FEASIBILITY STUDY OF REHABILITATION SMALL HYDRO POWER PLANTS: CASE OF NORDIC COUNTRIES

Lappeenranta–Lahti University of Technology LUT

Master's thesis

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Examiner(s): Professor Leonid Chechurin,

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ABSTRACT

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Feasibility study of rehabilitation Small Hydro Power Plants: case of Nordic countries

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The master's thesis provides an assessment of the role, significance of management in the rehabilitation of SHPP (Small hydroelectric power plants). The guarantee of appropriate management in conformance with regional and particular conditions can ensure greater efficiencies with less time to return on initial invested funds. The paper, consisting of four parts, is intended to emphasize the relevance of effective management for long-term sustainability of SHPP from side of local community, investors, social congregations and municipal government. First is literature research on hydropower sustainability. Next analysis of current condition of hydroelectric power plants is presented. A briefly presentation of the numerical statistics of energetic infrastructure such as SHP of Nordic countries and policy regulating them in the current economic context are reviewed. An effort has been made to develop a recommendation for feasibility study of rehabilitation project of the Askola small hydropower plant in Finland, including best decision for the planning step by step rehabilitation, respecting all the requirements and using modern technologies suitable for energy management. To justify the validity of the SHPP rehabilitation project, the feasibility study of small hydropower plant was determined based on parameters of rehabilitation project of "Askola" SHPP located in Finland. Some of the obtained results of developed feasibility study may be used reasonably for managerial and investment decision-making process at the planning stage for a specific area for development of such projects as rehabilitation of small hydropower plants. The article closes with certain findings and references.

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LIST OF ABBREVIATIONS

CEM	Clean Energy Ministerial
HPP	Hydropower Plant
ICSHP	International Center on Small Hydro Power
IHA	International Hydropower Association
IoT	Internet of Things
LCC	Life cycle cost
O&M	Operation and maintenance
SCADA	Supervisory Control And Data Acquisition
SDG	Sustainable development goals
SHPP	Small Hydropower Plant
UNIDO	United Nations Industrial Development Organization
WSHPDR	World Small Hydropower Development Report

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1. INTRODUCTION

1. 1. Background

Starting from the beginning of this century, the process of forming a new technological platform for the development of global energy has been observed in the world, which is associated with the need to solve several of economic, demographic, climatic and technological problems. One of the most important areas of this process, about which this study will be conducted, renewable energy sources (RES).

The modern definition of renewable energy is energy that uses inexhaustible energy sources. The key principle of using renewable energy is to extract it from processes constantly occurring in the environment and provide it for technical use. Renewable energy is produced from resources that are replenished naturally, such as geothermal heat, solar energy, wind, waves, and rain.

The main types of renewable energy today include hydropower, wind energy, solar energy, wave and geothermal energy.

Humanity began to use renewable energy sources earlier than it learned to extract coal, oil and gas. However, with the rising use of energy due to the industrialization of society, the burning of fossil fuels came to the aid in ensuring a stable supply of energy.

Now humanity is thinking again about the use of renewable energy sources due to the transition to zenith energy and the Sustainable Development Goals.

The previous scale of the use of renewable energy sources is no longer relevant. Sustainable energy generation and its management issues are urgent all over the world.

The most common way of extracting energy from an inexhaustible source nowadays is hydropower. The theoretical potential of the global wind power industry is estimated at approximately 52 PWh/year divided over 11.8 million locations, what is equal to 33% of the annually required energy (Olivier A., 2017).

Hydropower is an area of human economic activity, a set of large natural and artificial subsystems that serve to convert the energy of a water stream into electrical energy. A clear advantage is the cost, stability of energy production and the ability to control it by changing the speed of water flow. Among the disadvantages are a sharp change in the water level in artificial reservoirs, a violation of the spawning cycle of fish and a decrease in the amount of oxygen in the water, which harms the flora and fauna of the reservoir.

However, compared to larger hydropower plants, the construction of small hydropower plants has a limited impact on the environment, particularly when dams are not constructed.

Small hydropower plants generate relatively small amount of energy. A universal concept of capacity interval for small hydropower plant does not exist, their installed capacity is accepted as the main characteristic of such HPPs. According to the definition of the European Association of Small Hydroelectric Power Plants, a small hydropower plant is the hydropower plant that generates up to 10 megawatts.

From the development of a network of small hydroelectric power plants, the positive aspects in comparison with large hydroelectric power plants are not diminished, and the negative impact on nature decreases or disappears.

The sphere of management of small hydropower has its own features. The deceleration in recent decades of scientific and technological progress in the field of creating new power equipment has led worldwide to the prolongation of the terms of technological aging of working equipment. In

addition to this global trend, the economic problems of energy investment have also been superimposed. As a result, the regulatory terms of operation of power equipment are violated everywhere, renovation processes are slowed down, as a result, increased aging of equipment. In these conditions, in fact, the only way out of this situation is to improve the management of small hydropower plant.

The history of hydropower management dates back to the 3rd-4th century BC, it was then that the first dams, reservoirs and water wheels appeared. The first installation with a hydraulic turbine was created in 1827 by the French engineer B. Fourneyron (turbine - History of water turbine technology - Britannica, 2012).

The management of hydropower on a large scale in each country began at different times, depending on changes in socio-economic conditions and technical revolutions.

In order to optimize lifecycle efficiency, increase return on investment and achieve life cycle cost predictability, management should always include all process related to the energy generation from small hydropower. Right developed management strategy gives measurable and guaranteed benefits, such as availability and performance, productivity gains and cost benefits.

Abubakar Tadda and his team states in his research that a sustainable strategy for managing of a hydroelectric power plant begins to form even before the design of structures and continues to be adjusted and optimized during the service life (Abubakar Tadda *et al.*, 2020b). The management strategy cannot be developed once and for all, as it requires ensuring the safety of life and property without a negative contribution to the environment and enriching the national economy. That is why the development of a strategy for the management of small hydroelectric power plants should be given enough attention and funding so as not to lead to the loss of lives, property, economy and the environment

1. 2. Research problem, focus, and objectives

At the beginning of the 20th decade of the 21st century, 80% of energy is still obtained by burning minerals, that is, coal, oil, and natural gas (Fossil Fuels | EESI, 2021).

At the same time, there is a tendency to tighten environmental regulations in the field of renewable energy generation (Hille et al., 2020).

Among Renewable energy sources, technologies such as solar and wind energy are increasingly developing (*Renewable Energy Definition and Types of Renewable Energy Sources | NRDC*, no date).

Due to climate change, the old foundations and weather conditions are changing. The sun, water and wind are changing the usual influences, which makes it necessary to adapt the extraction of energy using renewable sources to new conditions (*What is Climate Change ? | Climate Change Knowledge Portal*, no date; *1. What is climate change? | Australian Academy of Science*, no date; Vardoulakis *et al.*, 2015).

The management of small hydroelectric power plants remains insufficiently studied with respect to its economic, social and environmental aspects, which is confirmed by the lack of conceptual theoretical and empirical studies using quantitative methods in this area.

In this work, it will be considered if it is justified in these conditions to increase the capacity of hydroelectric power plants through the rehabilitation of old small hydroelectric power plants.

Considering the research question the whole study is limited to the narrow research focus shown in Figure 1.2.1, feasibility study of rehabilitation small hydropower plants of Nordic countries. This focus arises from taking research object ‘justification of small hydropower plant

rehabilitation for investing perspective in Nordic countries. The object by itself lies on the intersection of such areas as small hydropower plant, Nordic countries and rehabilitation management.

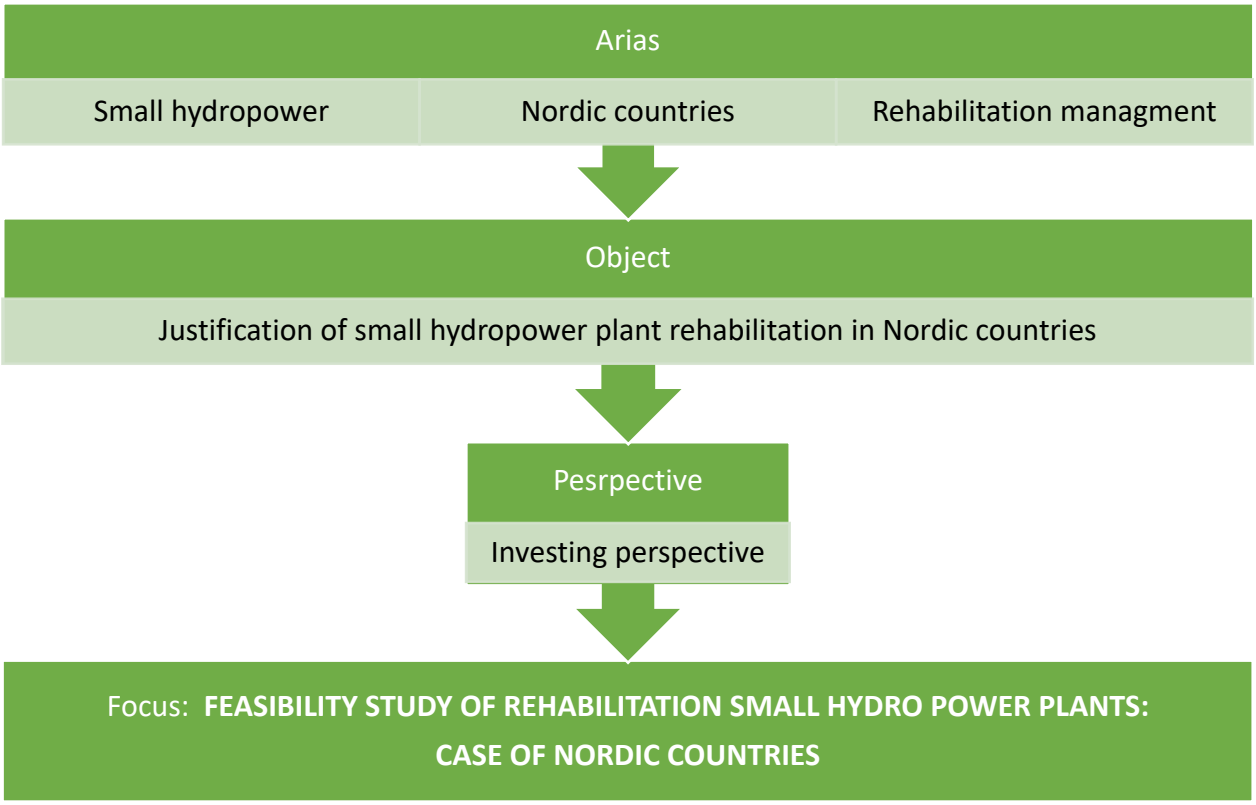


Figure 1.2.1. Research focus.

With the help of this research, a theoretical contribution will be made to the literature in the field of small hydropower energy generation. This research addresses the critical problem of understanding the input of small hydropower to sustainable energy generation (table 1).

Table 1. Research question and sub-questions

Is the rehabilitation of the old small hydroelectric power plant in the Nordic region justified?	What is the peculiarity of small hydroelectric power plants?
	What is the place of a small hydroelectric power station among other types of energy production?
	What means of support and regulation of small hydroelectric power plants exist?
	How to determine whether rehabilitation will be justified for each specific case?

The specific objectives of this paper are:

- To clarify importance of small hydropower plant;
- To study regulations and ecological restrictions for small hydropower plant;
- To suggest an algorithm for determining the need for rehabilitation of a small hydroelectric power plant or its irrelevance;
- To identify rehabilitation management applicable a small hydropower plant;
- To justify rehabilitation of “Askola” small hydropower plant.

1. 3. Methodology

The final qualifying work included the following research methods: theoretical (classification, synthesis, analysis) empirical (survey, interview), analysis of the results obtained by statistical processing, generalization.

The main method of collecting the source of factual material and relevant information for the study of a small hydroelectric power plant at this stage were planning and reporting documents, audit materials, business plans and other materials. And also during the research work, materials were collected for conducting research within the framework of the dissertation topic, namely, the necessary extracts from the official documentation of the organization, current instructions, guidelines, regulatory documents, resolutions regulating the operation of the Askola small hydroelectric power plant. The collected material has been verified in terms of its reliability and effectiveness for the preparation of the final qualifying work.

