Article

Small Scale Hydroelectric Power Plants in Norway. Some Microeconomic and Environmental Considerations

Johannes Idsø †

Department of Social Sciences, Western Norway University of Applied Sciences, 5063 Bergen, Norway; johannes.idso@hvl.no

† Current address: 6851 Sogndal, Norway

Abstract: The development of small scale hydroelectric power plants in Norway is determined by natural conditions, policies, attitudes and property rights. The owner of the river is the central decision maker. It is he who decides whether he will develop the power plant himself, Whether he wants to enter into a contract with an external investor and let him develop the power plant, whether he will sell his property rights or postpone the decisions. All available choices will involve risk. In order for him to make the best choice he must find the certainty equivalent to each of the choices and choose the one with the highest certainty equivalent. This is the first time the utility theory of John von Neumann and Oskar Morgenstern has been applied to decision makers in the hydro power industry in Norway.

Keywords: small scale hydroelectric power; neumann-mortenstern utility theory; environmental effects of hydro power; hydropower and risk

---

1. Introduction

In Norway small scale hydroelectric power plants (SSH) are classified into three categories: "Small powerplants" has an installed effect between 1 and 10 MW. "Mini powerplants" has an installed effect between 100 kW and 1 MW and "micro powerplants" is power plants with in installed effect of less than 100 kW. In this paper we will— even if the application procedures for micro power plants are easier than for the others — include all three categories into one group and call it SSH.

About 95 percent of the electricity production in Norway is produced by hydro power plants. The public sector has been the dominant provider of electricity, and own almost 90 percent of the hydropower capacity[1]. In the period 1960–1990 Norway had net export in 28 years and net import in 3 years[2]. In the period 1991–2011 Norway had a net export in 13 years and a net import in 8 years. Total net export in that period was 57 TWh. In January 2017 the average expected annual production from already developed hydro power system is estimated to 133,4 TWh. Of these 9.9 TWh (7.4 percent) come from SSH[3].

Norway has endorsed the EU Renewable Directive and has plans to increase its renewable energy ratio from 58,2 percent in 2005 to 67,5 percent by 2020. In order to achieve this target, a common Swedish-Norwegian market for el-certificates is implemented from 1st January 2012. Renewable power plants where construction had started no earlier than 9.th September 2009 and where production will start no later than 31.12.2020 will be entitled to green certificates and can sell 1 certificate per MWh produced for a period of 15 years. This common green certificate market is expected to increase renewable power production in Sweden and Norway by 28,4 TWh by 2020[4].

Although Norway has the potential to increase the production of electricity from SSH by more than 15 TWh[5], and although Norway uses green certificates to encourage greater production, it is crucial that the owners of the rivers find this interesting. In the following we discuss the choices river owners face.

2. The Norwegian Water Resources and Energy Directorate (NVE) and its work

The Norwegian Water Resources and Energy Directorate (NVE) is a directorate under the Ministry of Petroleum and Energy with responsibility for the management of the nation's water and energy resources. Licenses issued by the NVE is given specified companies, granting them the right to build and run power installations and accessories as specified in the license. The license also states conditions and rules of operation. NVE has particular emphasis on preserving the environment[6].

In 2004 NVE estimated the potential for development SSH (in this case with an effect less than 10 MW) to 25 TWh[5]. Between 2004 and 2010 NVE gave about 400 new licenses to built SSH. In addition to license from NVE one also needs a license from the local authorities to develop SSH. *The goal of NVE is processing of license applications and to ensure that benefits of the proposed project is greater than the disadvantages* . . . .[3].

In order to operationalize the task of NVE we must formulate a profit function of the society. NVE have to process license applications and approve only those applications where π_s in the following profit function is positive:

$$\pi_s = \pi_p - d(k_i) - e(x) + b(n_j) \tag{1}$$

where

π_s	=	the economic surplus for the society
π_p	=	the econmic surplus (the added value) of the power plant
$d(k_i)$	=	the negative environmental effects measured in money
$e(x)$	=	other negative external effects measured in money
$b(n_j)$	=	positive replacement effects measured in money

In the social profit function (1) π_p is the consumer surplus minus the opportunity cost of the produced quantity. We assume an efficient market and that implies that π_p is equal to the private profit (the added value) of the SSH.

A SSH may have negative effects on the environment. In equation (1) the negative environment is a function where $d(k_i)$ where k_i is quantity of the natural resource that is already used in other projects. The derivative $d'(k_i)$ is the cost for the society of using one more unit of the natural resource i. Both $d'(k_i) > 0$ and $d''(k_i) > 0$. That means the cost for the society grows exponentially if more and more of a natural resource is used[7]. Fragmentation of the nature may have the same effect. In scientific reports this is often expressed as the sum effect or the cumulative effect of the projects[8]. If we assume that the project may affect the environment in n different ways, every $i \in n$ have to be considered and translated into a money amount.

