the waterfall is assumed to be longer. On the other hand, the daily consumption price used as a basis for the calculation of cruise benefits is also higher in Mardalsfossen, because the part of the consumption belonging to the cruise package is also included in the overall daily calculation (apart from daytime expenses, for instance food). The reason for this is that the cruise to Mardalsfossen is dependent on the success of the waterfall visit, and therefore the price designated to accommodation can also be included. It is estimated that if the project is successful, the number of cruise ships will increase to 15. Although it is unknown how much the number of ships will actually increase, the estimate is considered to be cautious in comparison with the cruise tourist visiting Åndalsnes. 15 small ships of 600 people each in Mardalsfossen equals 4.5 big ships of 2000 people each, which is the average size of the cruise vessels visiting Åndalsnes (Mongefossen). The number of ships planned to arrive to Åndalsnes harbor are 25 and therefore the number of tourists in Mardalsfossen represent only 28% of the tourists vessels visiting Mongefossen.

6.2.1 The problem of the present regime: Hypothesis 5

H5: – *The present regulation is detrimental to a potential increase in NPV.*

The MF regime adopted in Mardalsfossen permits Grytten to have smaller water flows than the MF in August (from the 1st to the 20th of August), if the smallest of the two basins connected to Mardalsfossen is dry (Fossafjellvatn). The water could, however, be taken from the other basin (Sandgrovvatn). It is assumed that a marginal increase of flow (at low flow rates[2]) leads to at least an equal increase on tourist utility and that this is reflected in an equal increase in tourist benefits. If the waterfall does not reach the minimum flow in August it will presumably be disappointing for tourists and can jeopardize the whole cruise project. It is estimated that Grytten can save up to 1 831 986 NOK if the waterfall is left dry in August – by dry, a water flow of 0.5 m^3/s is assumed. The results are reflected in the difference of LR between Case 2 and 2.1. The potential looses from 'cruise tourism' amounts to 11 812 500 NOK if the the whole project does not succeed (Case 2.1 compared to Case 2.2), and 9 450 000 NOK in Case 2.4 if only the cruises in August were canceled.

The increased NPV of Case 2.2 with respect to Case 2 indicates that there is room for pareto improvement, meaning that those who gain from the project could compensate those who loose and still be better off. The average price paid by the tourist per day to the cruise company amounts to 1500 NOK out of the 2625 NOK of total daily consumption. Since the cruise benefits from tourism are calculated from a total of daily consumption per person of 2625 NOK divided by 2 (spending half of a day to see the waterfall), it is assumed than the benefits from the utility of the tourists will be reflected on the earnings of the tourist company. Since the tourism cruise from Eresfjord will earn more from Mardalsfossen in comparison to the cruise companies travelling to Åndalsnes, and since the project is dependent on the success of Mardalsfossen as a tourist attraction, it is even more likely in the case of Mardalsfossen that tourist companies would be willing to pay to Grytten for the extra costs of upholding the minimum flow rate in August. The costs of reaching the minimum flow in August would amount to a maximum of 1 831 986 NOK, as compared to having a dry in August. According to the results of the analysis

[2]By low flow rates the the author means from rates ranging from 0 up to the designated 'high flow rates' of Mongefossen and Mardalsfossen respectively

for Case 2.4, the cruise company would be willing to pay to Grytten if the probability of having a dry August is approximately more than 30%, given the assumptions presented. The probability of the cruise project failing if the waterfall is dry is assumed to be high in the analysis, because it will likely be the same company arranging the trips every year and and this company is expected to learn from experience (i.e. if the the cruise tourists were often dissatisfied due to having a low flow via the waterfall in August). The difference in utility of seeing low flow due to drought and seeing a minimum flow are significant, assuming high variability of utility at marginal increases of flow at low flow rates.

6.2.2 Proposed solution for both Mongefossen and Mardalsfossen: Research question 2

> RQ2: – *Which form of flow regulation yields the highest social surplus for Mongefossen and Mardalsfossen?*

For Mongefossen, Case 1.8 represents the environmental measure with the highest NPV, corresponding to 496 219 799 NOK. The daytime/nighttime adjustment 'demanding tourist' option achieves this through a comparatively low share of costs with respect to environmental benefits –approximately 31%– combined with the highest absolute values of environmental benefits, 41 460 887 NOK, largely owing to those represented by tourism which amounts to around 75% of this. This high amount of tourism related revenue is again explained by the high flow, and the fact that the flow period covers the whole high tourist season. The relatively small costs may be explained by the daily adjustment of the water flow. The NPV represents an increase of 82% compared to Case 1 and the costs increase by 60%.

Case 2.6 applies daytime/nighttime adjustment for the EBCA is performed in Mardalsfossen in order to increase the flow at daytime and capture a higher number of tourists that with the minimum flow rate. The period is also extended to the high tourist season. The environmental benefits from tourism amount to approximately 40 million NOK and the share of costs compared to benefits is lower than in Case 1.8 for Mongefossen, representing 25%. The difference of costs with respect to Case 2.2 minimum flow is approximately 1.5 million NOK, representing and increase on costs of 17.7%. The NPV of Case 2.6 amounts to 707 330 543 NOK, which represents an increase in the NPV of 105% with respect to case 2.2.