Analysis of the current situation of small hydropower plants in the world and in Nordic countries is a method of analyzing documents, that is, a specially created object for storing and transmitting information. The method is widely used to study data from both individual manufacturing industries and society.

Survey

A survey was conducted among the owners/managers of small hydroelectric power plants in order to identify current condition of small hydropower industry.

Electronic surveys were chosen due to they usually are a less personalized form of data collection method than interviews, and based on same research protocol as questionnaire surveys. Advantage of this type of surveys is that they are not time consuming and not resource-intensive. Also, advantages of surveys that they are suitable for accessing a large number of participants and asking standardized questions (Israel, 2007).

The residential area for the interview was selected together with the Finnish startup company Finnrunner that provides maintenance services for small hydroelectric power plants during an internship. The preliminary meeting was carried out in January 2022, when the main discussion topics were the target of the research and the research plan. After accepting the topic of the interview, the cooperation agreement and the non-disclosure agreement were signed in January 2022.

The cooperation of Business Finland with the startup company Finnrunner allowed using the database of owners of small hydroelectric power plants in Norway and Sweden as source data. The database contains information related to small hydroelectric power plant facilities up to 10 MW, such as the names of owners and names of small hydroelectric power plants, addresses and some data about the hydraulic installation: year of installation, date of last renovation, classification and location. The names of the property owners were included in the data provided, but there were no postal e-mail addresses and phone numbers. An Internet search was used as a

method of identifying the contact information of owners of small hydroelectric power plants for conducting interviews. Since the survey were conducted online using Google Forms and the invitation to participate in the survey was sent by e-mail, the task was to find out the e-mail addresses of the owners of small hydroelectric power plants and their phone numbers.

The data collection using survey followed the qualitative research methodology (Bell & Bryman, 2007).

This study is classified as a qualitative study in which the survey group was selected appropriately. Sampling of research is probability sampling - simple random.

The most potential target group for interviews is in the Nordic countries where there are developed networks of producers of energy from hydropower. Practically, this means that many small hydroelectric power plants were built in remote mountainous areas where there was a need for electricity for the population. The regions of the Nordic countries, especially countries such as Norway and Sweden, were the most interesting for the survey, because it is there, based on the analysis of the current state of small hydroelectric power plants analyzed in the last chapter, a large number of installed capacities from the total hydro potential are used. The return of small hydroelectric power plants in these countries is very diverse, which makes it possible to consider the current conditions of small hydroelectric power plants.

Research provided by comminating with Norwegian and Sweden small hydropower industry manufacturers based on electronic questionary of analytical department managers. Survey was provided by using Google Forms, 84 random Norwegian and Sweden small hydropower industry manufacturers were emailed with invitation to participate in survey. Only 31 from the list of 84 companies get involved to interaction and participated in phone interview. As a result, the coverage of the surveyed companies is 37%. In this thesis, all data contact details of the interviewees were handled anonymously and with confidentiality.

All small hydropower facilities from the provided database, whose contact information was found, were included in the survey, since it was impossible to predict how many of them would want to participate in the survey. At the beginning of the survey, it was confirmed that the interviewee is engaged in the management of a small hydroelectric power plant.

The questionnaire was prepared jointly with Finnrunner. The survey included a total of 24 questions related to the management of the operation of a small hydroelectric power plant. The questions were from different aspects of ecology, economics and social aspects of the functioning of a small hydroelectric power plant.

The initial questionnaire survey was written in English is attached as Appendix 1.

The quantitative data from the questionnaire was analyzed by Excel sheets using circular diagrams.

Interview

To collect information about the management strategy of the Askola small hydroelectric power plant, an interview was conducted with the owner of Askola. An interview was conducted with the owner of small hydroelectric power plants Askola in order to identify current condition of small hydropower for developing recommendations further rehabilitation project. The data collection using interview followed the qualitative research methodology (Bell & Bryman, 2007).

In the study, an unstructured direct interview was chosen, where a formal questionnaire is used before the final interviews, an introductory phase is held, during which unstructured interviews are contacted and conducted with respondents. These interviews are useful for gaining a clearer understanding of the problem and determining which areas should be explored. In the unstructured direct interviewing method, the interviewer has general instructions regarding the desired type of information and asks

the necessary direct questions to obtain this information, using the protection and order that seems most appropriate in the context of this interview.

An interview with the owner of the small hydroelectric power station was scheduled for February 12 in the business center of Lappeenranta. The main issues were the basics of Askola management, the desire to improve the existing strategy for managing the operation of the station.

Next section concludes the Introduction with an overview of the whole study structure.

1. 4. Study structure

The whole thesis is divided into six consequent parts, namely “Introduction”, “Literature review”, “Analysis of hydropower plant current condition”, “Recommendations for developing feasibility study of rehabilitation of the Askola small hydropower plant”, “Results”, and “Discussion and Conclusion”. They are illustrated in Figure 1.4.1 enriching analytical part that consists of “Analysing…” and “Recomandations…” with details.

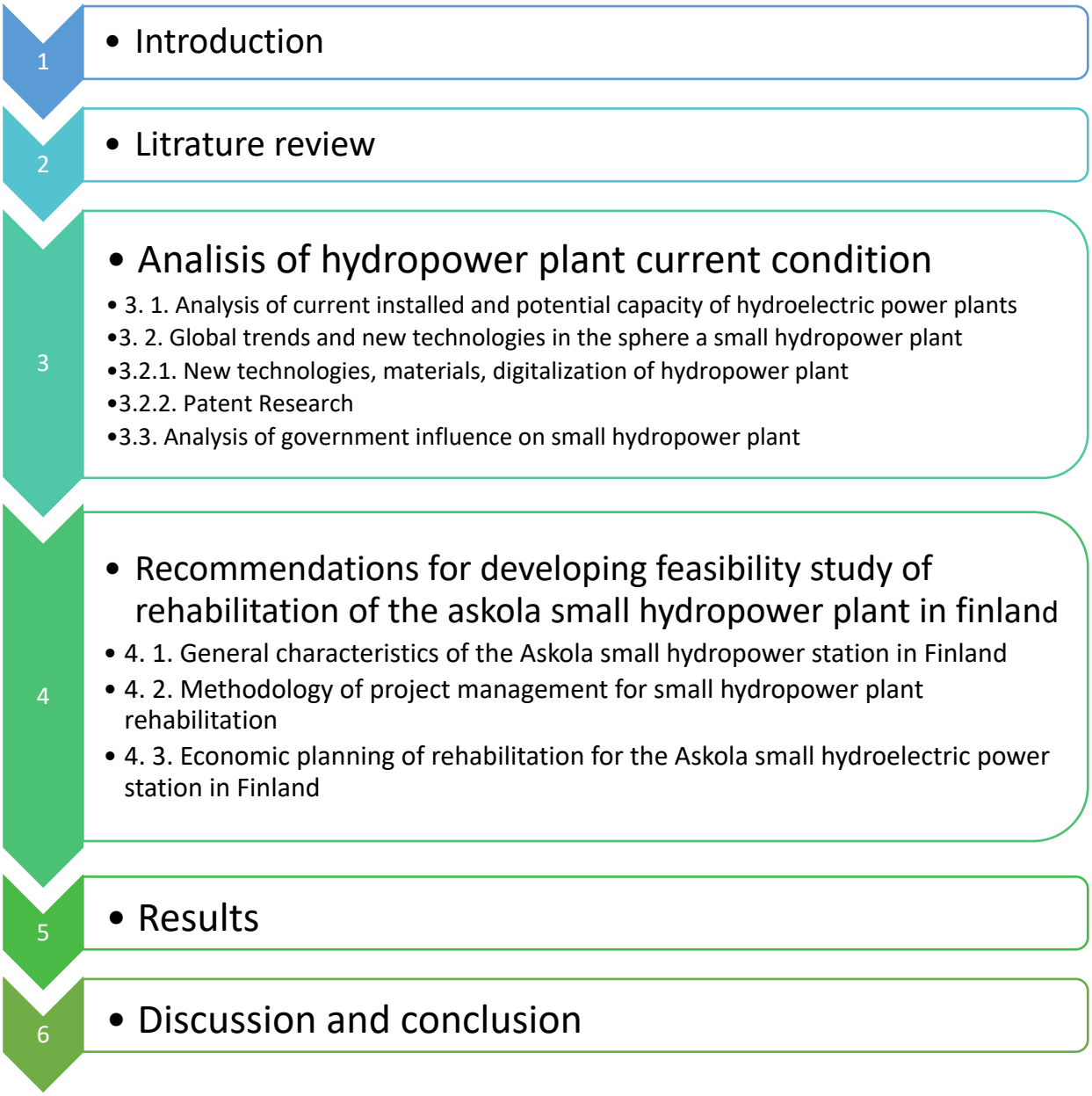


Figure 1.4.1. Study structure.

2. LITERATURE REVIEW

2.1. Hydropower generation energy research

Management of small hydropower plant in the scientific literature are reviewed from different overview focuses.

The following scientific works are devoted to the economic, social and environmental effects of renewable energy development by: D. Cook, R. Ferroukhi, R. Haas, M. Haller, D. Gielen, M. Islam, A. Khalid, G. Kiefer, T. Low, S. Mekhikev, D. Nagpal, G. Schellekens, H. Reinisch, M. Taylor, M. Willembacher, etc.

A review on hydropower plant in science literature were condacted by N. Kishor, J. Goldberg, J. Paidipati, K.M. Kibler, D.D. Tullos, D. Kumar, H. Sachdev, Thiago BA Cuoto, B. Pavlakovič, etc.

Literature in the field of maintenance and rehabilitation management was overviewed by R. Dekker and P. Scarf, L. Pintelon and F. Puyvelde, A. Tsang, H. Wang, A. Garg and S. Deshmukh, L. Pinciroli, Anup C., Liszka D, etc.

Sustainability of operation and maintenance management practices for hydropower plant was studied by P. Singh, C. Rothballer, J. Barr, V. Kumar, K. Kumar, D. Kumar, D. Retno, R. Bhandari, etc.

To analyze the main research in the field of operation and maintenance management for small hydropower plant, scientific articles published in censored journals in the period from 2000 to 2022 from the international data source as Web of Science, Scopus, and others were selected. The articles were searched by the keywords: small hydropower plant, management, rehabilitation, feasibility study, sustainability. For the purposes of the study, works related to the field of rehabilitation management and small hydro power plant were selected, in which justification of rehabilitation is the primary topic of the study or one part of the studied phenomena. 32 articles were included in the final list for further analysis.

As noted, the purpose of this article is to provide an overview past of literature on management for small hydropower plant, to determine the relationship between conducting feasibility study of rehabilitation project for long-term sustainability investing on small hydropower plant. In this we rely on the concept of the development of scientific theories in management (Edmondson and Mcmanus, 2007), which was developed by A. S. Emondson and S. E. McManus.

Literature review

Systematic literature review which was provided by us was to address the questions:

- What is the peculiarity of small hydroelectric power plants?
- What are advantages and disadvantages of a small hydroelectric power plant of energy production?
- What does mean to be sustainable for small hydroelectric power plant?

Considering specific research questions, the objectives of our systematic literature review are as follows:

- Comprehension of what is already known in the field of ongoing research about:

a) about small hydropower industry;

b) about management in hydropower industry;

c) about importance of sustainability approach;

d) about small hydropower plant sustainability;

e) about reinforcing linkages between management and sustainability.

- Collection, comparing and generalizing the outcomes of past studies in order to evaluate the current state of the publications in the area of studies;

- Detection of problem points and gaps in the current literature;

- Design of research trends for continued study within the scope of our ongoing release;

- Focusing and specifying our research problem;

Methodology of our systematic review of the publications was mainly influenced by the approach used in 2007 by S.L. Newbert for his study in the area of the resource approach to the company. In order to escape working with a large amount of very varied and mainly irrelevant literature, we consider the most suitable step-by-step process of systematic search for Newbert literature. After adjusting the approach for the purposes of our current research, the literature research includes the following rules and steps:

1. Finding published journal articles.

2. Operate with four databases: Elsevier, Springerlink, Scopus, LUT Primo in order to get as many relevant results as possible.