Hydro power may also be an important part in a sustainable energy power system[9], [10]. If hydro power production replaces fossil power production, it will be beneficial for the society in m different ways. In equation (1) the function $b(n_j)$ where $j \in m$ represents these benefits measured in money.

The component $e(x)$ is non environmental external effects. This may for instance be different negative cultural effects or negative effects on Sami interests or negative effects on other businesses such as for instance tourism. The so-called "nimby" effect is a subset of such non environmental external effects. Sometimes these external effect are positive such as when development reduces the risk of floods. This is not usual in cases of SSH but it may happen.

Since the task of NVE is to ensure a license is given to only those power plants were the benefits is greater than the disadvantages, NVE has to calculate π_s and approve only those where $\pi_s > 0$ that is:

$$\pi_s = \pi_p - d(k_i) - e(x) + b(n_j) > 0 \Rightarrow \pi_p + b(n_j) > d(k_i) + e(x) \tag{2}$$

Peer-reviewed version available at *Sustainability* **2017**, *9*, 1117; doi:10.3390/su9071117

The sum of the added value (π_p) and the benefits of replacing non sustainable energy production $(b(n_j))$ must at least be greater than the environmental damage $(d(k_i))$ and other non environmental external effects $(e(x))$ caused by the project.

The environmental damage $(d(k_i))$ is a function of n variables. In practice that means NVE has to have a list of variables to assess. This list is time dependent and varies as one gets greater knowledge about the nature or the governments attitude towards preservation of the environment. To illustrate we will give an example from an application sent to NVE in 2016 to develop a SSH with an expected annual production of 3,7 GWh[1]. The following factors was assessed in this report:

1. Hydrology. NVE require a minimum of water in the river. This requirement is the 5-percentile measured in liters pr second. There is a requirement for the summer and one for the winter season.
2. The water temperature, the ice conditions and the local climate.
3. The groundwater and the risk of erosion and flooding.
4. The biodiversity.
5. The fish and freshwater biology.
6. The flora and fauna.
7. The landscape.
8. The cultural effects.
9. The agriculture.
10. The water quality and water supply.
11. The Sami interests and reindeer herding.
12. The societal impacts.
13. The consequences of new power lines.
14. The consequences of breaking the dam and pressure pipes.

To measure the negative environmental effects and the external effects and translate these into money amounts is not easy, but it is possible to find some help in the literature. See "*Measuring Sustainability*"[11] and "*Sustainability Assessment*"[12].

3. The river owners and small scale hydro power development

Most farms in mountainous parts of Norway are small. Few farmers own a whole river by himself. An investigation in the county Sogn og Fjordane in 2012 showed that in average a river is owned by seven owners. It is possible to find rivers with a single owner and also rivers with more than twenty owners but this is not usual. In our discussion we use the concept "the river owner (RO)". Usually RO is more than one individual. The starting point of our discussion is that a RO that considers the possibility to increase his income by developing a SSH has the following options:

1. Sign contract with an external investor and let the investor develop the power plant. In this case the profit is shared according to the contract. The value of this option is L_1.
2. RO may finance and develop the power plant by himself. The value of this option is L_2.
3. RO may sell his property right. The value of this option is S.
4. Do nothing and wait. In this case he has the possibility to choose one of the other options and choose L_1, L_2 or S in the future. The value of this option is Z.

We now follow C.J. Mckenna[13]. We also assume that the RO has a von Neumann-Morgenstern utility function $U(\cdot)$[14]. This implies that his utility function is complete, continous and transitive. The goal of RO is to maximise his utility. From the vector given in expression (3) he chooses what gives the greatest utility:

$$\text{Maximise } [U(L_1),\ U(L_2),\ U(Z),\ U(S)] \tag{3}$$

[1] The planned power plant is Auneelva Minikraftverk in the river Sørlivassdraget in Lierne municipality.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 May 2017 doi:10.20944/preprints201705.0046.v1

Peer-reviewed version available at *Sustainability* **2017**, *9*, 1117; doi:10.3390/su9071117

In 3 all choices are uncertain, but with our assumptions it is possible to find certainty equivalents. That is the certain amount that generates indifference to a given choice with uncertain outcomes. That means that the choices given in 3 can be translated into certain money amounts m_j. This means for instance that there exist an amount , say m_1, that make RO indifferent between the utility of the uncertain project L_1 and the amount m_1. Using standard notation we may write it in this way: $U(L_1) \approx m_1$.