Since the cruise project will occur already next year, and the concession reevaluation is not until 2020, it is interesting to propose a second-best solution that can be quickly implemented before the cruise project takes place, although such a measure would have a lower NPV. The second-best solution assumes that the compensation from the cruise companies, previously mentioned, will not be enforced by NVE and therefore the best case solution would entail an increase in costs compared to Case 2 for Grytten. The solution is exemplified by Case 2.5 and yields a NPV of 564 515 817 NOK. The night-time/daytime adjustment combined with high daytime flows during the MF period would aim on the one hand to keep the costs low, on the same level as when the waterfall is dry in August. Therefore the case would not involve higher costs for Grytten in dry seasons, and will in fact be lower in the case of a normal season. On the other hand it secures a high daytime flow, meaning that one may assume a high likelihood of the pilot project succeeding. Since it assures that all parties are satisfied, it is more probable that it can be implemented before the revision of the concession that takes place in 2020. Indeed the second-best option is socially preferable over a delayed best case option. Firstly, although there is some difference between the NPV of the first-best and the second-best option, the second-best option is preferable because the difference in NPV is not that large taken into account that the second-best provides an increase over 60% to the status quo in case 2.2. Secondly, and more importantly, the difference in NPV between the best and second-best solutions is irrelevant if cruise tourism fails as a result of the delayed measure. If the second-best is option is not implemented and the cruise tourism is not developed, the possibility exists that there is not going to be any *best case* option to be implemented by the concession-reevaluation in 2020.

The NPV of the worst case scenario of the best case solution (that is, using low estimates in the analysis) amounts to 175 874 198 NOK (assuming tourism develops). The value is greater than the corresponding NPV of the worst-case scenario of the second-best solution in Case 2.5. The NPV of the worst-case scenario amounts to 167 826 424 NOK. Both Cases 2.5 and 2.6 yield a higher worst case scenario than that of Case 2, which amounts to 57 480 828 NOK. Due to the relative importance of cruise tourism as compared to the best solution in Mongefossen, Case 1.8, both worst-case scenarios are greater than that of Mongefossen, which amounts to 12 452 791 NOK. At the same time the best solution in Mongefossen, Case 1.8, yields a lower worst-case scenario NPV than the worst case scenario of Case 1, which is 51 922 724 NOK. The fact that in the case of Mongefossen the best solution yields a lower worst-case scenario than Case 1 may seem surprising. The reason for this is the fact that the same low estimates proposed in section 4 are used for both worst-case scenarios, giving the same quantity of benefits, while the costs are still higher in Case 1.8. If the amount of tourism did not respond significantly with respect to a high flow as compared to the MF, Case 1 would then be more socially desirable. This possibility cannot be totally discarded and therefore further inquiry should address the topic on how utility responds to a marginal increase in flow, as suggested in section 1.0.3.

6.3 Tourism, recreational fishing and low prices: Hypothesis 6

H6: – *When considering what type of regulation to implement, variables such as tourism, fishing and electricity prices are relevant for decision-making.*

According to Innovasjon Norge [2013], national tourists stay the highest number of nights in Norway while international tourist have the highest consumption per day. International tourists are the ones who mostly hire package holidays and the tourists who plan to visit the Norwegian nature are more satisfied than the average tourist. National and international tourism related benefits are embodied by the environmental benefit categories called 'other tourism' and 'cruise tourism' respectively. As has been discussed through the different cases, the benefits from total tourism alone outweighs the costs incurred by the hydroelectric power plant except when longer periods than the high tourist season are evaluated – cases 1.4 and 1.5 –, and when the cruise tourism in Mardalsfossen does not succeed – case 2 and 2.1. In Cases 1.4 and 1.5, tourist related benefits remain the largest as compared to those of WTP and Fish. However, even in Cases 2 and 2.2 where tourism related benefits do not alone outweigh costs, they nevertheless remain significant. Furthermore, high flow rates – even without daytime/nighttime adjustment – in Cases 1.3 and 1.7 are socially preferable to cases with MF rates – Cases 1 and 1.6 – because of the importance of an increase in tourism benefits, caused by a higher flow rate. Therefore, this thesis affirms that tourism is relevant for decision-making.

With regards to recreational fishing benefits, this thesis deems them not relevant for decision-making. Even in Case 1.4 where recreational fish benefits are the highest – as explained previously when discussing both Case 1.4 and 1.5. The benefits from recreational fish affected by the plant are located in the river where the water from the turbines is discharged, instead of the rivers directly connected to the waterfalls. Note that the results would likely have been different if the negative impact of the plant on fish population was greater.

Concerning low prices, this thesis shows that although contributing to increase the NPV, they are not relevant for decision-making, unless the the assumption made about the high tourist response to marginal increases in flow (at low rates) does not hold. Low prices make the loss of revenues weigh less in comparison to benefits than when prices are high. The green certificate market and the expectation of future low prices favor measures with a higher cost-benefit ratio than when prices of electricity are high, since a negative NPV can become positive with low prices. Having said so, the benefits related mainly to tourism are so high in the case of Gryten that the NPV would only become 0 with unrealistically high prices.

As seen in the analysis, the cases with high cost-benefit ratio are more sensitive to an increase in electricity prices than those with low cost-benefit ratios. For instance, Case 1.7, which has the highest cost-benefit ratio of 47% among the profitable projects, the NPV decreases by 15% when the high price estimate is used. However, in cases where that ratio is lower, for example Case 1.8 with a ratio of 31% (where daytime/nighttime adjustment is used), the decrease of the NPV experienced by the high estimate price is also lower, amounting to 8 %. Therefore, the price needed to achieve a 0 NPV is comparatively lower in Case 1.7 than in Case 1.8, amounting to 593 NOK/MWh and 886 NOK/MWh respectively. Despite Case 1.7 being the most price sensitive case among the other cases with positive NPVs, the price that yields a NPV of 0, 593 NOK/MWh, is still high compared with the historical electricity prices of Molde of the last 15 years. The highest value was reached in 2010, amounting to 465.46 NOK [?] – adjusted by the CPI –, is lower than this. Hence, although low prices favor the adoption of high cost-benefit ratio environmental measures, it is not decision-making relevant, since the NPV is very high due to the high levels of tourist benefits. Note that with lower rates of tourism and thereby lower NPVs, low prices could have been relevant for decision-making.