3. Search for articles and paper which have been published in 2000 – 2022.

4. Searching for appropriate keyword research using two approaches (which depends on the type of a certain database).): 1) look for any keyword in the headline or abstract of articles, 2) search for the full phrases in the headline, abstract and entire text of articles.

5. Search for the papers about the relationships between conducting operation and maintenance management of small hydropower plant and small hydropower plant sustainability is searched by the following keywords and full phrases:

a. Focusing on the issues which study management by keywords: “management”, “managing”;

b. Eliminating the studies in small hydropower plant management by keyword “small hydropower plant”, “small hydroelectric power plant”, “SHPP”, “Small HPP”, “small hydropower”, “SHP”, “hydropower plant”, “hydroelectric power plant”, “HPP”;

c. Focusing on the issues which consider management relationship to sustainability of small hydropower plant by one of the keywords: “sustainability”, “sustainable”, “sustainable development”, “ecology*”, “economy*”, “society*”;

d. Eliminating irrelevant articles by including one of the “management” keywords: “energy generation”, “feasibility study”, “practice”, “strategy”, “theory”;

e. Eliminating the studies in renewable energy production by including one of the keywords: “energy generation”, “renewable energy production”, “hydro”, “clean-energy”, “renewable energy*”, “renewable resources”, “renewable energy sources”;

f. Ensuring empirical content by one of the “methodological” keywords: “data”, “empirical”, “test”, “statistical”, “finding”, “result”, “evidence”.

6. Ensure theoretical and empirical relevance by reading all remaining abstracts.

While of critical literature review we rely on the concept of Wallace and Wray who suggested the use of review questions. These are specific questions reader asks through the reading, which will be linked either directly or indirectly to the research question (Wallace and Wray, 2011). While reading the articles we emphasized how with the help of the author's reasoning we can answer the question: ‘What managers of small hydropower plant are taking in consideration when they are

developing operation and maintenance management strategy in order to make energy generation more sustainable in modern conditions?'

7. Eliminate duplicate articles through databases.

8. Ensure theoretical and empirical relevance by reading all remaining papers.

Table 2 demonstrates the number of articles returned from the methodology used at each step from 5.a. through 8.

Table 2. Number of research papers returned from the systematic literature review methodology

Database	**Step 5a**	**Step 5b**	**Step 5c**	**Step 5 d-f**	**Step 6**	**Step 7**	**Step 8. Final**
Elsevier	management	hydropower	sustainability				
	11216	11249	12056		12	12	1
	management	small hydropower plant	sustainability				
	11216	52258	18148		13	15	7
		small hydropower plant	sustainable	Management			
		8471	9797	18297	7	7	4
Scopus	management	small hydropower plant	sustainability				
	4738351	478	196		7	7	1
	management	hydropower	sustainable	advantage			
	4738351	20328	9363	655	5	5	2
		small hydropower plant	renewable energy	advantage			
		2604	1251	103	13	10	3
Springerlink	management	small hydropower plant	sustainability				
	3455300	472	253		10	9	4
		small hydropower plant	renewable energy	advantage			
		18230	407	242	6	5	2
	management	small hydropower plant	sustainability				
	6301	18230	3547		5	3	2

LUT Primo		small hydropower	sustainability	stratagy			
		3650	1272	787	9	6	3
	management	hydropower	sustainability	Feasibility study			
	14262207	53059	17170	1031	16	3	1
Total:					**109**	**86**	**32**

Comments on the literature research results:

Total result of the search for relevant papers by the keywords and full phrases within search systems of four databases gave 109 papers. After elimination of 4 duplicates at step 7 and another 10 papers, which were found not relevant by reading their full texts at steps 8, final number of relevant papers of the systematic literature search became 32. While Springerlink and Elsevier databases were found to be the most convenient sources of research papers providing 8 and 12 relevant papers correspondingly.

As it could be seen from Table 2, sometimes flexible approach (marked as "flex.") was employed in order to find more number of relevant articles and that considers exclusion of step 5.b., which provides search by one of the full phrases like: "operation and maintenance management" and "small hydropower". As this kind of search by full phrases is pretty strict, in the cases when the search within some particular database found papers of high quality but little number of them. I evaluated that database as highly important and, thus, considered opportunity for extended search by excluding 5.b. step from the literature review process. The flexible search justified itself.

Dropping out steps 5.b., 5.c. during several search processes is explained by limited options of search systems.

2.2. Advantages and disadvantages of hydroelectric power plants, in particular small hydroelectric power plants

Even with all the attractiveness inherent of small hydropower (SHP), less than half of the global potential of small hydropower is used, namely 44% is analyzed in this sub-chapter (World Small Hydropower Development Report | UNIDO, 2020).

The delegates of the World Hydropower Congress 2019 in Paris agreed that the real value of hydropower has not yet been fully recognized for everyone in the world ("Hydropower Status Report Sector trends and insights," IHA 2021).

Next, the advantages and disadvantages of energy extraction from small hydropower plant will be considered related to the management of small hydropower.

Green energy source

The extent of the contribution that hydroelectric power plants make in avoiding the formation of additional greenhouse gases and pollution is demonstrated further. If we imagine a situation where for a year the amount of electricity that usually is produced by hydroelectric power plants would be produced by burning coal, up to 4,000,000,000 tons of additional greenhouse gases would be emitted worldwide. And also in this situation, global emissions from the processing of fossil fuels amounted to 10% more. ("Hydropower Status Report Sector trends and insights," IHA 2021)

Access to electricity

Another advantage of small hydroelectric power plants is the increased access to electricity in those rural areas that have not yet been electrified, and this is 3% of the world (Ritchie, 2020).

Self- sufficiency

To those countries whose electricity security depends on imports, the quality of relations between countries, other risks, the networks of hydroelectric power plants and small hydroelectric power plants, including in the country, can lead to an increase in self-sufficiency if natural conditions allow. For example, the energy-intensive basic industries of Finland, its climate with cold winters puts energy in priority areas to achieve quality of life for Finnish residents and competitiveness in the market. Finland depends on imported fuel, the country's energy policy is based on diversified and reliable energy supplies and increased self-sufficiency. So until the 1960s, energy in Finland was produced by hydroelectric power plants and wood burning (Finnland Työ- ja elinkeinoministeriö, 2019).

Renewable and sustainable

The positive aspects of hydroelectric power plants can be considered regarding the Sustainable Development Goals adopted by all countries in order to preserve the planet for future generations. In addition to climate change mitigation (SDG13) and the creation of clean energy for the environment (SDG 7), hydropower also provides freshwater management (SDG 6), infrastructure development (SDG 9).

Education and cooperation

To be self-sufficient and at the same time to unite and cooperate is a great base for the energy sector, including. The example of Finnish cooperation illustrates the interconnectedness of the active and open position of the country and its energy industry. Finland has been cooperating at the Clean Energy Ministerial (CEM) level since the first meeting in 2010, the participants of this meeting are countries representing about 80% of global energy consumption. Clean Energy Ministerial meetings are held to support initiatives in hydropower, wind energy, solar energy and LED, smart electricity network, energy efficiency, electric vehicles, Clean Energy Solutions Centre, bioenergy, energy and women, sustainable development. Finland participates in initiatives on "Women in Energy", partnership "Up to 30 years", energy partnership of the 21st century, initiatives related to smart grids and electric vehicles, as well as campaigns for more flexible use of power plants and electric transport between cities.

Dependable source of energy

Hydropower as an energy source is more reliable than other renewable energy sources. This is because hydropower is based on water; an endless resource and converts its kinetic energy into electricity and water can be stored in dams. Hydropower plants are situated next to the energy source; water, so it has constant access to it, making it a clean, stable, and reliable source of energy production. Unlike power plants that require fossil fuels, in which the fuel must be first mined and then transported to the power plant.

This is good for organizing management because after the construction of a high-quality feasibility study, there are very few uncertainties left, and all changes in natural conditions will not change their nature and can be predicted

Hydropower as flexible energy

Hydroelectric power plant is a very flexible source of energy. The power plant is attached to the power grid and therefore can provide supplement for an increase in demand of energy. The controlling

of energy output is done by opening or closing water gates in the dam, which control the amount of water that flows through the turbines.

If for any reason the amount of stored water in the dams starts to decrease, the flow of water can be decreased to preserve or increase the water level in the dam. If the water level starts to significantly rise, the gates can simply be opened.

Low cost per energy unit

Significant number of countries use small hydropower as a low-cost power source as these can be constructed anywhere if the few requirements are met. The most expensive part of investment for hydropower plant is related to primary step of constructing, which is expensive to build but a correctly constructed dam lasts a very long time and will keep the overall costs of operating the power plant to a minimal. All other components required to build the power plant are relatively cheap. Once the power plant is in operation, the cost per energy unit is low.

In comparison with other environmentally friendly energy sources, such as wind energy, hydropower takes the first place as the least expensive, and the hydroelectric power plant is characterized by a significantly low cost of producing a unit of electricity compared to the cost of electricity produced at thermal power plants and nuclear power plants.

Also, to the surprise of connoisseurs of energy extraction by burning reschuss, in accordance with recent studies, it turned out that the cost of electricity production by such renewable sources as onshore wind farms, biomass-based, geothermal and hydroelectric power plants is lower or equal to the cost of electricity production by burning coal, gas and diesel power plants, even if the price of oil will fall and if not take into account the financial support of renewable energy sources from the state (Strielkowski, 2020). The cost of electricity cut down by a small HPP can be controlled and calculated with the help of proper management.

Industry infrastructure creation

Hydropower plants can be a good way to create working places to areas with low employment rate and improve the living conditions in the community. This would in turn stimulate the economic growth in the area, as the employees would provide customers to local commerce. With economic growth comes more stability.

The construction of networks of small hydroelectric power plants can serve as a way to enrich the region not only through its electricity generation, but also become a tourist attraction. When making decisions in favor of investing in projects such as small hydroelectric power plants, it should be taken into account that new energy-consuming opportunities are emerging in the region, for example, factories, which in turn will enrich the region.

Designers, owners and operators of hydroelectric power plants - all of them must show a steadfast dedication to the safeguarding of health and protection of security in the workplace, which is ensured by the manager.

Adaptation to climate change

Due to climate change, an increase in the average outdoor temperature and precipitation is expected, which in turn will lead to an increase in the potential for hydropower production. Prognoses assume an increase in hydroelectric energy generation by 5 per cent over 40 years due to an increase in sediments. One of the disadvantages of increased precipitation in summer is that it can make peat extraction more difficult. Finland has taken climate change adaptation into account when developing its energy modeling related to the preparation of energy policy (Finnland Työ- ja elinkeinoministeriö, 2019).

Additional activities

Artificial lakes can be used for additional activities such as flood prevention, irrigation of land, serve as bridges and others. Experts came to the conclusion that in addition to the electricity produced by a small hydroelectric power station, the design, in the presence of reservoirs, can additionally provide itself and carry out a number of auxiliary services.

Also, waterlogging significantly affects existing biodiversity, which has important consequences for people's lives and livelihoods.

Further, they will be introduced to the disadvantages of small hydropower, which also has many important points that cannot be ignored when managing small hydroelectric power plants.