To be able to choose, RO has to calculate the certainty equivalents of the utility of all the choices: $U(L_1) \approx m_1$, $U(L_2) \approx m_2$, $U(Z) \approx m_z$ and $U(S) \approx m_s$ and choose the one with the highest certainty equivalent. We will discuss the choices of RO.

Some words about the notation. Below we will describe a lottery with two outcomes x_1 and x_2 and related probabilities p_1 and p_2 in the following way:

$$L_i = [\{p_1,\ x_1\},\ \ \{p_2,\ x_2\}]$$

3.1. Signing a contract with an investor

If RO choose the option L_1 and sign a contract with an investor, his new situation may be modeled as a lottery with two outcomes:

$$L_1 = [\{(1-p_1)(1-p_2)(1-p_3)(1-p_4),\ \pi(c_i) - x\},\ \ \{p_5,\ 0\}] \tag{4}$$

where

p_1	$\in$	$[0,1]$	The probability that there are red-listed species in the river.
p_2	$\in$	$[0,1]$	The probability that the municipality rejects the application.
p_3	$\in$	$[0,1]$	The probability that NVE rejects the application.
p_4^i	$\in$	$[0,1]$	The probability the investor reverse his decision and stops the project.
p_5	$\in$	$[0,1]$	The probability the project is stopped for some reason.
$\pi(c_i)$	≥ 0		The expected risk adjusted net present value of the profit paid to RO.
x	≥ 0		The net present value of all negative effects measured in money on RO's utility.

In (4) the two outcomes are $(\pi(c_i) - x)$ and 0. If the power plant is built, RO gets a profit of $(\pi(c_i) - x)$ where $\pi(c_i)$ is the risk adjusted net present value of the cash flow that he receives from the contract with investor i and x is the net present value of the all negative effects translated into money amounts caused by the power plant on RO's welfare. In practice, $(\pi(c_i) - x)$ is not always positive. The value of seeing a pristine landscape can be greater than the money that the power plant he expects to get from the project. In this case RO will not sign a contract with an investor.

3.1.1. The probabilities

We will now discuss what determines the probabilities in equation 4. Clearly when RO choose he uses his subjective probability but we assume this is the same as the objective or true probability. We assume that RO is well informed and we do not discriminate between subjective and objective probabilities. If one of the probabilities p_i, where $i \in [1,4]$ goes up the probability that the SSH will be built goes down and hence the certainty equivalent m_1 will go down. The size and changes of the probabilities and of the expected risk adjusted net present value of the profit to RO will affect the certainty equivalent and the actions taken by RO. This is in line with results presented on other scientific papers[4].

The first probability $(1 - p_1)$ is the probability that there are no red-listed species in the river. In Norway it is illegal to built a hydro electric power plant if there are red-listed species in the river. We relate this to the profit function of the society, equation (1) above. If there are red-listed species in the river the environmental damage $d(k_i)$ are set to ∞ and hence $\pi_s < 0$ and the application will be rejected.

Peer-reviewed version available at Sustainability 2017, 9, 1117; doi:10.3390/su9071117

In Norway there are independent firms that examines the river and write a report which is submitted with the application to the the local authorities and to NVE. To send such a report is compulsory. Neither the applications nor the environmental reports are confidential and may be downloaded from NVE[15]. These studies will differ somewhat from applications to application. For example in most places in South Norway it is not necessary to examine the consequences for the Sami people while this is important in North Norway.

After some discussions about the credibility of these environmental effect reports, NVE decided to do a follow-up study in 20 rivers that had been examined by a company before the application to NVE was sent. The follow-up study was completed in 2012. It was discovered some major discrepancies in the results presented by the companies and the result in the follow-up study. The number of red-listed lichens and mosses were 12.8 times higher in the follow-up study — 166 red-listed findings versus 13 discoveries the in small hydro power studies. In the study done by NVE it was found almost twice as many habitats, including 14 with very high value, compared with only 1 in the reports that was submitted along with the applications. Generally, the values was considered to be substantially higher, the scope more negative and the consequences more negative in follow-up study. Differences in values, scope and consequences varied simultaneously significantly between projects[16].

It is not unlikely that NVE in the future will require that investors or ROs that want to develop a SSH, use more resources to examine the river before any licence is given. If so p_1 will increase and reduce the probability of getting an approval on the application. This will also reduce de value of the deferral option (Z) or the selling price (S) in expression (3) and the probability that RO choose deferral or sale will be reduced.