6.4 Sensitivity analysis, choice of social discount rate and KAF variable and time horizon

As mentioned before, the cases where high flow rates are explored without combining them with daytime/nighttime adjustment are also more sensitive to price changes, since the ratio cost-benefit is also higher. In addition, they are also the cases that yield the lowest NPVs when the worst-case scenario is performed, where they can even become negative as shown in Case 1.7, amounting to -114 426 126 NOK. The reason is also here the high cost-benefit ratio: the costs remain even greater when using worst-case scenarios and benefits become smaller. However, the first options both for Mardalsfossen and for Mongefossen yield a positive NPV even in the event of worst-case scenarios. This is due to the benefits of daytime/nighttime adjustment, which enables to achieve an increase in benefits with a comparatively smaller increase in costs.

Choosing the social discount rate was not as important as expected at the beginning of this study since all the benefits and costs of the different projects – or in this case environmental measures – turned out to happen at the same time, sharing a common time structure. For example, since none of the cases have an initial inversion, choosing a high social discount rate does not favor one option over another. It is not true either that low social discount rates favor the environment in that case. For instance, when in Cases 1.4 and 1.5 a period of 1 year is evaluated in order to mainly know whether or not the fish benefits outweigh costs, the NPV becomes negative. The NPV becomes even more negative the lower the social discount rate of 2% is used, instead of 4%. By having a more negative NPV by using the low social discount rate, the fish related benefits are even less valued. Thereby, a low social discount rate does not favor environmental benefits over costs. The reason for this is that a low social discount rate of 2% leads to the the negative value of the NPV also being discounted slower than with a higher social discount rate of 6%. However, low social discount rates may have the opposite effect in for example the case of CO_2 emissions, which are accumulative and spread over time. If in those cases a high social discount rate is used, the negative environmental impacts of the CO_2 emissions would weigh less in comparison to commercial benefits yielded by the project that happen in the present. The choice of the discount rate would however be relevant in the analysis if the KAF variable was generally applied. The effects of the KAF variable would be different depending on whether or not the social discount rate was high. As suggested by the analysis of this thesis, the smaller the social discount rate, r, is, the higher the impact of the KAF variable. By employing a KAF with a lower social discount rate of 2% instead of 4%, the result of the NPV would favor environmental benefits over costs.

The time horizon was chosen to be 30 years – the time period between revisions of concessions – although the possibility of using longer periods than these were acknowledged at the beginning of the thesis in order to calculate the NPV. Such extended time horizons should be considered in the event that the impacts on fish benefits would have been more significant. With significant fish related benefits one could argue that consequences for fish upon decisions for each concession period can extend beyond the 30-year period. But since the fish related benefits are not significant in this case, this thesis assumes that the consequences for the environment cease once the decision about the water flow changes.

Furthermore, this thesis also assumes that the decision taken today about the best environmental measure to be applied in the revision of the concession, would be unchangeable for 30 years, since this is the time period stipulated by law between revisions of concessions (after the law of 1992). However, the decision about the environmental measure adopted on the waterfalls should ideally be subjected to more flexibility: increasing/decreasing the flow in order to allocate the water towards the purpose in which it is valued the most. Since both the public authorities and Grytten are legally bound by the concession, Grytten is entitled to know what the framework of operation is, and what to expect in order to plan its electricity production and maximize profits. In order to remove legal uncertainties that a variable allocation of water may entail, the possibility of offering a compensation from the 'winners' to the 'loosers' for the additional costs, yields the most socially desirable outcome. In this respect, if for instance the additional costs incurred by Grytten would be significantly lower than the increase in tourist earnings, the compensation could be handled by a third, neutral party – for instance the state – by charging a fee to all the cruises that visited the waterfalls. This option seems to be more plausible and at the same time less invasive than for example giving a compensation in a yearly payment between the two (or more) affected parties. The subject of how to design the most appropriate compensation scheme for Grytten is out of the scope of this master thesis, and further study of the topic is encouraged.

Chapter 7

Conclusion

An Environmental Benefit-Cost Analysis (EBCA) framework has been employed as a social appraisal procedure to take into consideration the new situation which surrounds the waterfalls Mardalsfossen and Mongefossen: Low electricity prices, increased importance of tourism and recreational activities such as hiking and fishing. The point of comparison for all the case-scenarios considered has been the current operational regime devised by NVE –The Norwegian Water Resources and Energy Directorate– for Mardalsfossen, which requires that a water flow of 2-2.5 m^3/s be released through the waterfall between the 20th of June until the 20th August. This mode of regulation has been referred to as the minimum flow regime (MF).

The possibility of having the same mode of operation for Mongefossen, i.e., having a water flow of 2-2.5 m^3/s between the 20th of June until the 20th August, has been considered in order to answer the first research question – *Is it welfare enhancing to employ NVE's proposed minimum flow regime for Mongefossen from mid-June until mid-August?* This flow and period corresponds well with NVE's proposal to introduce a minimum flow regime for Mongefossen that causes upto 5 % of production loss for Grytten, for the reevaluation of the concession in 2020. Case 1 concludes that such a measure should be adopted: The EBCA yields a positive social Net Present Value (NPV), – even if all benefits other than the willingness to pay (WTP) for the non-use value of the waterfall (i.e. its existence value) were disregarded. The share of loss in energy production by Grytten power plant upon acceptance of this measure is relatively low, amounting to 5.7% of its yearly production, and is outweighed by both the additional benefits as represented by increases in WTP and revenues from tourism separately. However, when comparing this measure with the other considered case-scenarios discussed in this thesis, this is not the option that yields the highest social NPV.