Nature hydro limitations

Frosty winters and dry seasons are the main obstacles to the constant production of electricity by small hydroelectric power plants. Continuing on the example of Finland, its energy consumption has been growing since 1960, hydro resources remained limited, the issue of new energy sources was considered as a priority, the exploitation of coal and oil began to increase rapidly. Figure 2.3.1 shows the current distribution of the different energy sources which Finland now have. Figure 2.3.2 shows the primary energy supply by energy sources in the World Energy Model forecast until 2040. (Finland Työ-ja elinkeinoministeriö, 2019)

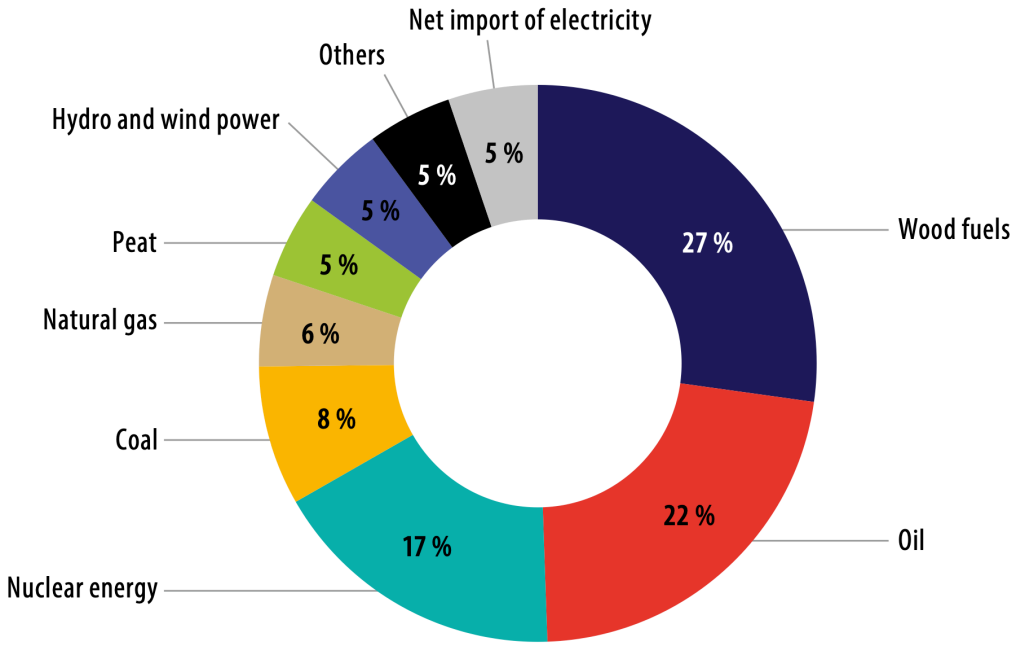


Figure 2.3.1 Finland distribution of the different energy sources in the total energy supply in 2018. Source: Statistics Finland

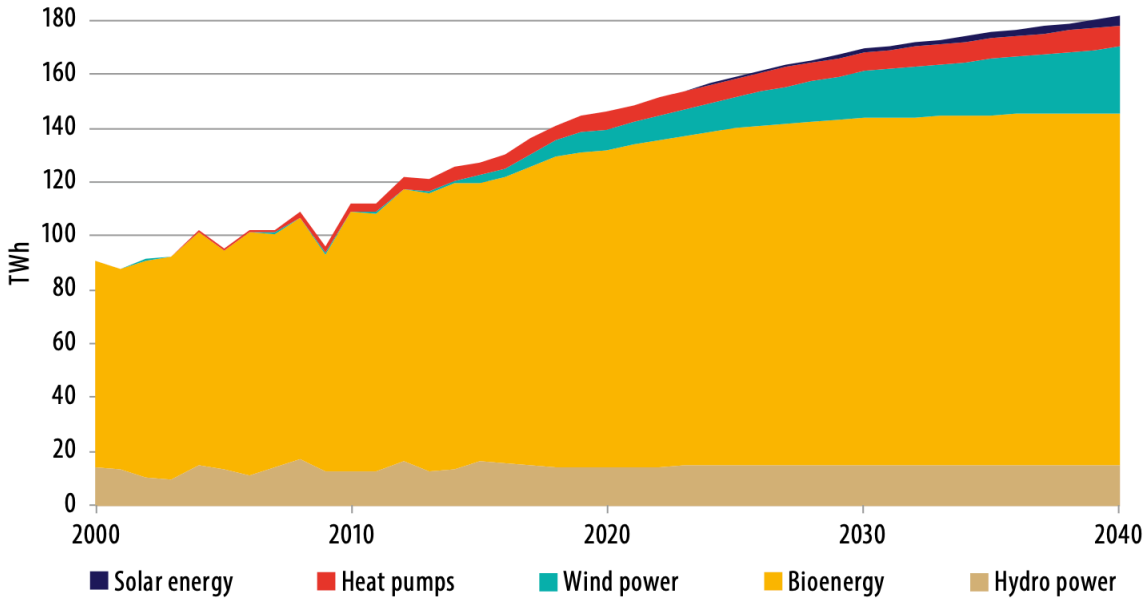


Figure 2.3.2. Historical development of renewable energy between 2000 and 2017 and the projected development based on current policies until 2030 and an outlook until 2040. Sourse: Finnland Työ- ja elinkeinoministeriö, 2019

Influence to environment

Due to the construction of hydroelectric power plants, including small ones, natural riverbed changing occurs, flows are disrupted, places which have been covered by water may dry up and vice versa, oxygen deficiency will affect water quality, noise pollution will be produced, which may lead to a change of natural habitat conditions for animals. If proper attention is not paid to the management of fish passages, some types of fishes, for example salmon, may not be able to get downstream. In view of the construction of a hydroelectric power station, people can cause additional pollution. But in scales of small hydropower plant, especially in species without dams, all mention changes have small impact usually even nonrecognizable compared to large hydroelectric power plants.

Significantly high cost of construction

The first thing that stops the desire to build a small hydroelectric power plant after all natural conditions allow it to be built is the price of the initial investment and a relatively long payback period. It depends on the technologies used, production efficiency, government support and subsidies, as well as the tariff.

When building a small hydroelectric power station, it must be borne in mind that it will pay off with long-term operation. Repair and digitalization, monitoring can also be resource-intensive.

The unit price of the energy produced remains cheap and the initial and planned costs of partial replacement of equipment are expensive. The calculation of the payback for the rehabilitation of a small hydroelectric power plant is presented in section 3.2.

Dangers from accidents

There have been several accidents related to hydropower in the history of humanity. Accidents at small hydroelectric power plants occur mainly in view of such cases as errors in preliminary calculation and construction; the second due to incorrect operation and due to inadequate O&M; the third due to wars and not predicted natural disasters.

One of the losses of 2009 can be considered an accident at the Russian Sayano–Shushenskaya HPP due to poor-quality technical operation. This accident can illustrate consequences of continues lack of maintenance and the as a result sensational failure that happened due to inadequate O&M.

The accident that occurred in the east of Switzerland can serve as an example of a technical malfunction at a hydroelectric dam, what led to a power outage in the national park, and the death of thousands of trout.

The consequences of accidents from small hydroelectric power plants cannot be compared in scale, but due to their greater prevalence, their prevention and safety is one of the important tasks of small hydroelectric power plant management.

Further expansion

Owing to the limited places that can be suitable for the generation of hydroelectric power, the extension of hydropower networks is more complicated than for other energy sources.

Hydropower and Covid-19

Plans to ensure the continuity of business and important sectors of the economy thanks to hydropower were implemented, thereby demonstrating the sustainability, reliability and flexibility of hydropower during the global crisis (“Hydropower Status Report Sector trends and insights,” IHA 2021). As presented on the example of the pandemic-related crisis, it was verified that hydropower can play an important role in efforts to restore and transition to clean energy. Since hydropower it is a fairly large source of renewable electricity, and also has its own storage characteristics, it shows flexibility in integration with other renewable energy variables.

Hydropower can make an even greater contribution to the global economy, this requires the support of the "green recovery" as part of the global response to Covid-19 from the governing bodies. This plan presupposes new investments from the public and private sectors, which will facilitate modernization, decarbonization and further stimulate the economy. The plan contains: acceleration of processes, extension of the terms of existing state programs, introduction of credits and tax benefits with special low interest rates, compensation for flexible hydropower services.

The following recommendations can serve to increase the advantages and underestimate the disadvantages of managing small hydroelectric power plants:

- high-quality primary studies are needed, followed by monitoring and forecasting the impact of a small hydroelectric power plant on the surrounding space, including water quality, water inhabitants, people living nearby;

- it is necessary to focus on the conservation of nature in the production of energy by small hydroelectric power plants, to use the benefits and privileges provided by the state, to attract investors with the environmental side and flexibility and self-sufficiency pushing the long-term payback;

- to develop the entire infrastructure as a whole, not to forget about the opportunities to develop additional activities to small hydroelectric power plants, such as tourism or industries using the received electricity;

- it is necessary to unite, overcome crises together, share successful and failed experiences, develop strategies for managing small hydroelectric power plants in accordance with the Sustainable Development Goals;

- to remember about the safety of installations, workers, nearby residents and nature, to form strategies for operational and maintenance management, observing safety requirements.

Summing up, small hydropower is renewable energy, which is excellent for providing electricity to the local population. SHP combines reliability and affordable electricity production compared to other

alternatives with the same capacity. In addition to economic and social benefits, small hydropower produces energy in an environmentally friendly way without the formation of greenhouse gases and pollution, as occurs when burning petroleum products and coal. Small hydropower can be a solution for providing energy to industry, which will increase its sustainability and competitiveness, which will contribute to job creation, infrastructure improvement and, in general, an increase in income generation. As well as small hydroelectric power plants safely provide clean water to the population, agriculture and energy-intensive enterprises, while mitigating the consequences or preventing droughts, floods and other extreme weather events. An area with efficient production from small hydroelectric power plants also can develop itself by providing vital transport infrastructure, investments in utilities and leisure for residents of this area.

At the same time, small hydropower is not a new, it is long-established technology that is widespread all over the world. The experience of assessing the conditions and developing new hydroelectric power plants, the operation of existing plants is somehow available in any country. Small hydroelectric power plants, unlike large hydroelectric power plants, are still not popular in some countries, despite the fact that they have a huge untapped potential at the local level.

In the process of managing small hydropower, it is important to take into account and successfully apply its advantages over other sources of electricity production. The management strategy of small hydroelectric power plants should be built in accordance with the requirements and meet the set goals. Small hydropower should give priority to the use of new technologies, continue the process of improvement and receive support from the state.

2.3. Hydropower sustainability research

The sustainability that will be discussed is much broader than the definitions of the word "stability" from technical science, but it has many similarities. Stability in mechanics is the ability of a system to maintain its current state under the influence of external influences. The sustainability of the organization, enterprise, production reveals what is meant by "the influence of external influences" for the organization and business.

In the corporate sphere, Harvard Business School proposed to measure sustainable business practices based on the effect a business has on the environment, and the effect a business has on society (*What Is Sustainability in Business? | HBS Online*, 2017).

Although the concept of sustainable development is a relatively new nation, the movement as a whole has deep roots in social justice, environmental protection, internationalism and other movements of the past with a rich history. By the end of the twentieth century, most of these ideas had come together in a call for "sustainable development.

In 1983, the United Nations nominated former Norwegian Prime Minister Gru Harlem Brundtland to lead the new World Commission on Environment and Development. After decades of efforts to raise living standards through industrialization, many countries still face severe poverty. It turns out that economic development at the expense of ecological health and social justice did not lead to long-term prosperity. It was clear that the world needed to look for a way to harmonize ecology with prosperity.

After four years, the Brundtland Commission published its final report, Our Common Future It is known that sustainable development is defined as “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”(Nations, 2005).

In 2005 World Summit Outcome Resolutions adopted by the General Assembly described three pillars of sustainability that shown on figure 2.3.1(Nations, 2005).

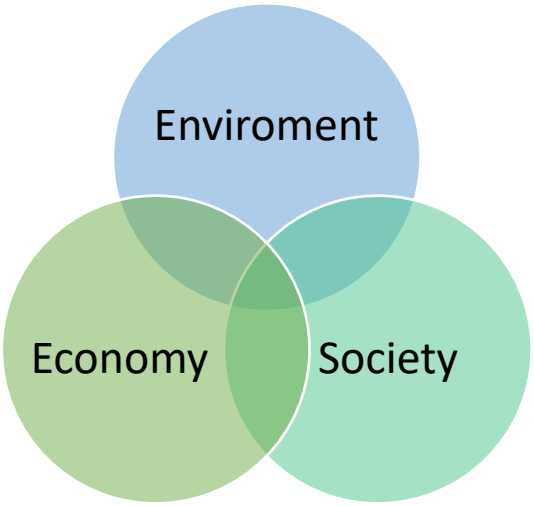


Figure 2.3.1. Three pillars of sustainability

Sustainable development is a holistic approach that considers environmental, social and economic aspects, recognizing that in order to reach lasting prosperity, everything needs to be considered combined.