The probability $(1 - p_2)$ is the probability that the municipality will approve the project. The municipality must obey laws given by the central government. Since many laws are enabling acts the question weather to approve or not is to some extent a local political question. The local authorities may have several reasons for not approving an application. Generally many of the reasons may be classified as negative external effects. Here are some examples:

1. The project have for some reasons negative effects on other peoples welfare.
2. The project has a negative effect on the tourist industry or other businesses.
3. The project has harmful effects on the environment.
4. The project affect the landscape in a negative way. This may happen when it is necessary to mount long transmission cables.

Lawyers have discussed whether it is legal for the local authorities to reject a project because the profit sharing between RO and the investor is disadvantageous for RO[17]. The attitude of the local authorities will to some extent determine the size of p_2 and it will be different from municipality to municipality. Municipalities' attitude, involvement and perceived barriers to development of more hydro electric power is discussed by Saha[18].

The probability $(1 - p_3)$ is the probability that NVE will approve the project. The task of NVE is to implement the policy of the central government. Policy change by changing concerns about the environment. Media, NGOs and lobbyists try to influence politicians, policy and executive officers. Generally these organizations may, by their work, change p_2 and p_3.

The general economic situation will also play a role. A refusal from NVE has a related annual opportunity cost equal to the annual added value of the power plant if it had been built. A rich country can afford to protect rivers while a poor country may experience higher opportunity costs and are more likely to give licenses. Both p_2 and p_3 decrease with increasing opportunity costs.

From August to December 2016 NVE processed 11 applications concerning SSH. Seven of the applications were rejected[19]. The reasons for the rejections is different from one application to another. For example in one of the applications mentioned above it was because of: "*negative impacts on the landscape, the reindeer husbandry and the biological diversity.* In another application the reason was *very high level of conflict and because of the value of the landscape*[19].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 May 2017 doi:10.20944/preprints201705.0046.v1

Peer-reviewed version available at Sustainability 2017, 9, 1117; doi:10.3390/su9071117

The project may also have negative external effects as for instance negative effects on other peoples welfare or negative effects on some other businesses. We may relate this to the social profit function in equation (1). With high value on $e(x)$ the probability that $\pi_s < 0$ is large. If the negative external effects are large, and NVE or the municipality have correct information about this, p_2 or p_3 will be close to one and it is likely that the application will be rejected. A practical problem is to measure the size of negative external effects. This may be difficult both for NVE and the municipality.

The probability p_4 is the probability that the investor will not develop the power plant even if he has signed a contract with RO. After having read more than 20 contracts between a RO and an investor, we see that it is common that the investor for any reason can withdraw from the contract without any economic consequences. On the other hand we have not found any contract where RO has the same option to terminate the contract.

Since in our case there is only two possibilities, develop or not develop the plant, we may simplyfy equation 4. If q is the probability that the investor get a licence to built the plant, we will have:

$$q = q(p_1, p_1, p_3, p_4) = (1 - p_1)(1 - p_2)(1 - p_3)(1 - p_4) \Rightarrow p_5 = 1 - q \tag{5}$$

and we get:

$$L_1 = [\{q,\ \pi(c_i) - x\}\ ,\ \{(1 - q),\ 0\}] \tag{6}$$

In our case the project will stop if there are red-listed species or if the municipality or NVE do not approve or if the investor reverses his decision. We see that equation 4 can easily be extended if there are other institutions involved that has to approve the application.

3.1.2. The river owners profit from a contract with an investor

If RO has signed a contract with an investor that develops the plant, the investor and RO will share the profit. Below we will come back to common contract terms. Here we discuss it more generally. $\pi(c_i)$ is the risk adjusted net present value of the cash flow that RO gets if he has signed at contract with investor i.

Developing a power plant may have negative effects on the utility of RO. During the construction time — usually between one and three years — RO may be affected by dust, dirt, noise and the visual pollution due to a lot of mess on his property. During the operation phase which is literally for ever, there are several reasons for the loss of welfare. He may for instance miss the beauty of seeing the flow of an untouched river or he may suffer because of less fish in the river. If the project has negative effects on other peoples welfare, there may be social effects such as RO may loose friends or get a worse relationship to his neighbours. We assume RO is able to evaluate and set a price on all negative effects and we assume that the negative effects measured in money is x. If so RO's and the net present value of the risk adjusted cash flow is less than the disadvantages, we get $\pi(c_i) - x < 0$ and RO will not sign a contract.

A necessary conditions for RO to choose L_1 is that $\pi(c_i) > x$. The negative effect of the power plant on RO's own utility must be less than the risk adjusted net present value of the generated cash flow. In practice it may be information problems. It is very difficult to evaluate future negative utility effecs. Some RO have reported they ex ante believed $\pi(c_i) > x$, but ex post — when it was too late — realized that $\pi(c_i) < x$.