Different flow rates and periods have been explored in separate case-scenarios and compared with that of the MF operation regime in Mongefossen and Mardalsfossen, in order to answer the second research question – *Which form of flow regulation yields the highest social surplus for Mongefossen and Mardalsfossen?* Nine cases are considered for Mongefossen (Cases 1.0 to 1.8) and seven are considered for Mardalsfossen (2.0 to 2.6). For each waterfall, the water flow can either be channeled into energy production at Grytten power plant, or can be allowed to go via the waterfalls. The positive externalities of water flow in the waterfalls have been divided into tourism, recreational fishing and existence value. The last of these is valued according to the willingness to pay (WTP) for the non-use value of the waterfalls. The analysis of this thesis pursues to allocate the water where it is highest valued, and the EBCA framework is used to carry out the assessment in the typical manner of a public-sector agency – like NVE. Especially three variables have been identified to be important in this analysis: Daytime/nighttime adjustment, flow rates, and the period of flow in the waterfalls.

Daytime/nighttime adjustment has been employed in two different ways. First, the water flow in the waterfalls was decreased at night while leaving the daytime flow unaltered, in order to reduce the loss in energy production (Case 1.1). Second, the nighttime flow was reduced while increasing the daytime flow (Case 1.3), leading to a slight net increase of water flow. In this way, the water flow is allocated to the period in which there are most visitors. Both options yield a higher NPV than in Case 1, with the latter being the most favorable. This is because the latter option yields a higher social surplus due to the high flow in the daytime stimulating an increase in tourist benefits. At the same time, the increase in costs are modest, and the WTP will presumably not decrease since the overall quantity of flow will be slightly higher on average than in Case 1. In the former option of Case 1.1, the benefits from tourism remain unchanged. The reduction of water flow does reduce revenue losses. However, this is modest compared to the increase in benefits due to tourism in Case 1.3. It is also foreseeable that the WTP for the non-use value of the Mongefossen will decrease with respect to Case 1 if the overall quantity of water released is reduced. Therefore, it is more socially desirable to use daytime/nighttime adjustment with the purpose of increasing the daytime flow, than to reduce the overall flow. Case 1.1 would, however, be the preferable option in the event that the share of tourist benefits were small compared to WTP, or if higher flow rates have a low impact on tourist benefits.

Among the case-scenarios considered, the use of daytime/nighttime adjustment consistently leads to high NPVs. Hence, this option in some form should be considered in the concession-reevaluation in 2020. Furthermore, it is possible that this option is relevant also when assessing other environmental projects on similar hydropower plants. Some conditions apply, however:

- Technical feasibility. For instance, at the moment such daytime/nighttime adjustment might be cumbersome for Grytten since the dam control systems are not designed for dynamic regulation of the sort considered here. Nevertheless, given that it was possible for Grytten to temporarily increase the water flow during the Eikesdal town festival on the 9th of August 2014, the technical modification necessary to perform such adjustments on a regular basis should not be insurmountable.

- Influence on fish stock. In order that the variation in the amount of water poured into the rivers does not cause problems for fish populations, it might be recommended that, as in the case of Grytten, the waterfalls are not directly connected with rivers in which significant fish populations exist. If it is the case that the high fishing values are located in the river directly connected to the waterfall, the daytime/nighttime adjustment should be used in a different way. One possibility can perhaps be to have a less pronounced variation than the one applied in the present cases.

Apart from the use of daytime/nighttime adjustment, it turns out that increased flow rates will also be socially desirable. Based on the analysis, the NPV of the 24 hour high flow cases are greater than those of minimum flow rates (the exception being the case of whole-year minimum flow). The benefits are driven mainly from tourism and are high enough to outweigh the costs. WTP also increases in comparison with those of cases with MF rates. Nevertheless, daytime/nighttime adjustment remains the preferred environmental project for both Mardalsfossen and Mongefossen: The benefits from tourism are increased equally, but the adjustment reduces the costs.

Having discussed daytime/nighttime adjustments and flow levels, the remaining important variable is the period in which water is allowed to flow in the waterfalls. Extending the periods further than the NVE minimum flow period, turns out to be welfare enhancing as long as the influx of tourists is still high. When the period is extended to three months, instead of two, in order to cover the high tourist season, the increase on tourism benefits outweighs the loss of revenues. On the other hand, when the period is extended to the whole year, the project ceases to be socially beneficial because of the low amount of tourism in the wintertime. Another conclusion could have been drawn if, for instance, the benefits from recreational fishing increased, or if WTP increased dramatically with respect to the MF period.

Jointly considering all the parameters discussed so far, it indeed turns out that the case-scenario with the highest NPV is the one which combines daytime/nighttime adjustment, high flows and an extended period to cover the high tourist season. This is exemplified in Case 1.8 in Mongefossen and 2.6 in Mardalsfossen. Compared with the NVE minimum flow in Case 1, Case 1.8 results in an increase of approximately 80% in social benefits and a corresponding increase in costs by 60% for Mongefossen. The increased NPV indicates that there is room for pareto improvement, implying that those who gain from the project could compensate those who loose and still be better off. If the additional utility provided to tourists lead to a similar increase in the cruise ticket price for cruises traveling to Åndalsnes (in vicinity of Mongefossen), the cruise companies will be willing to pay the extra costs incurred by Grytten power plant as compared to the costs incurred in Case 1.

For Mardalsfossen in Case 2.6, the NPV almost doubles, while the increase of costs is approximately 18% as compared to the NVE minimum flow regime in Case 2.2. A factor which may prove to be important in the case of Mardalsfossen is the possibility of cruise tourism in its vicinity –to Eresfjord. There is currently a pilot project in which 3 cruises will be visiting Eresfjord, and if successful it is expected that the number of cruise tourists will increase. The NPV of Cases 2.2 and 2.6 is calculated assuming that the cruise tourism will succeed. One obstacle to success is the fact that the current NVE regulation of minimum flow applied in Mardalsfossen allows Grytten to release less water flow than the assigned minimum in August, in the event of a dry season. If there is not enough water in the smallest of the two basins connected to Mardalsfossen –Fossafjellvatn–, although there is water from the biggest of them –Sandgrovvatn–, Grytten does not need to open the dam from the biggest on them and let the water pass through Mardalsfossen. The waterfall, then, does not need to reach the minimum flow and therefore the viability of the cruise project may be endangered, which leads to a lost in the benefits provided by cruise tourism. Since Mardalsfossen is going to be the main attraction of the cruise trip, it is even more likely than in the case of Mongefossen, than the cruise or harbor company benefits from the increased utility of the tourists, and thereby they are willing to pay a compensation to Grytten hydroelectric plant in order to ensure that the minimum flow is upheld in August.