Ecological sustainability is when ecological integrity is maintained, all ecological systems of the Earth are in balance, while the natural resources inside them are consumed by people at a rate at which they are able to replenish themselves.

Economic sustainability is when Human communities around the world are able to maintain their independence and have access to the resources they need, financial and others, to meet their needs. Economic systems are not damaged, and activities are available to everyone, for example, reliable sources of livelihood.

Social sustainability is when universal human rights and basic needs are achievable for all people who have access to sufficient resources to maintain the health and safety of their families and communities. Healthy communities have just leaders who ensure that personal, labor and cultural rights are respected and that all people are protected from discrimination.

The mentioned ideal stability is impossible while we live in an imperfect world. The responsibility for sustainability lies with everyone, especially large enterprises and businesses.

For sustainability, the business undertakes a wide range of possible practices with an environmentally sound goal, while balancing between long-term benefits and immediate returns. Such practices in the production of electricity include: the purchase of equipment from suppliers engaged in the retail trade, disposal with a lower carbon footprint, reduction of energy consumption, reduction of the carbon footprint, and others.

Conversations about sustainability have become popular recently, as large companies have set themselves goals in the field of sustainable development. Such commitments as reducing total emissions by a certain percentage, abandoning packaging by a certain year, producing products and services with zero waste - these and many other things that companies agree to themselves in order to be sustainable in the market in the long term.

Energy is essential for economic and social development and improving the quality of life. Energy is one of the five key areas for sustainable development in which progress is possible using the resources and technologies currently at our disposal. However, most of the world's energy is produced and used in ways that may not be sustainable in the long run.

The seventh goal of sustainable development is aimed at solving the problems of energy poverty, economic accessibility of energy resources, as well as ensuring sustainable energy development (THE 17 GOALS | Sustainable Development, 2015).

Sustainable hydroelectric energy plays an essential role in decreasing the global dependance on fossil fuel. As a renewable source of energy, it is very important that hydro power develops sustainably. To achieve this, it is required to consider certain principles of sustainable development, that is, environmental, social and economic factors, as well as a comprehensive approach to energy strategy and diverse strategies. P. and S. Singh suggest a power policy strategy approach to power saving and energy efficiency improvement, where the multifunctional use of hydropower infrastructure must be taken into consideration as a well-designed strategy (Singh *et al.*, 2020b). Nevertheless, in the contexts of the practices of sustainable management of maintenance at hydroelectric power plants, strategies need to take into consideration such variables as maintenance control, operation characteristics, intellectual data and communications, water resource management, etc. Involving the community at an initial phase of the decision-making procedure will not just reinforce the tenet of sustainability, but will also show public concern in a transparent, structured and repeatable path. It is imperative to consider the ecological principle of sustainability, that is, the management of water resources, the effects on the environment that can affect climate change on water ecosystems and aquatic resources. The aim is a study to advance the policy of sustainable maintenance management in hydropower by creating a conceptual framework and sharing knowledge about its role in renewable energy systems, responsible water management and ecological factor.

Based on the quantitative survey of various Hydropower plant, P Singh and S. Singh have classified operation hydropower management practices that help to reach sustainability by offering maintenance management conceptual framework for such three areas as: economic, social and environmental performances table 1.2.1. They help in progress in research in the field of composite materials for the development of hydropower turbine blades was also discussed the role of composite materials to increase the service life of turbine blades (Singh *et al.*, 2020b).

Table 1.2.1. Principles of sustainable maintenance Hydropower management

Economic	Society	Environment
Record Keeping Production Loss Machine health Condition Digitalization Maintenance Management Policy	Cyber security Worker's health and Safety Operational Performance Maintenance Decision-Making Smart Information Communication system Maintenance Workforce	Environmental impact Water management

While part of society is not laying finances for sustainability, researchers confirm that improved economic sustainability helps to enable other forms of sustainability. B. Powder showed the importance of post-construction support using the example of a micro-power plant to encourage the production of hydroelectric power in sufficient volume and reliability, which will further stimulate the consumption of generated energy by households and small businesses (Poudel *et al.*, 2021).

J. Huang considered together two aspects of the maintenance strategy to achieve production sustainability and energy conservation and came to the maintenance control cannot determine the optimal maintenance level that can be used in the field of small hydropower (Huang *et al.*, 2019).

Summarizing the above, it can be emphasized that the safety, reliability and efficiency of production processes are the basis for sustainable development in capital–intensive industries such as small hydropower. Many owners are faced the need to improve the management strategy of operation and maintenance, renovation of equipment in order to create a basis for economic growth and sustainability of production with tightening environmental and social requirements.

Small hydroelectric power plants need to be assisted in developing their technological strategies, managing their physical assets and creating conditions for continuous improvement in the areas of reliability, occupational safety and industrial safety.

When developing a strategy for managing the operation of a small hydroelectric power plant, it is necessary to use proven methodologies, expert experience and international practices in all three aspects, such as economy, society and ecology, in order to be stable in the market.

3. ANALYSIS OF HYDROPOWER PLANT CURRENT CONDITION

3. 1. Analysis of current installed and potential capacity of hydroelectric power plants

The final qualifying work included the following research methods: theoretical (classification, synthesis, analysis) empirical (surveys, interviews), analysis of the results obtained by statistical processing, generalization.

Analysis of the current situation of small hydropower plants in the world and in Russia is a method of analyzing documents, that is, a specially created object for storing and transmitting information. The method is widely used to study data from both individual manufacturing industries and society.

Energy is still the most pressing topic for discussion among economists, environmentalists, engineers and managers, at the same time, energy is the most necessary thing if we are talking about the elementary production and primary living conditions. According to statistics compiled by the International Center on Small Hydro Power (ICSHP) and the United Nations Industrial Development Organization (UNIDO), there are still 13% of people in the world who are not connected to electricity. UNIDO experts believe that Small hydropower can become one of the main solutions to change this situation for the better without harming nature. In order for this to become a reality, not only natural foundations are needed, but also its management.

The current global situation of small hydropower according to the World Small Hydropower Development Report (WSHPDR) 2019 shown on Table 3.1.1 and figure 3.1.1 below.

Table 3.1.1. Current world's total share occupied by small hydropower (<10MW)

1.5%	electricity installed capacity
7.5%	hydropower capacity
4.5%	renewable energy capacit

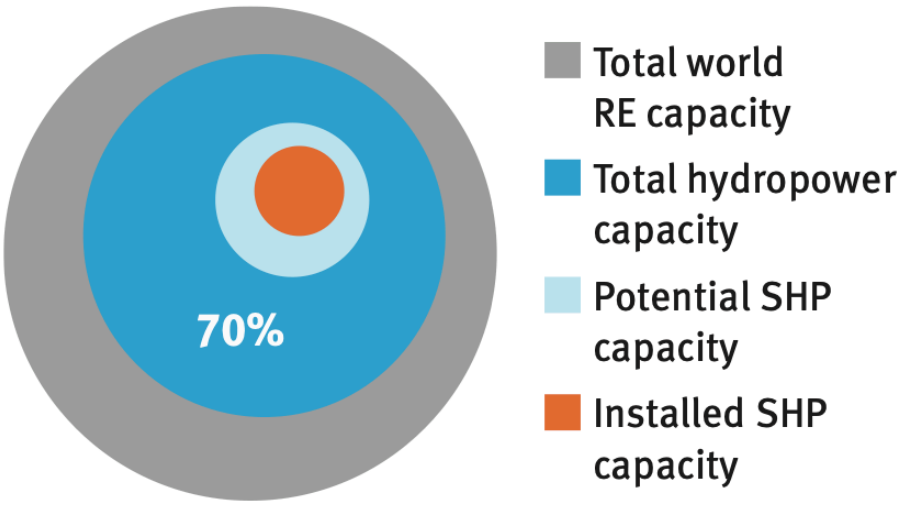


Figure 3.1.1. Share of SHP in the global electricity sector Source: WSHPDR 2019

In total, less than half of the potential of hydropower is used in the world, or rather 34% according to the latest World Report on the Development of Small Hydropower (WSHPDR) for 2019. This situation was presented 3 years ago without the impact of the pandemic associated with the spread of coronavirus infection Covid-19.

The figure 2.1.2 below is showing that according to the World Report on the Development of Small Hydropower (WSHPDR) for 2019, the global installed capacity of hydroelectric power plants (<10 MW) increased from 71 GW to 78 GW and the global SHP potential from 177 GW to 229 GW (by 10% and 30% correspondingly) compared to the same report in 2013. This was a consequence of the increased awareness, knowledge and support for the sustainable use of water resources for hydropower development and management.

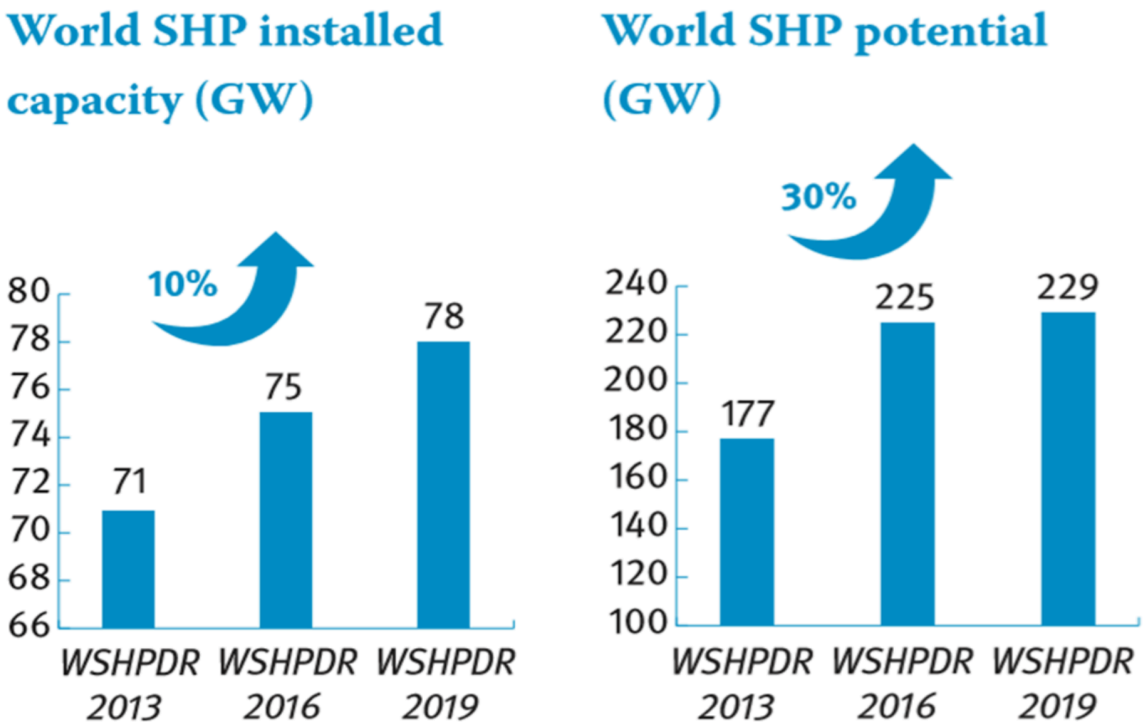


Figure 3.1.2 Global installed capacity and potential of Small hydro power. Source: World Report on the Development of Small Hydropower (WSHPDR) for 2019

Over the past 25 years, the accounting conducted by The International Hydropower Association (IHA) hydropower sector has grown by two and now amounts to 1,300 GW ("Hydropower Status Report Sector trends and insights," IHA 2021).

What contribution each part of the world has made to the change in indicators between the latest report for this moment and the previous report, for three years, is shown in Figure 3.1.3.