3.1.3. About the terms of the contracts

A usual contract term is that the contract is confidential. This have some methodological implications when writing an article about small scale hydropower where contracts are discussed.

When doing a research project financed by Sogn og Fjordane County on small scale hydro power plants many people sent us some contracts. Most of these contracts were signed but some were drafts. We received a total of about 20 contracts. In addition meetings with consultants working in this business and meetings with ROs that were in negotiations with investors gave us information

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 May 2017 doi:10.20944/preprints201705.0046.v1

Peer-reviewed version available at *Sustainability* **2017**, *9*, 1117; doi:10.3390/su9071117

about the terms of the some contracts. However, we did not have access to the whole population of contracts in the whole country and we have never been in the position that we could pick a random sample of contracts. As a consequense when we refer to contracts this is cases. We do not claim that these cases are representative. However we have a strong suspicion that the investors have read each others contracts since they seems to be to be made by the same tailor.

In Norway a RO can choose between several contract partners, normally less than ten. Normally the contracts have a duration of 30 to 60 years. Forty and sixty years contracts are quite usual. When the time specified in the contract is out, RO has the right to buy the power plant from the investor. The buy back price is different for different contracts. Here are two terms used in many contracts "*half of what it would cost to build the power plant at the acquisition date*". In another contract the buy back price was set to "*book value*". Since a power plant is depreciated linearly with 2.5 percent per year. To buy the power plant for book value after 40 years is equivalent to get it for free if there has been no reinvestments.

When it comes to the sharing of the profit between RO and the investor there are two kind of contracts: Gross contracts and net contracts. If the partners have signed a gross contract, RO will get some percent of the total revenue from the power plant while a net contract determines how the surplus should be shared between the parties

A gross contract give a more predictable payment to RO than a net contract. In the cases we have seen the percentage of the revenue that is paid to RO varies between 3 and 10 percent.

If RO have signed a net contract, the investor and RO share the surplus of the SSH. In many cases the investor can according to the contract to some extent define what is meant by surplus.

If RO have signed a contract, he has no financial risks. However, in the cases we have studied the net present value of the cash flow when signing a contract is usually between 33 and 50 percent of what it would have been if he had developed the SSH by himself.

In practice the investors offers different contracts so $\pi(c_i) \neq \pi(c_j)$ when $i \neq j$. Few RO are able to calculate $\pi(c_i)$. To choose the best contract information is needed, but there are large information problems and the information is also asymmetric between RO and the investor. When working with the project mentioned in [20], we tried to find an answer to the question: Why do any RO sign a contact at all? Here are the main reasons:

1. Some RO is very risk averse. Even if the risks related to the development of SSH are small there are risks and some people are very risk averse.
2. Some RO can not agree. As said before, a river has normally many owners. Sometimes they can not agree. All people do not trust their neighbor.
3. Lack of a leader. To develop a power plant requires a leader. Sometimes there is no leader among RO.
4. RO is not able to finance the project. This may happen when the expected investment cost divided by the expected annual production is high. If this figure is larger than 5 NOK/kWh it might we difficult to finance the project. However, this question has not been scientifically studied in Norway.

3.2. RO choose to develop the power plant himself

A RO will only choose to build a power plant if he finds it profitable. That is, the net present value of the cash flow he experience from the power plant n must be positiv. A necessary but not sufficient condition is:

$$\pi(e) = -e + \sum_{j=0}^{T} \frac{r_j - v_j - a_j - \overbrace{(t_j^1 + t_j^2 + t_j^3 + t_j^4)}^{tax}}{(1+i)^j} > 0 \tag{7}$$

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 May 2017 doi:10.20944/preprints201705.0046.v1

Peer-reviewed version available at Sustainability 2017, 9, 1117; doi:10.3390/su9071117

where

$\pi(e)$	=	the net present value of the cashflow the owner recives
e	=	the capital RO has invested in the power plant project
r_j	=	the income from sale of electricity in year j
v_j	=	all variable costs paid in year j
a_j	=	all fixed payable costs paid in year j. Depreciation is not a payable cost
t_j^1	=	tax on the profit of the power plant in year j
t_j^2	=	property tax in year j
t_j^3	=	resource rent tax in year j
t_j^4	=	natural resource tax in year j
i	=	the risk adjusted cost on equity in year j
T	=	the lifetime of the power plant, normally at least 60 years

Equation 3.2 is a necessary but not sufficient condition for the RO to go ahead with the project. A necessary and sufficient condition is:

$$\pi(e) - x > 0 \tag{8}$$

where x is the net present value of all negative effects measured in money on RO's utility. This is the same effect at we mentioned in equation 4. On may ask if x in all cases are so small that it is neglectable. A RO that had planned a possible SSH told me the following story:

> *''Yesterday my wife walked down to the river. When she came back she was crying. I asked her what was wrong and she said: I mourn because the river will disappear and we will lose this beautiful nature. In that moment the I decided to stop the project''.*

We do not know how many other projects that have been stopped because of similar reasons, but we can conclude that we must take into account the adverse effects of natural destruction and that at least one project has been stopped because of this.