In the event that cruise tourism should not succeed in Eresfjord, a second best solution has been considered. This may be the most realistic solution for instance if the measures suggested in Case 2.6 (daytime/nighttime adjustment, high flow and an extended period) which aims at increasing tourism are not implemented before the cruise pilot project takes place in 2016. Case 2.5 proposes a daytime/nighttime adjustment of a high flow in Mardalsfossen ($3.2m^3/s$) in order to make the costs of Grytten decrease to the equivalent level as if less water than the assigned minimum is allowed to flow in August due to drought. Since the revision of the concession is not until 2020, this second best option seems to be the most appropriate to be implemented before the revision of the concession takes place in 2020, since it gives economic incentives to Grytten as compared to the status quo and at the same time secures that the minimum flow (and more) is reach in

August if there is water in any of the basins connected to Mardalsfossen (not just on one of them).

Some important considerations with regard to cases which employ high flow values must be made. If daytime/nighttime regulation is not also employed (Cases 1.2 and 1.7) a high cost to benefits ratio arises. In turn, this makes their corresponding NPVs sensitive to the electricity prices. Nevertheless, if it is assumed that a marginal increase of flow (at low flow rates[1]) leads to at least an equal increase on tourist utility (and that this is reflected in an equal increase in tourist benefits), this analysis reveals that low prices would not be decision-making relevant. Even for example in Case 1.7 where the ratio of cost to benefits is the highest (while still giving a positive NPV), the price that gives a 0 NPV is higher than any average year price seen during the last 15 years (Molde area prices). Although low electricity prices favors the social profitability of the environmental projects considered in this thesis, the main decision-making relevant driver is tourism. Contrary to expectations at the beginning of this thesis, it turns out that recreational fishing does not have any significant effect on the appraisals, since the impact on the fish from the hydroelectric plant is low.

This master thesis has given an overview of the present situation concerning the Grytten Hydroelectric power plant, and has discussed several alternatives that may lead to a higher NPV than the current NVE minimum flow regime, through the allocation of more quantity of water to other purposes than to electricity production. This thesis may hopefully function as motivating groundwork for further inquiry, having identified the main factors of importance and discussed their interrelation. In particular, further studies should focus on ways of giving a more accurate assessment of how tourism and WTP will respond as flow rates and periods are changed from those of the NVE minimum regime.

[1]By low flow rates the the author means from rates ranging from 0 up to the designated 'high flow rates' of Mongefossen and Mardalsfossen respectively

Appendix A

Background data for the analysis of Mongefossen

A.1 Tables

The background data for the analysis of Cases 1.1 to 1.8 found in sections 5.2 to 5.9 are here supplied. To avoid unnecessary repetition, several of the numbers that are not subject to variation from tables 5.1 to 5.4 of Case 1 discussed in sections 5.1.2 to 5.1.6 are not displayed.

A.1.1 Case 1.1

TABLE A.1: Case 1.1 baseline data for calculating loss of revenue

Parameter	**Value**
f_a	3.5 m^3/s
f_b	3 m^3/s
t_a [hrs]	492
t_b [hrs]	240
LE excl. pumping energy [MWh]	22303.05
Pumping energy [MWh]	1524.80
Pump consumption [%]	0.0684
LE of yearly production [%]	0.038
LR excl. pumping costs [NOK]	6213485.82
Pumping Costs [NOK]	383806.59
Pump cost share [%]	0.0618
Yearly Total LR [NOK]	5829679.24

TABLE A.2: Case 1.1, environmental benefits of fish.

Fish	
Report [NOK]	21932987.06
LE of yearly production [%]	0.0379
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	83270.14
NPV of benefit for period 11	**54090.7**

A.1.2 Case 1.2

Table A.3: Case 1.2 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	4 m^3/s
f_b	4 m^3/s
t_a [hrs]	984
t_b [hrs]	480
LE excl. pumping energy [MWh]	53483.49
Pumping energy [MWh]	3656.52
Pump consumption [%]	0.0684
LE of yearly production [%]	0.0910
LR excl. pumping costs [NOK]	14900152.74
Pumping Costs [NOK]	920380.91
Pump cost share [%]	0.0618
Yearly Total LR [NOK]	**13979771.82**

TABLE A.4: Case 1.2, environmental benefits divided into tourism, fish and willingness to pay.

Tourism	
Cruise tourism	
Visiting waterfall [hrs/day]	2
Number of cruises 2015	25
Number passengers [per cruise]	2500
Total cruise tourism [NOK]	**11718750.00**
Other tourism	
Passengers/car	5
Total visitors	13333.33
Time per visit [day per pers.]	0.67
Total other tourism [NOK]	**10444444.44**
Total tourism	**22163194.44**
Fish	
LE of yearly production [%]	0.0910
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	199684.67
NPV of benefit for period 11	**129711.35**
WTP	
Total households	397673
Total WTP [NOK]	**13216769.69**

A.1.3 Case 1.3

Table A.5: Case 1.3 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	4 m^3/s
f_b	1 m^3/s
t_a [hrs]	732
t_b [hrs]	732
LE excl. pumping energy [MWh]	33427.18
Pumping energy [MWh]	2285.33
Pump consumption [%]	0.0684
LE of yearly production [%]	0.0569
LR excl. pumping costs [NOK]	9312595.46
Pumping Costs [NOK]	575238.07
Pump cost share [%]	0.0618
Yearly Total LR [NOK]	**8737357.39**

Table A.6: Case 1.3, environmental benefits divided into tourism, fish and willingness to pay.