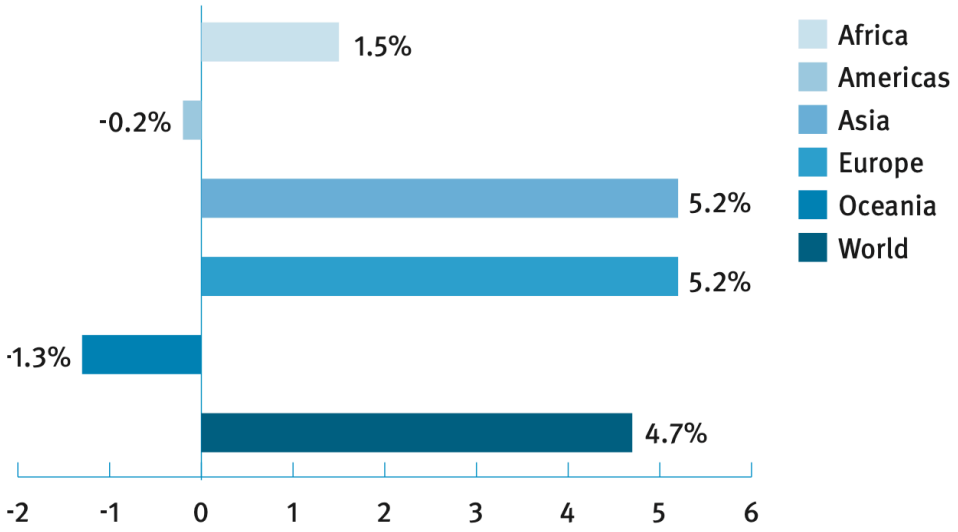


Figure 3.1.3. Installed SHP capacity change for WSHPDR 2016 - 2019 Source: WSHPDR 2019

As can be seen from the figure above, Europe and Asia equally increased the global contribution to the installed capacity of the hydropower used during these three years before the pandemic. But the relative contribution of each is different, Europe has increased more capacity relative to its potential than Asia.

Africa boasts only a 1.5% contribution. While the indicators of installed hydropower capacities of the United America and Oceania countries, on the contrary, decreased, this happened due to updated information about their own resources in the field of small hydroelectric power plants, and in Oceania the current situation was affected by natural disasters. Using the example of Africa, it can be noted that for the overall development of the hydropower sector, it is necessary to have enough money, qualified specialists, developed infrastructure and access to new technologies. Unfortunately, when the state does not have the opportunity to invest in the previously mentioned areas, hydropower without proper management will not develop the region. The ratio of the potential and installed capacity of each part of the world was clearly displayed by WSHPDR 2019 (Figure 3.1.4).

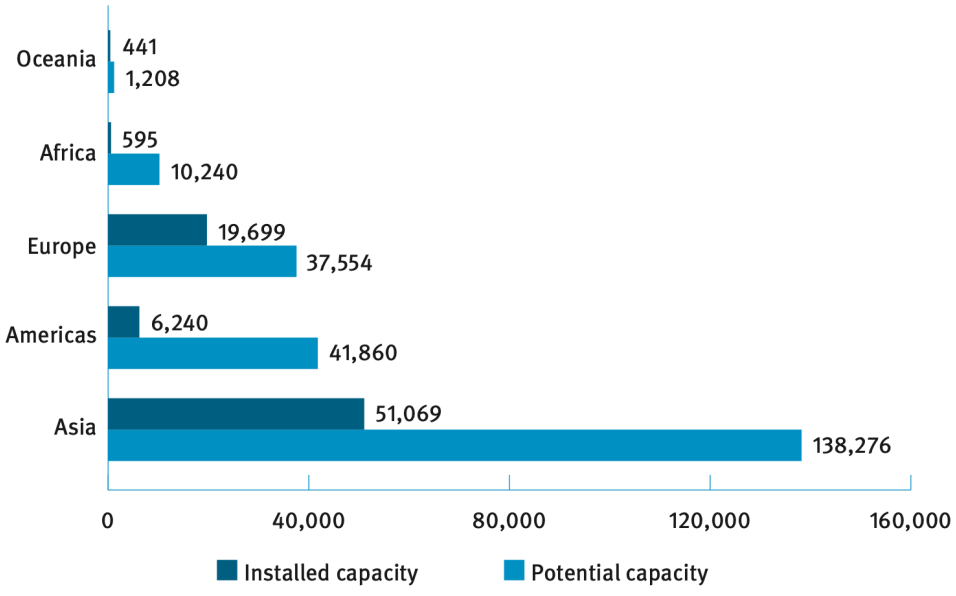


Figure 3.1.4. Regional installed SHP capacities up to 10 MW in WSHPDR 2019. Source: WSHPDR 2019

Asia has the largest installed capacity and the potential for generating hydropower. The potential capacity of Asia is about 4 times larger than Europe, but the installed capacity is 37%. Europe, on the contrary, has the highest percentage of using the potential of hydropower with the help of its small small hydroelectric power plants, namely 52%. Western Europe is already using 5/6 of its potential. The second place in the world in the use of small hydropower is occupied by Eastern Asia 3/5 of the potential. As it was revealed at the stage of my patent research, China is the leader of patenting in the field of control systems for small hydroelectric power plants. What can we say about the imminent entry into a high level of use of its natural potential for generating electricity.

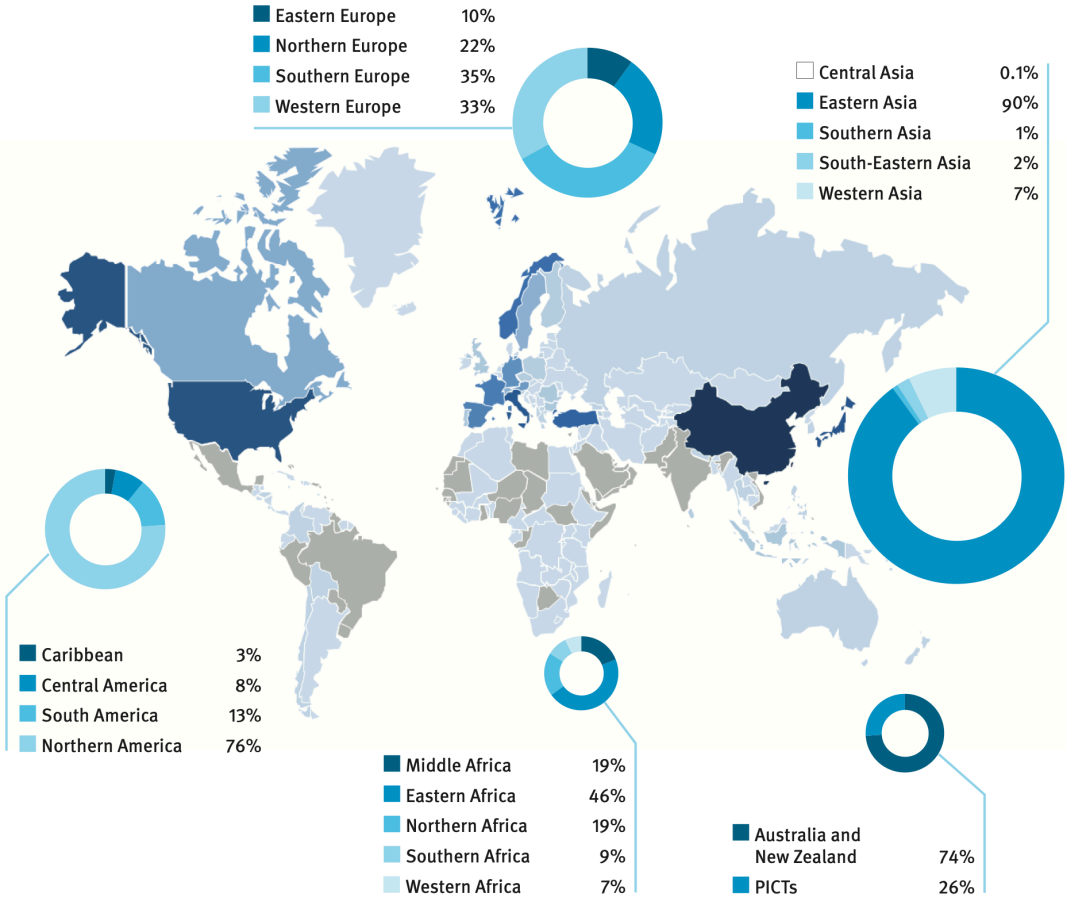


Figure 3.1.5. Installed SHP up to 10 MW capacities worldwide Source: WSHPDR 2019. Note: SHP up to 10 MW. Countries without available data on SHP up to 10 MW are not included and highlighted in grey.

It follows from the map presented by WSHPDR 2019 that the picture of capacity distribution cannot be fully described, because not all countries provided data or did not assess their installed capacity and potential at all. According to known data, installed capacities in different parts of the world are located unevenly, this was influenced by both natural and political components. In Africa, half of the installed capacity of small hydroelectric power plants is occupied by the Eastern part (46%), in Asia - the Eastern part (90%), in America - the Northern part (76%). Europe presents the situation differently: almost all capacities are distributed evenly across all regions, except Eastern Europe. The countries of mostly the former Soviet Union are characterized by low installed capacity compared to other regions of Europe. In Russia, approximately 20% of the potential of a small hydroelectric power plant is installed capacity.

Further, the figure 3.1.6 shows the gradation of the regions of the world starting with the largest with potential in small hydropower.

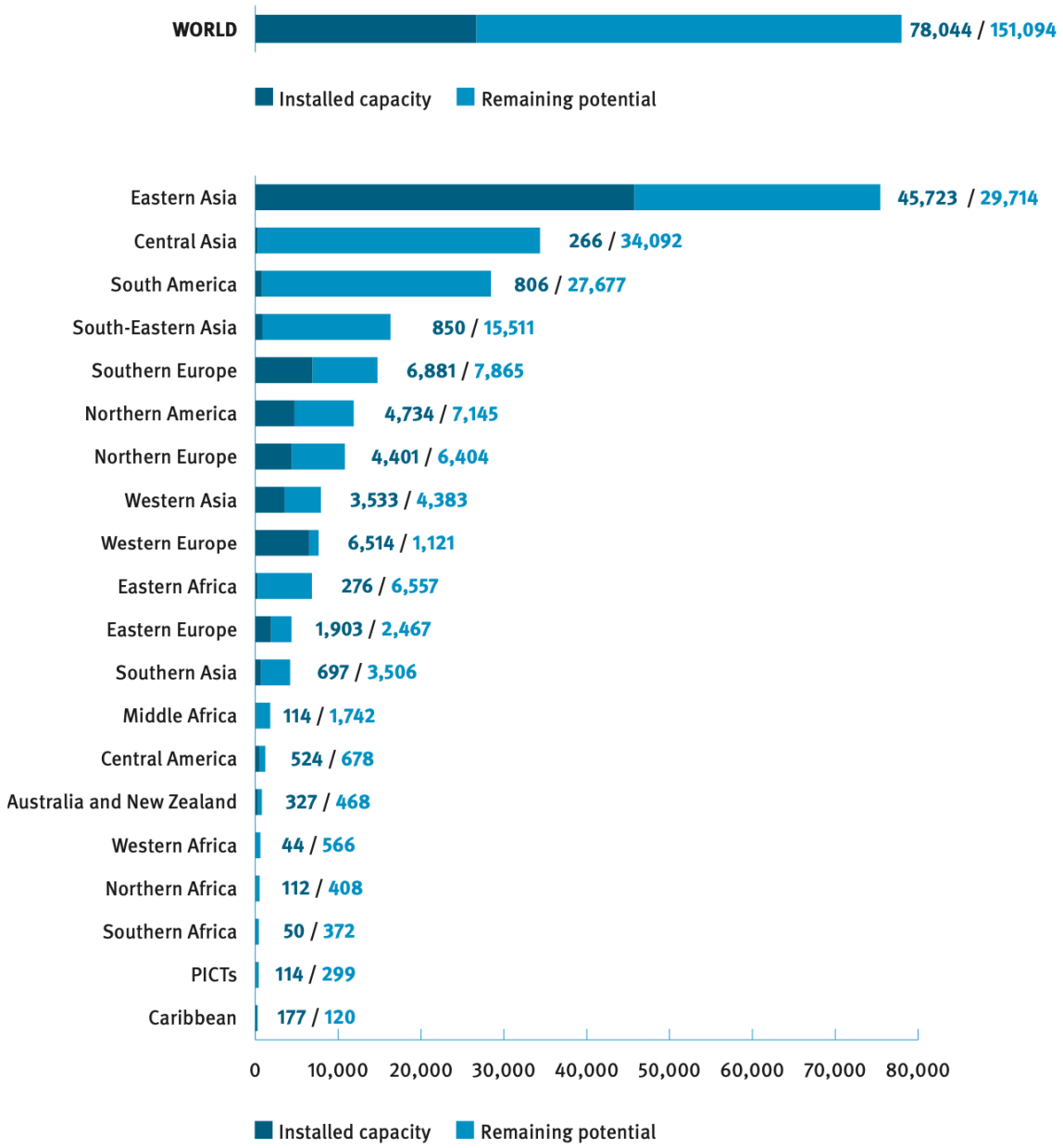


Figure 3.1.6. Remaining SHP potential by region (MW) Remaining SHP potential by region (MW)

What follows from the figure above is that at the time until 2020, 34 percent of the calculated potential of small hydropower is installed.