3.2.1. The risks of developing a small scale hydro power plant

If the RO chooses to develop the power plant himself, he will bear all risks associated with the project. The risk is related to the following factors:

1. The expected annual production. The annual production depends on rainfall and the size of the catchment area. The catchment area can be calculated using a map available on NVE's website[21]. By using the internet application NVE-atlas and the application "Low tide", one can estimate the rainfall field and its hydrological properties. The application "Low tide" is using meteorological data from the period 1961–1990. Based on this it is possible to estimate average flow of water that will flow into the planned power plant. Even if the calculated rainfall is based on a 30 years period, there are some uncertainties. According to NVE, the discrepancy between calculated expected rainfall and observed rainfall may be up to 20 percent.

   As an example we will use two cases, both from Sunnfjord in Sogn og Fjordane County in Norway. The two cases are Nydal Kraft and Stølslia Kraft with an expected production of 7,3 GWh and 5,14 Gwh respectively. The table below shows production and the production in percent of expected production in the years 2011–2015:

Table 1. Production and production in percent of expected production in two SSH.

Name	2015	2014	2013	2012	2011
Nydal (expected 7300000 kWh)	8665758	6354643	5974126	7402959	7776902
Nydal percent of expected	119	87	82	101	107
Stølslia (expected 5140000 kWh)	6193010	4074295	3792117	5184148	5628571
Stølslia percent of expected	120	79	74	101	110

From the table we see that the production varies from 20 percent above to 26 percent below the expected annual production.

Normally the production in the winter is very small since most rivers are frozen. About 80 percent of the electricity from a SSH in Norway is produced in May, June and July. The production takes place in the months of snowmelt. To some extent the production is predictable. If there is plenty snow in the mountains, we know the production in the spring will be large.

2. The investment cost will be uncertain, but NVE has made a good tool: A very reliable publication can free of charge be downloaded the internet[22]. As stated in this publication, the large part of the costs associated with the construction of small power plants is based on standard solutions. In Norway there are also competent independent consultants that calculates the investment cost. In practice this means that development costs is largely predictable.

   When an expected annual production and investment costs are calculated, one can find the key figure investment cost divided by the expected annual production. This ratio are widely used in the power industry as an indicator of the power plant's profitability. The ratio is also used in determining the contract terms for landowners who enters into an agreement with an external investor.
3. The future price of electricity. This in turn depends on factors that affects supply and demand such as:
   (a) The electricity grid in Norway. In Norway there are five price areas for electricity. This is due to limited transmission capacity between areas.
   (b) Electricity cables to other countries. The transmission capacity between Norway and some other countries will be significantly improved when the planned cables to England and Germany are completed. The Norwegian Government has granted Statnett a license to built two new interconnections for power, one to Germany and one to the United Kingdom. Altogether, this will increase Norway's capacity for power exchange with foreign countries by almost 50 percent. Statnett plans that cable to Germany to be commissioned in 2018, while the cable to the UK is scheduled to be completed in 2020[23].
   (c) The demographic trend in both Norway and Norway's electricity trading partners will affect supply and demand and hence the price of electricity in Norway.
   (d) Changes in the industrial structure in Norway that will affect the demand of electricity.
   (e) The growth in energy production in Norway and it's electricity trading partners.
   (f) For a SSH the amount of snow in the mountains in the winter determine very much of the annual production.
4. Natural risks such as avalanches and prolonged drought.
5. Technical risks such as technical failures or sand in the turbine.
6. Financial risk. Most small power plants are initially more than 90 percent debt-financed and are vulnerable to interest rate increases[20].

As shown in the above list, many things can go wrong. This is probably also the main reason why practically all landowners who build a SSH establishes a limited company.