Tourism	
Cruise tourism	
Visiting waterfall [hrs/day]	2
Number of cruises 2015	25
Number passengers [per cruise]	2500
Total cruise tourism [NOK]	**11718750.00**
Other tourism	
Passengers/car	5
Total visitors	13333.33
Time per visit [day per pers.]	0.67
Total other tourism [NOK]	**10444444.44**
Total tourism	**22163194.44**
Fish	
LE of yearly production [%]	0.0569
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	124802.92
NPV of benefit for period 11	**81069.60**
WTP	
Total households	310257
Total WTP [NOK]	**10311475.29**

A.1.4 Case 1.4

TABLE A.7: Case 1.4 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	4 m^3/s
f_b	4 m^3/s
t_a [hrs]	1464
t_b [hrs]	7296
LE excl. pumping energy [MWh]	320024.17
Pumping energy [MWh]	21879.20
Pump consumption [%]	0.0684
LE of yearly production [%]	0.5448
LR excl. pumping costs [NOK]	89156651.63
Pumping Costs [NOK]	5507197.27
Pump cost share [%]	0.0618
Yearly Total LR [NOK]	**83649454.36**

Table A.8: Case 1.4, environmental benefits divided into tourism, fish and willingness to pay.

Tourism	
Cruise tourism	
Visiting waterfall [hrs/day]	2
Number of cruises 2015	38
Number passengers [per cruise]	2500
Total cruise tourism [NOK]	**17812500.00**
Other tourism	
Passengers/car	5
Total visitors	20266.67
Time per visit [day per pers.]	0.67
Total other tourism [NOK]	**15875555.56**
Total tourism	**33688055.56**
Fish	
LE of yearly production [%]	0.5448
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	1194834.51
NPV of benefit for period 11	**776141.71**
WTP	
Total households	397673
Total WTP [NOK]	**13216769.69**

A.1.5 Case 1.5

Table A.9: Case 1.5 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	2.5 m^3/s
f_b	2 m^3/s
t_a [hrs]	984
t_b [hrs]	7776
LE excl. pumping energy [MWh]	164505.58
Pumping energy [MWh]	11246.81
Pump consumption [%]	0.0684
LE of yearly production [%]	0.2800
LR excl. pumping costs [NOK]	45830182.91
Pumping Costs [NOK]	2830925.72
Pump cost share [%]	0.0618
Yearly Total LR [NOK]	**42999257.19**

Table A.10: Case 1.5, environmental benefits divided into tourism, fish and willingness to pay.

Tourism	
Cruise tourism	
Visiting waterfall [hrs/day]	1.5
Number of cruises 2015	38
Number passengers [per cruise]	2000
Total cruise tourism [NOK]	**10687500.00**
Other tourism	
Passengers/car	4
Total visitors	16213.33
Time per visit [day per pers.]	0.50
Total other tourism [NOK]	**9525333.33**
Total tourism	**20212833.33**
Fish	
LE of yearly production [%]	0.2800
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	614194.04
NPV of benefit for period 11	**398968.74**
WTP	
Total households	397673
Total WTP [NOK]	**13216769.69**

A.1.6 Case 1.6

TABLE A.11: Case 1.6 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	2.5 m^3/s
f_b	2 m^3/s
t_a [hrs]	984
t_b [hrs]	1200
LE excl. pumping energy [MWh]	44386.91
Pumping energy [MWh]	3034.62
Pump consumption [%]	0.0684
LE of yearly production [%]	0.0756
LR excl. pumping costs [NOK]	12365905.45
Pumping Costs [NOK]	763840.72
Pump cost share [%]	0.0618
Yearly Total LR [NOK]	**11602064.73**

TABLE A.12: Case 1.6, environmental benefits divided into tourism, fish and willingness to pay.

Tourism	
Cruise tourism	
Visiting waterfall [hrs/day]	1.5
Number of cruises 2015	35
Number passengers [per cruise]	2000
Total cruise tourism [NOK]	**9843750.00**
Other tourism	
Passengers/car	4
Total visitors	14933.33
Time per visit [day per pers.]	0.50
Total other tourism [NOK]	**8773333.33**
Total tourism	**18617083.33**
Fish	
LE of yearly production [%]	0.0756
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	165721.91
NPV of benefit for period 11	**107649.79**
WTP	
Total households	310257
Total WTP [NOK]	**10311475.29**

A.1.7 Case 1.7

TABLE A.13: Case 1.7 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	4 m^3/s
f_b	4 m^3/s
t_a [hrs]	984
t_b [hrs]	1200
LE excl. pumping energy [MWh]	79786.85
Pumping energy [MWh]	5454.82
Pump consumption [%]	0.0684
LE of yearly production [%]	0.1358
LR excl. pumping costs [NOK]	22228096.71
Pumping Costs [NOK]	1373027.27
Pump cost share [%]	0.0618
Yearly Total LR [NOK]	**20855069.44**

Table A.14: Case 1.7, environmental benefits divided into tourism, fish and willingness to pay.