The top-5 regions with the greatest potential of small hydroelectric power plants are the following (in descending order): East Asia, Central Asia, South America, Southeast Asia, Southern Europe.

In contrast, the top-6 regions with the least remaining potential are as follows: Western Europe, East Asia, Southern Europe, Eastern Europe, Northern Europe and North America.

More details about the reasons why Europe sets its naturally given potential in small hydropower to a greater extent than other parts of the world are described below.

The current status of small hydroelectric power plants in Europe

Europe is becoming a leader in the use of its potential of small hydroelectric power plants (52%) due to many reasons: the long-term development of this area, the lack of sufficient fossil fuels, the

initiation of the transition to green energy and establishing Feed-in tariffs (FITs) for SHP. The Feed-in tariff will be described in more detail in the following subsection 3.3.1.

In Europe, simultaneously with the same environmental incentives, there are also reverse forces of nature conservation. The challenge is that strict environmental regulations in some cases in a number of countries may, on the contrary, hinder the development of new small hydropower networks. There are also European countries where the damage caused to nature from the production of electricity from small hydroelectric power plants (up to 10 MW) is equated to damage from the production of large hydroelectric power plants, in view of not introducing differences in regulatory policy, which in turn hinders the development of small hydropower. The distribution of the installed and potential capacity of Europe is shown in Figures 3.1.7 and 3.1.8 below.

Figure 3.1.7. Installed SHP up to 10 MW capacities of Europe. Source: WSHPDR 2019

As can be seen from the figure above, Italy and Norway (marked as dark blue) are the regions with the largest installed capacity, according to their local measurements, 3,395 MW and 2,571MW correspondingly. Recently in Italy, an agreement about installing digital modernization at 33 hydroelectric power plants across the country was signed.

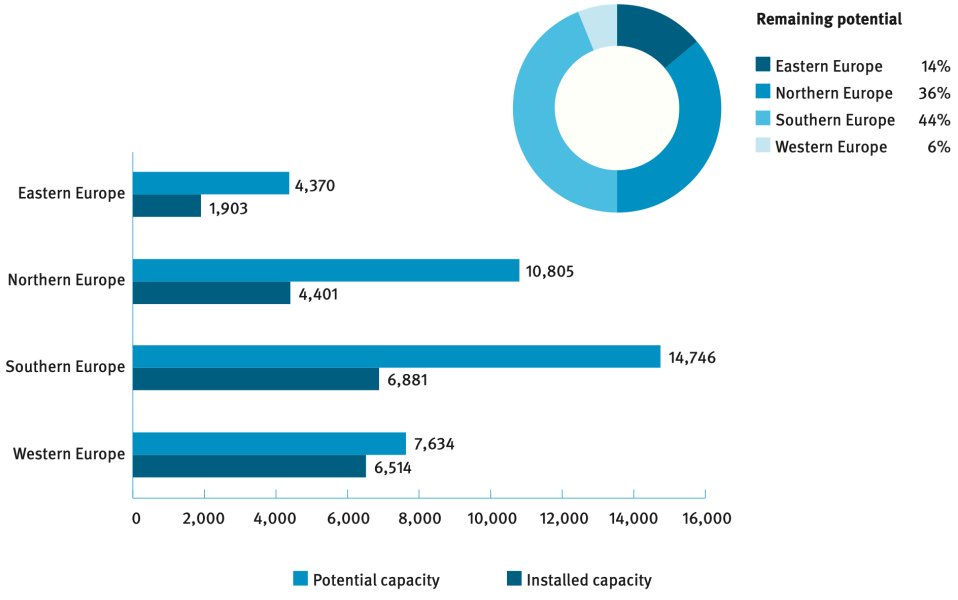


Figure 3.1.8. Installed and potential capacity in Europe's regions for SHP up to 10 MW (MW) Source: WSHPDR 2019

According to the figure above, it can be concluded that southern Europe has a great potential for small hydropower, but unlike western Europe the installed capacity of Southern Europe is two times less than the potential.

Further, the current situation with small hydroelectric power plants in Northern Europe is considered in more detail.

The current status of small hydroelectric power plants in Nordic countries.

There are 10 countries in Northern Europe: Denmark, Estonia, Finland, Ireland, Ireland, Latvia, Lithuania, Norway, Sweden and the United Kingdom of Great Britain and Northern Ireland. An overview of the countries in Northern Europe is presented in Table 3.1.2

Table 3.1.2. Overview of countries in Northern Europe. Source: World Small Hydropower Development Report 2019

Country	*Total population (million)*	*Rural population (%)*	*Electricity access (%)*	*Electrical capacity (MW)*	*Electricity generation (GWh/year)*	*Hydropower capacity (MW)*	*Hydropower generation (GWh/year)*
Denmark	5.7	12	100	14,247	30,556	10	19
Estonia	1.3	31	100	2,885	12,176	7	35
Finland	5.5	15	100	17,175	66,199	3,159	15,634
Iceland	0.3	6	100	2,767	19,239	1,984	14,059
Ireland	4.8	37	100	10,459	28,157	530*	692
Latvia	2.0	32	100	3,095	7,340	1,564	4,386
Lithuania	2.8	32	100	3,665	3,866	1,028*	1,147
Norway	5.3	18	100	33,800	149,300	31,837	143,000
Sweden	10.1	13	100	39,991	152,600	16,181	61,700
UK	65.6	17	100	78,300	339,000	4,400*	8,400
Total	**103.4**	-	-	**206,384**	**808,433**	**60,700**	**249,072**

Note: *Including pumped storage hydropower.

Speaking about the potential in small hydropower, its territorial location and the number of rivers, the presence of lowlands and mountains are considered. The Nordic countries are generally located on the lowland territory but with mountain ranges. The region is rich in rivers and lakes. The longest river is the Glomma (Norway, 621 km, 720 m3/s).

All components of potential hydropower depend to some extent on the climate. The territory of Northern Europe mainly has one climate. The region is characterized by long cold winters, short and cool summers (+8 — +16 ° C — depending on latitude). In winter, the severity of the climate is noticeably mitigated by the North Atlantic Current, influenced by the presence of the Gulf Stream. There is a lot of precipitation everywhere in the region. Thus, we can say that the climate does not hinder the development of small hydropower in the Nordic countries, although there are seasonal declines in hydropower generation.

Many of the countries of Northern Europe are part of the European Union (EU), where the policy regulating hydropower is formed in accordance with EU directives.

Northern Europe is fully electrified and installed hydropower capacity in the region is slowly increasing. This is due to the fact that the main goals of the EU before the pandemic and now are a constant increase in electricity production due to renewable energy sources and the gradual abandonment of imported petroleum products.

According to the World Small Hydropower Development Report, the distribution of the shares of installed capacity in the region until 2019 is was as follows (figure 3.1.9)

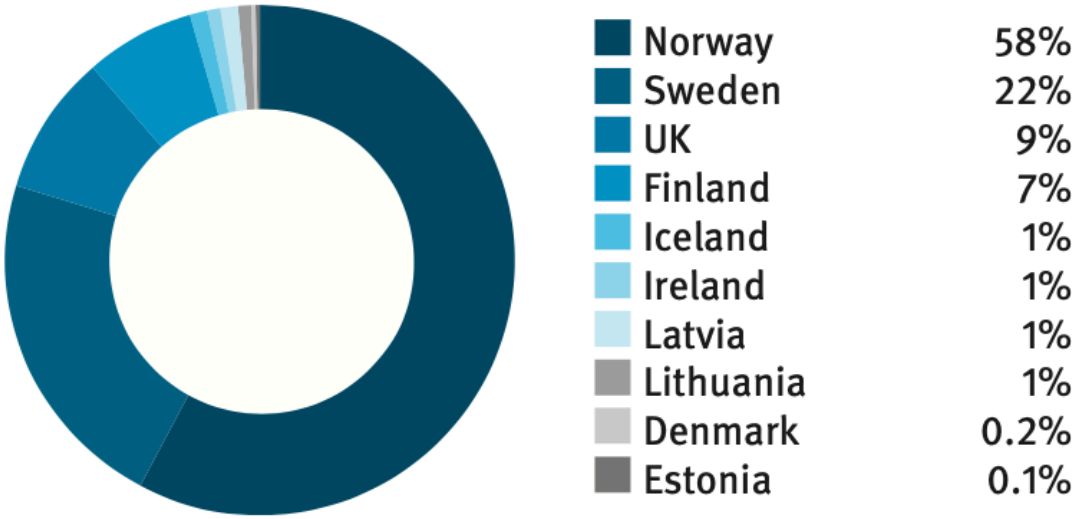


Figure 3.1.9. Share of the regional installed capacity of small hydropower up to 10 MW by country in Northern Europe (%). Source: WSHPDR 2019

The Northern Europe region according to WSHPDR-19 at the time before the pandemic had installed capacity of 4,401 MW, which is 2.5 percent more than at the end of 2016 (Figure 3.1.10). At the same time, 80 percent of the installed capacity of the region is distributed between the two countries Norway and Sweden and 20 percent between the remaining 8 countries.

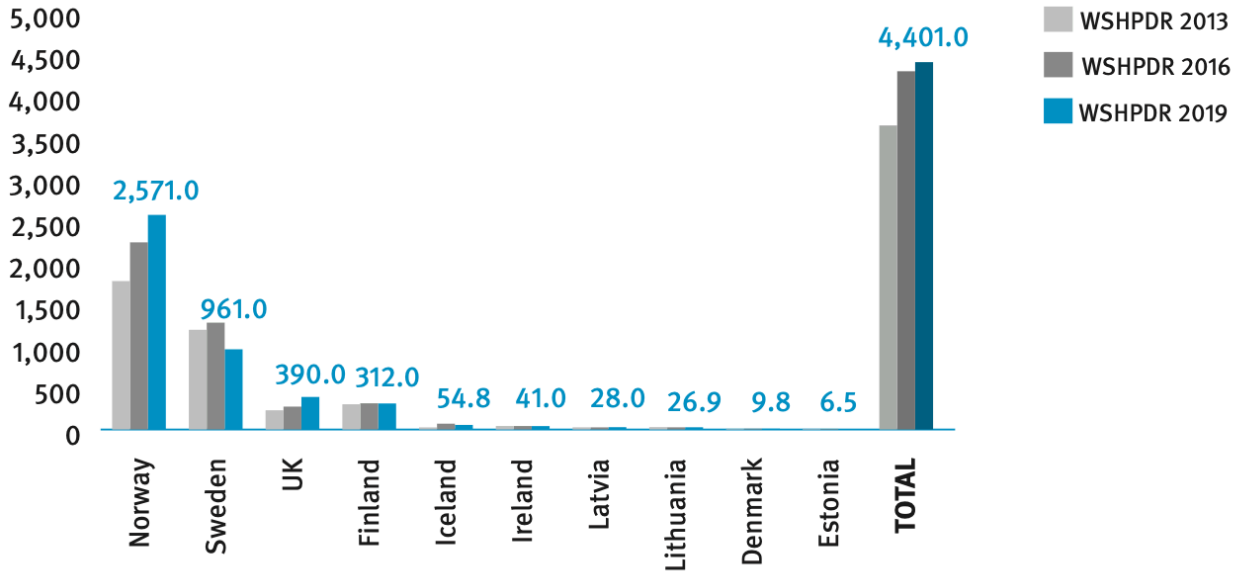


Figure 3.1.10. Change in installed capacity of small hydropower from WSHPDR 2013 to 2019 by country in Northern Europe (MW). Source: WSHPDR 2019

As an analysis limitation of this dissertation, hydropower has been studied in the context of representatives of Nordic countries with great potential in hydropower: Norway, Sweden, Finland.