Despite the risks many RO choose to take the risk and develop a SSH without writing a contract with an investor. In 2012 it was given 89 small hydro power concessions in Sogn og Fjordane County. In 66 (75 percent) of these cases the RO developed the powerplant and took all the risk[20]. This indicate that the loss by signing a contract does not correspond to the risk of not doing so.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 May 2017 doi:10.20944/preprints201705.0046.v1

Peer-reviewed version available at *Sustainability* **2017**, *9*, 1117; doi:10.3390/su9071117

Sparebanken Sogn og Fjordane — a local bank — in Sogn og Fjordane County has financed more than 50 SSH characterized the risk in the small hydro industry as very small. The bank had never had any losses that could be linked to this industry. In 2011, the regular borrowing rate to small scale hydro plant developments from this bank was 4.5 percent[20]. At that time this was the same rate as the bank spent on loans for housing to families with regular income. This indicate that the bank regarded loans to SSH as low risk loans.

We will now look at the choice L_2. In this case RO choose to finance and develop the power plant himself. He will start with the cheapest survey for red-listed species. In this case we assume — as it is in practice today in Norway — that the red-listed species examination is the cheapest. In this case we may model RO's first step as a lottery (L_2) with two outcomes:

$$L_2 = [\{(1 - p'_1),\ (L_2^1 - y_1)\},\ \{p'_1,\ -y_1\}] \tag{9}$$

where

L_2^1	≥ 0	is the value of lottery L_2^1
p'_1	$\in [0,1]$	is the probability of red-listed species. RO is applicant
y_1	> 0	is the cost of the red-listed species investigation

If there are red-listed species, he has to pay the amount y_1 and the process will not go any further. If the are not red-listed species, RO can continue and make plans for his power plant. To make these plans and write the application to NVE, RO has to engage a company. The cost of the application process is y_2. The next step is modeled as L_2^1:

$$L_2^1 = [\{(1 - p'_2)(1 - p_3)(1 - p_f)\ ,\ (\pi(x) - y_2)\},\ \{p_4,\ -y_2\}] \tag{10}$$

where

p'_2	$\in [0,1]$	the probability of not accepted from the municipality. RO is applicant.
p_3	$\in [0,1]$	the probability of not accepted from NVE. RO is applicant.
p_f	$\in [0,1]$	the probability that RO can not finance the investment.
$\pi(c)$	≥ 0	the risk adjusted expected net present value of the cash flow of power plant
y_2	> 0	all planning costs

If NVE or the municipality do not approve RO has to pay y_2 and the process stops.

In equation 10 we use the probabilities p'_2 instead of p_2 as in equation 4. The reason is that it is not obvious that these probabilities are independent of the applicant. The reason is that the municipality may care about the local economy. If the power plant is developed by en external investor, most of the added value of the power plant leaks out of the local economy[24]. For that reason the local authorities may be more positive to local owners than to external investors. So it may happen that $p'_2 < p_2$.

The table below shows some total results from some SSH from the in the years 2006–2015. These are all power plants owned by RO's. Power plants owned by external investors is not included. We do not claim that these companies are representative for the whole population of SSH in Norway. However it is shown as an illustration of the economy in this business:

From the table we see that the profit on equity after tax has been high in all years from 2006. The lowest was in 2015 and 2014 when it was 10 percent. Probably this was because of low energy prices in these years.

The profitability of SSH is determined by the investment cost and these depend on the natural conditions. Some power plants will show very good profitability. The power plant Nydal Kraft mentioned above had a return on equity of 28.7 percent over the years 2006–2015. Other power

Peer-reviewed version available at *Sustainability* **2017**, *9*, 1117; doi:10.3390/su9071117

Table 2. Profit on equity, equity ration and profit after tax in some SSH in Norway.

Year →	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number of plants	97	100	119	141	148	191	113	178	138	162
Profit on equity (%)	39	24	33	30	26	37	16	11	10	10
Equity ratio (%)	15	16	12	13	14	13	19	27	23	30
Profit (mill NOK)	55	38	52	64	72	107	42	75	42	66

plants have trouble gaining profitability. Very much depends on the initial investment and the annual production.

3.3. RO choose to deferr the development the power plant or sell his rights

To build a hydro electric power plant is not a now or never project. RO may start the delopment of the plant today or he may deferr it to next year. This flexibility has a value[25] but the value is time dependent. An example: If we assume the value of the landscape (v) is a function of what is already used of it (b). We have $v = f(b)$ where $f' > 0$ and possibly also $f'' > 0$. If the development continues with more and more projects that occupy nature, the value of the landscape and hence its opportunity cost may be higher in the future. If NVE in the future has the same instructions as today, the probability for an applicant to get a denial will be higher in the future. This will — ceteris paribus — reduse the value of the deferral option (Z) and its certainty equivalent in equation 3.