Tourism	
Cruise tourism	
Visiting waterfall [hrs/day]	2
Number of cruises 2015	35
Number passengers [per cruise]	2500
Total cruise tourism [NOK]	**16406250.00**
Other tourism	
Passengers/car	5
Total visitors	18666.67
Time per visit [day per pers.]	0.67
Total other tourism [NOK]	**14622222.22**
Total tourism	**31028472.22**
Fish	
LE of yearly production [%]	0.1358
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	297890.25
NPV of benefit for period 11	**193503.82**
WTP	
Total households	397673
Total WTP [NOK]	**13216769.69**

A.1.8 Case 1.8

Table A.15: Case 1.8 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	4 m^3/s
f_b	1 m^3/s
t_a [hrs]	1092
t_b [hrs]	1092
LE excl. pumping energy [MWh]	49866.78
Pumping energy [MWh]	3409.26
Pump consumption [%]	0.0684
LE of yearly production [%]	0.0849
LR excl. pumping costs [NOK]	13892560.44
Pumping Costs [NOK]	858142.04
Pump cost share [%]	0.0618
Yearly Total LR [NOK]	**13034418.40**

Table A.16: Case 1.8, environmental benefits divided into tourism, fish and willingness to pay.

Tourism	
Cruise tourism	
Visiting waterfall [hrs/day]	2
Number of cruises 2015	35
Number passengers [per cruise]	2500
Total cruise tourism [NOK]	**16406250.00**
Other tourism	
Passengers/car	5
Total visitors	18666.67
Time per visit [day per pers.]	0.67
Total other tourism [NOK]	**14622222.22**
Total tourism	**31028472.22**
Fish	
LE of yearly production [%]	0.0849
Total impact for total E prod. [%]	0.10
Benefit fish in period 11 [NOK]	186181.40
NPV of benefit for period 11	**120939.89**
WTP	
Total households	310257
Total WTP [NOK]	**10311475.29**

Appendix B

Background data for the analysis of Mardalsfossen

B.1 Tables

The background data for the analysis of Cases 2.1 to 2.6 found in sections 5.11 to 5.16 are here supplied. To avoid unnecessary repetition, several of the numbers that are not subject to variation from tables 5.5 to 5.8 of Case 2 discussed in section 5.10 are not displayed.

B.1.1 Case 2.1

TABLE B.1: Case 2.1 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	2.5 m^3/s
f_b	0.5 m^3/s
t_a [hrs]	984
t_b [hrs]	480
LE [MWh]	24659.40
LE of yearly production [%]	0.0451
LR [NOK]	6869947.47
Yearly Total LR [NOK]	**6869947.47**

TABLE B.2: Case 2.1, environmental benefits divided into tourism and fish.

Tourism	
Cruise tourism	
Number of cruises 2015	0
Number passengers [per cruise]	600
Total cruise tourism [NOK]	**0.00**
Other tourism	
Passengers/car	4
Total visitors	10666.67
Total other tourism [NOK]	**6266666.67**
Total tourism	**6266666.67**
Fish	
LE of yearly production [%]	0.0451
Benefit fish in period 11 [NOK]	98824.07
NPV of benefit for period 11	**64194.23**

B.1.2 Case 2.2

TABLE B.3: Case 2.2 baseline data for calculating loss of revenue.

Parameter	Value
f_a	2.5 m^3/s
f_b	2 m^3/s
t_a [hrs]	984
t_b [hrs]	480
LE [MWh]	31235.24
LE of yearly production [%]	0.0571
LR [NOK]	8701933.46
Yearly Total LR [NOK]	**8701933.46**

TABLE B.4: Case 2.2, environmental benefits divided into tourism and fish.

Tourism	
Cruise tourism	
Number of cruises 2015	15
Number passengers [per cruise]	600
Total cruise tourism [NOK]	**11812500.00**
Other tourism	
Passengers/car	4
Total visitors	10666.67
Total other tourism [NOK]	**6266666.67**
Total tourism	**18079166.67**
Fish	
LE of yearly production [%]	0.0571
Benefit fish in period 11 [NOK]	125177.15
NPV of benefit for period 11	**81312.69**

B.1.3 Case 2.3

Table B.5: Case 2.3 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	2.5 m^3/s
f_b	0.5 m^3/s
t_a [hrs]	984
t_b [hrs]	480
LE [MWh]	24659.40
LE of yearly production [%]	0.0451
LR [NOK]	6869947.47
Yearly Total LR [NOK]	**6869947.47**

Table B.6: Case 2.3, environmental benefits divided into tourism and fish.

Tourism

Cruise tourism	
Number of cruises 2015	15
Number passengers [per cruise]	600
Total cruise tourism [NOK]	**11812500.00**

Other tourism	
Passengers/car	4
Total visitors	10666.67
Total other tourism [NOK]	**6266666.67**

Total tourism	**18079166.67**

Fish

LE of yearly production [%]	0.0451
Benefit fish in period 11 [NOK]	98824.07
NPV of benefit for period 11	**64194.23**

B.1.4 Case 2.4

Table B.7: Case 2.4 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	2.5 m^3/s
f_b	0.5 m^3/s
t_a [hrs]	984
t_b [hrs]	480
LE [MWh]	24659.40
LE of yearly production [%]	0.0451
LR [NOK]	6869947.47
Yearly Total LR [NOK]	**6869947.47**

Table B.8: Case 2.4, environmental benefits divided into tourism and fish.

Tourism	
Cruise tourism	
Number of cruises 2015	12
Number passengers [per cruise]	600
Total cruise tourism [NOK]	**9450000.00**
Other tourism	
Passengers/car	4
Total visitors	10666.67
Total other tourism [NOK]	**6266666.67**
Total tourism	**15716666.67**
Fish	
LE of yearly production [%]	0.0451
Benefit fish in period 11 [NOK]	98824.07
NPV of benefit for period 11	**64194.23**

B.1.5 Case 2.5

Table B.9: Case 2.5 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	3.1885 m^3/s
f_b	0.5 m^3/s
t_a [hrs]	732
t_b [hrs]	732
LE [MWh]	24659.40
LE of yearly production [%]	0.0451
LR [NOK]	6869947.47
Yearly Total LR [NOK]	**6869947.47**

Table B.10: Case 2.5, environmental benefits divided into tourism and fish.