In some cases, RO's don't want to develop the power plants now. There may be many reasons for that: He may expect the investment costs to go down in the future or may expect that investors will offer better conditions in the future. In any case by choosing not to develop the power plant now, he is holding an option that has a certain value. The value of this option and its certainty equivalent depends of RO's information and expectations about the future. This is discussed in [4].

Sales are always a possibility, but it just means that the new owner enters into the same situation as the former where the relevant choices are L_1, L_2 or Z.

3.4. Conclusion

The development of small scale hydroelectric power plants in Norway is determined by natural conditions, policies, attitudes and property relations. Natural conditions, NVE, municipalities, financial institutions and river owners will together determine how many new power plants being built.

The owner of the river is the central decision maker when it comes to development of small scale hydroelectric power plants. It is he who decides whether he will try to build the power plant himself, whether he will leave this to an external investor or whether he will sell the fall rights or postpone the decisions. All available choices will involve risk. In order for him to make the best choice he must find the certainty equivalent to each of the choices and choose the one with the highest certainty equivalent.

Even if the owner of the river has made his choice, the power plant may not be built. Both central and local authorities must approve the plans.

Abbreviations

The following abbreviations are used in this manuscript:

SSH Small scale hydroelectric power plant.
RO The owner /owners of the river.
NVE The Norwegian Water Resources and Energy Directorate.

References

1. rsund, F.R.F. *Hydropower Economics*; Springer, 2007.

2. eng og Magne Holstad (ed.), A.C.B. Fakta om energi. Utviklingen i energibruk i Norge. Technical report, Statistics Norway, 2011.
3. https://www.nve.no/energiforsyning-og-konsesjon/vannkraft/vannkraftpotensialet/. 2017-02-27.
4. Linnerud, K.; Simonsen, M. Swedish-Norwegian tradable green certificates: Scheme design flaws and perceived investment barriers. *Energy Policy* **2017**, pp. 560–578.
5. (red.), T.J. Beregning av potensial for småkraftverk i Norge. Technical Report 19, NVE, 2004.
6. https://www.nve.no/licensing/ 2017-02-27.
7. R. Kerry Turner, David W. Pearce, I.B. *Environmental Economics: An Elementary Introduction.*; Harvester Wheatsheaf, 1993.
8. y og Olav Strand, P.J. Villreinen i Fjellheimen. Technical Report 411, Norsk institutt for naturforskning, 2009.
9. Zvonimir Glasnovic, J.M. Sustainable Electric Power System: Is It Possible? *Journal of Energy Engineering* **2010**.
10. VarunPrakash, Ravi Bhat, I.K. Energy, economics and environmental impacts of renewable energy systems. *Renewable and Sustainable Energy Reviews* **2009**, *Vol. 13 Issue 9*, 2716–2721.
11. Bell, S.; Morse, S. *Measuring Sustainability: Learning From Doing*; Earthscan, 2003.
12. Gibson, B.; Hassan, S. *Sustainability Assessment: Criteria and Processes*; Earthscan, 2005.
13. Mckenna, C.J. *The Economics of Uncertainty*; Wheatsheaf Books, 1986. Relevant pages: 21-28.
14. Neumann, J.v.; Morgenstern, O. *Theory of Games and Economic Behavior*; Princeton University Press, 1953.
15. NVE. https://www.nve.no/konsesjonssaker/, 2017.
16. Gaarder, G.; rn Hø itomt, T. Etterundersøkelser av flora og naturtyper i elver med planlagt. Technical Report 102, NVE, 2015.
17. Digernes, D. Vilkår for konsesjon til erverv av fallrettar etter jordlova. Høgskulen i Sogn og Fjordane.
18. Saha, P.; Idsø, J. New hydro power development in Norway: Municipalities' attitude, involvement and perceived barriers. *Renewable and Sustainable Energy Reviews* **2016**, *61*, 235–244.
19. http://energiteknikk.net/2016/10/over-60-prosent-avslag-pa-smakraftsoknader. 2017.03.06.
20. Idsø, J. Småkraft og regionaløkonomisk vekst. Technical Report 1/12, Høgskulen i Sogn og Fjordane, 2012.
21. NVE. https://gis3.nve.no/link/?link=nedborfelt, 2017.
22. Kostnadsgrunnlag for små vannkraftanlegg. Technical Report 1, NVE, 2010.
23. Sttem, J.B. Nye kabler til utlandet gir dyrere strøm. https://www.nrk.no/norge/, 2014.
24. Armstrong, H.; Taylor, J. *Regional Economics and Policy*; Blackwell Publishing, 2007.
25. Thomas E. Copeland, V.A. *Real Options: A Practitioner's Guide*; Texere, 2003.