Tourism	
Cruise tourism	
Package holiday cruise [NOK/day]	2625
Visiting waterfall [hrs/day]	0.67
Number of cruises 2015	15
Number passengers [per cruise]	700
Total cruise tourism [NOK]	**18375000**
Other tourism	
Passengers/car	5
Total visitors	13333.33
Total other tourism [NOK]	**10444444.44**
Total tourism	**28819444.44**

Fish	
LE of yearly production [%]	0.0451
Benefit fish in period 11 [NOK]	98824.07
NPV of benefit for period 11	**64194.23**

B.1.6 Case 2.6

Table B.11: Case 2.6 baseline data for calculating loss of revenue.

Parameter	**Value**
f_a	3.1885 m^3/s
f_b	0.5 m^3/s
t_a [hrs]	1092
t_b [hrs]	1092
LE [MWh]	36786.97
LE of yearly production [%]	0.0672
LR [NOK]	10248610.16
Yearly Total LR [NOK]	**10248610.16**

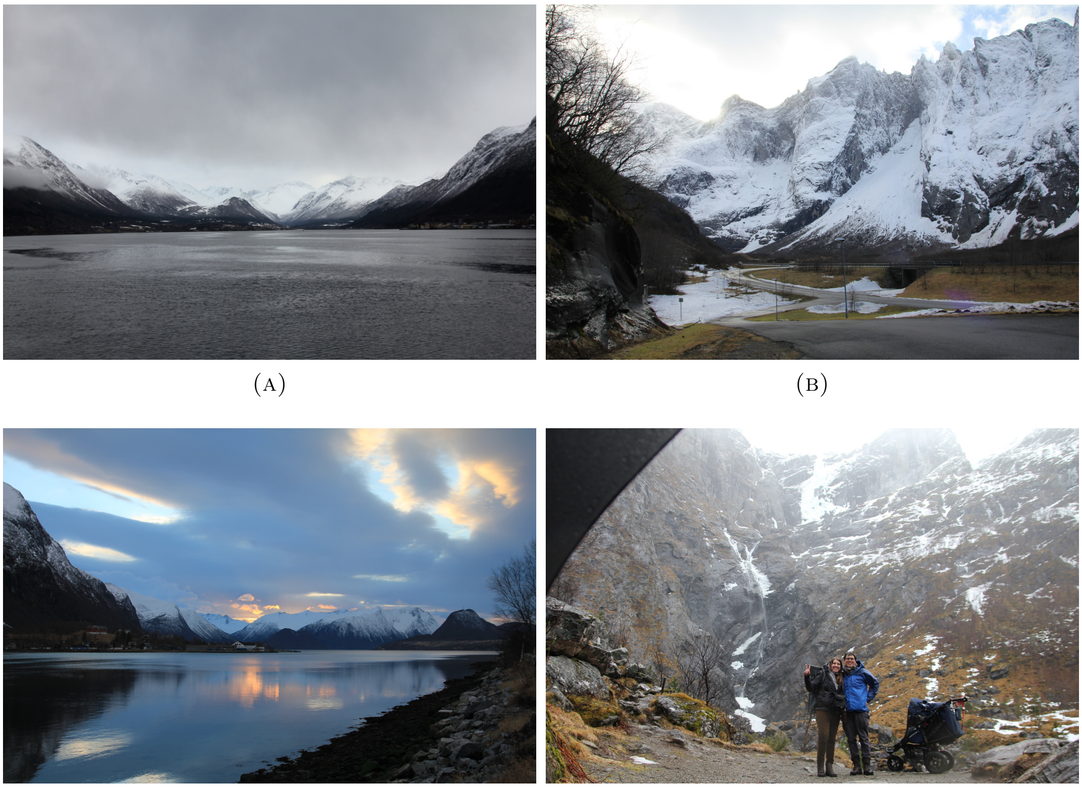
Table B.12: Case 2.6, environmental benefits divided into tourism and fish.

Tourism	
Cruise tourism	
Visiting waterfall [hrs/day]	0.67
Number of cruises 2015	21
Number passengers [per cruise]	700
Total cruise tourism [NOK]	**25725000.00**
Other tourism	
Passengers/car	5
Total visitors	18666.67
Time per visit [day per pers.]	0.67
Total other tourism [NOK]	**14622222.22**
Total tourism	**40347222.22**
Fish	
LE of yearly production [%]	0.0672
Benefit fish in period 11 [NOK]	147426.07
NPV of benefit for period 11	**95765,16**

Appendix C

Excursion to the Åndalsnes region

An excursion was made to Åndalsnes, Molde and Eikesdal between the 8th and 10th of March 2015 in order to gather data from local representatives with separate interests in relation to the regulation of the waterfalls Mardalsfossen and Mongefossen. Here some background information is given together with photos of the spectacular nature (fig. C.1), the Grytten hydroelectric power plant (fig. C.2), and some newspaper clippings from an exhibition in Eikesdal regarding the environmental activism the building of Grytten power plant (fig. C.3).



(a) (b) (c) (d)

Figure C.1: Spectacular nature in the Åndalsnes region. (a) Scenery from the drive between Molde and Åndalsnes. (b) The popular tourist site *Trollveggen* seen from the entrance to Grytten power plant. (c) View from Åndalsnes center during the evening. (d) The visit by the author to Mardalsfossen.

(A)

(B)

(C)

FIGURE C.2: Visit to the Grytten power plant. (a) The main entrance heading into the mountain. (b) The turbine room. The generator is located in the middle, while a spear turbine wheel is placed to the right. (c) The river Rauma.

(A)

(B)

FIGURE C.3: Some newspaper clippings regarding the Mardøla campaign. (a) People setting up camp to prevent construction, an act of civil disobedience. The title reads "We are singing while we wait for the police". (b) One of the initiators of the movement, Sigmund Kvaløy, being carried away by the police.

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