The distribution of installed capacities at the end of a given period may have different meanings. Consider Norway, Sweden and Finland.

The installed capacity of Sweden's SHP at the end of 2019 is 961 MW, but compared to the same report of 2016, the installed capacity of small hydropower in 2019 is less by 25 percent than in 2016, this was not a result of a drastic reduction of the actual installed capacity, but is due to access to more

detailed data. At the end of 2019, Sweden did not have an emphasis on increasing installed capacities, legislative acts are strict to environmental standards, and the increasing in capacity is mainly due to the reconstruction of existing small power plants (World Small Hydropower Development Report 2019, 2019).

Norway has a rich history of hydropower development. A large increase in the construction of small hydroelectric power plants was observed in the period after World War II, in 1991, due to changes in the electricity market, there was an overabundance of capacity, the prices of electricity received by small hydroelectric power plants were low. Later, the situation changed, the popularity of green energy in Europe began to grow, management and introduction of new technologies affected the efficiency of the electricity received. The implementation of the North Sealink electric cable project and the new Trans-European Networks for Energy TEN-E also contributed to a new growth in the number of new small hydroelectric power plants. Since 2000, the number of small hydroelectric power plants in Norway has increased by 66% ("NVEs overview and database for hydropower plants, 2018). But now there is a tendency to reduce the cost of developing a new wind farm, which is becoming an obstacle to the growth of investment in hydroelectric projects.

Finland at the end of 2019 was the owner of 167 small hydro power plants (with a total capacity of 312 MW). The state implements grants for small hydropower research and investment programs. But compared to 2016, the number of small hydroelectric power plants has not increased, only decreased. This happened due to the reconstruction of one of the power plants, which attracted an increase in installed capacity beyond the threshold value of SHPs (10 MW) and was no longer taken into account by SHPs.

Summing up the current situation of small hydropower, it can be concluded that in order to manage small hydropower in our time, it is necessary to fully study:

- Availability and accessibility of energy resources in society, what are the social dynamics and side effects of demand;
- Natural disposition to obtain hydropower and its energy efficiency;
- Ensuring environmental safety, what does it have to do with climate change and from it, and circular economy development;
- Availability and development of energy technologies for extraction, storage, transportation and digitalization;
- How business is implemented, market policy and structure, investments, trade and prices;
- What are macroeconomics, geopolitics, global trends and attitudes towards renewable energy sources in general.

3. 2. Global trends and new technologies in the sphere a small hydropower plant

3.2.1. New technologies, materials, digitalization of hydropower plant

Further, new technologies in the field of small hydroelectric power plants will be demonstrated.

Digitalization in hydropower

Digital transformation is a ongoing progress in practically all areas of everyday life With regard to the generation of electricity from hydropower, settled business model and procedures are significantly changing due to new components, ideas, techniques and models, such as "Hydropower 4.0", artificial intelligence, data mining and Internet services, Internet of Things,

cyber-physical systems, artificial intelligence machine learning. Serbian researchers B. Ristić and I. Basic have collected all modern technologies for digitalization of hydroelectric power plants, they include in addition Industrial Internet, Smart Grid, Smart Energy Systems, Digital Twins and other (Ristić, Bozic a, 2021).

Vagnoni et al showed that through digital modelling technique possible correctly predict the power generation of the hydropower plant already from one month operating (Vagnoni *et al.*, 2021).

Digitalization will also impact the operation and maintenance of hydro power plants due to the possibility of reduced costs and enhanced effectivity of human resources management. As digital technologies are changing fast, there are many issues that make the introduction of digital technologies in hydro-electric power plants a complex challenge.

Networked platform solutions

Kassem and his team have estimated impact of network platform solutions on corporate social responsibility related topics and further strategic decisions, claim in their research that a collaborative network platform help to long-term sustainability through exchanging expertise, sharing information and data (Kassem *et al.*, 2016).

Network platform solutions at hydro power plants should integrate earlier separated information and data systems. Data entry and analysis are available centrally and locally due to network planform. Innovative measures in the field of digital hydropower include improving managing outages, equipment for condition monitoring, improving equipment and fleet, cybersecurity, the efficiency of asset management.

Such innovations are aimed at reducing costs in the construction, operation and maintenance of small hydroelectric power plants. The monitoring of energy costs and production, the creation of a more effective hydropower turbine and the advancement of mechanization and data-based service bring hydro-energy services to an unprecedented level. Together, these innovative technologies give the owners of hydro-power resources useful information based on data to increase the effectiveness of hydropower resources.

Remote monitoring hydropower plants

The need for installing monitoring equipment for hydropower plant's critical parameters came from the need to increase the efficiency and safety of these structures. It is common to have the monitoring equipment be built-in or have them positioned in the vicinity or the hydropower plant. Ahmad I. in his research proves that On-Line Monitoring for Hydropower Plants is less costly in case of major defects occurring in the plant and it also not required the operator to wait for the periodic shutdown for routine maintenance. (Ahmad, 2017). Most of the hydropower plants that have sensors in their structures are equipped with electrical sensors meant for remote monitoring. Some of the more frequent sensors for this purpose are:

- serial digital output sensors
- inductive, frequency output sensors
- current or voltage output industrial sensors
- resistive sensors
- vibrating wire sensors

Many sensors are needed for monitoring the performance of the complex dam structure. These control points, which are situated in key areas, are then monitored independently.

Modelling techniques

In designing good equipment, it is important to consider all factors that might have effect on the efficiency of turbines and other equipment. Measuring the effects of these factors can be done by using advanced computer software. Computer software can also be used to optimize all other operating aspects of the hydropower plant.

Small-scale models and digital 3D models are used in designing hydropower plants. With the advancement in modern processors, it is much more convenient to use software in optimizing a model.

Outage management

The article of D. Shuffleton is mentioning experience of Outage Management within the Electricity Supply Industry (ESI) and which assist in predicting, diagnosing, and/or managing an incident in a utility service area (Shuffleton, 1998).

Condition monitoring equipment

H. Mikkonen concludes that condition monitoring makes possible to standardistion and synchronisation procedures for more efficient predictive maintenance and to involve specialists from different fields to take part in diagnostics and problem-solving cases(Mikkonen and Lahdelma, 2014)

Internet of Things (IoT) in hydropower

Adepoju's study illustrates how the Internet of Things (IoT) is leading to high productivity, increased business value, and cost-effectiveness in constriction field that can also be used in hydropower plant (Adepoju, 2022).

SCADA hydropower

Many hydro power plants are in the progress of rehabilitation and upgrading in order to provide optimal performance. One of the ways to improve the small hydropower plant is remote monitoring of all energy units using a dispatch control and data acquisition system (SCADA). This type of system processes both software and hardware methods based on the resources of a transmission devices power, transmission line, intelligent sensors and data transmission personal computer, remote terminal blocks. The SCADA system requirements are as follows: self-test capability

- availability and correctness (accuracy)
- user friendly interface
- data security and reliability
- real time operating
- adaptability
- up and down openness

Garber has found SCADA System as high efficiency of the data processing process and shortening the time interval in which the DM makes the decisions (Garbea, 2021).

Artificial intelligence and machine learning

The results of Bernardes' at al. research showed that Machine Learning tools for hydropower plants usually apply for river flow forecast and reservoir operation optimization for long-term scheduling horizon (Bernardes *et al.*, 2022).

Advanced materials

Soil particles in water cause wearing in mechanical parts. Temporary solution is to cover the metal parts by coating them in hard material, such as ceramic.

High peaks in power producing may also cause wearing down of mechanical parts, such as equipment meant to reduce high voltages. Also, the parts that are constantly exposed to high pressure and stress caused by the movement of water are worn down faster. Damage in mechanical parts means less efficient power plant and so they need more frequent maintenance.

There are also some problems in continuously using hydropower plants as flexible energy source as they are not actually designed for this. Continuous restarting may cause structural damage to the turbines.

Costs of repairing or changing the turbines with damage from things such as cavitation are high. There are however technologies that allow shooting particles of metal at high velocity into the parts with significant damage. The friction causes the particles to be welded into the turbine, which adds material to the worn part. This means the turbine will not change shape and will maintain its efficiency. However, protective coating is more efficient way to reduce the downgrade of the turbines.

Benefits of Composites for Hydropower

Researchers of composite turbines for hydroelectric power plants have shown that composite turbines provided a superior friction and wear performance, especially under water lubricated conditions (Somberg *et al.*, 2021).

Colin Tong discussed advance materials for small hydropower and admit that advance materials can help make more compact support structures, reduce technology cost, reduce carbon footprint to achieve economic feasibility (Tong, 2019).

Figure 3.2.1 shows how multiple CF filaments, through precise machinery, can be wound rotationally around symmetrical parts such pipes, turbines, beams (Connova 2017).

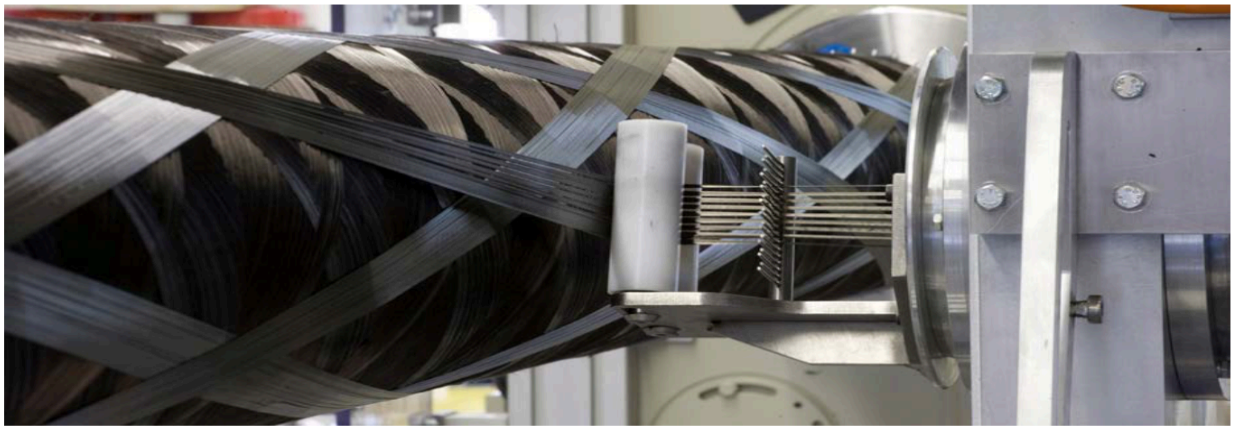


Figure 3.2.1 Rotary filament winding around a symmetrical object. Source: Connova AG.

3.2.2. Patent Research

The purpose of this patent research is to see whether patents related to small hydroelectric power plants and their management system are published, how often they are published, whether there is now an increased interest in patents on the chosen topic, in which countries.

After having determined the purpose of the study, there was a keyword selection stage to make sure that we cover all aspects of the invention, without duplicating effort.

The patent research was carried out using the Espacenet Patent search website.

The table 3.2.1 shows the search words I used and the number of answers found is presented below.

Table 3.2.1. Keywords used and number of answers found on Espacenet Patent search

	Keyword	Number of answers found
1	nftxt = "hydropower"	113 478
2	nftxt = "hydropower station"	15 737
3	nftxt = "hydropower" AND nftxt = "management"	15 024
4	nftxt = "hydropower" AND nftxt = "station" AND nftxt = "management"	5 423
5	nftxt = "hydropower station" AND nftxt = "management"	2 149
6	nftxt = "small hydropower station"	592
7	nftxt = "small hydro power station" AND nftxt = "management"	1
8	nftxt = "small hydropower station" AND nftxt = "management"	174

Basically all the latest patents are related to:

- remote centralized control and quick service;
- water level automatic monitoring management system;
- optimization regulating, dam safety management;
- key information communication terminal;
- active and reactive power control system;
- ecological flow automatic discharge transformation device.

To understand the distribution by year of patents relevant to the research objectives, a graph was drawn up, which is presented below.

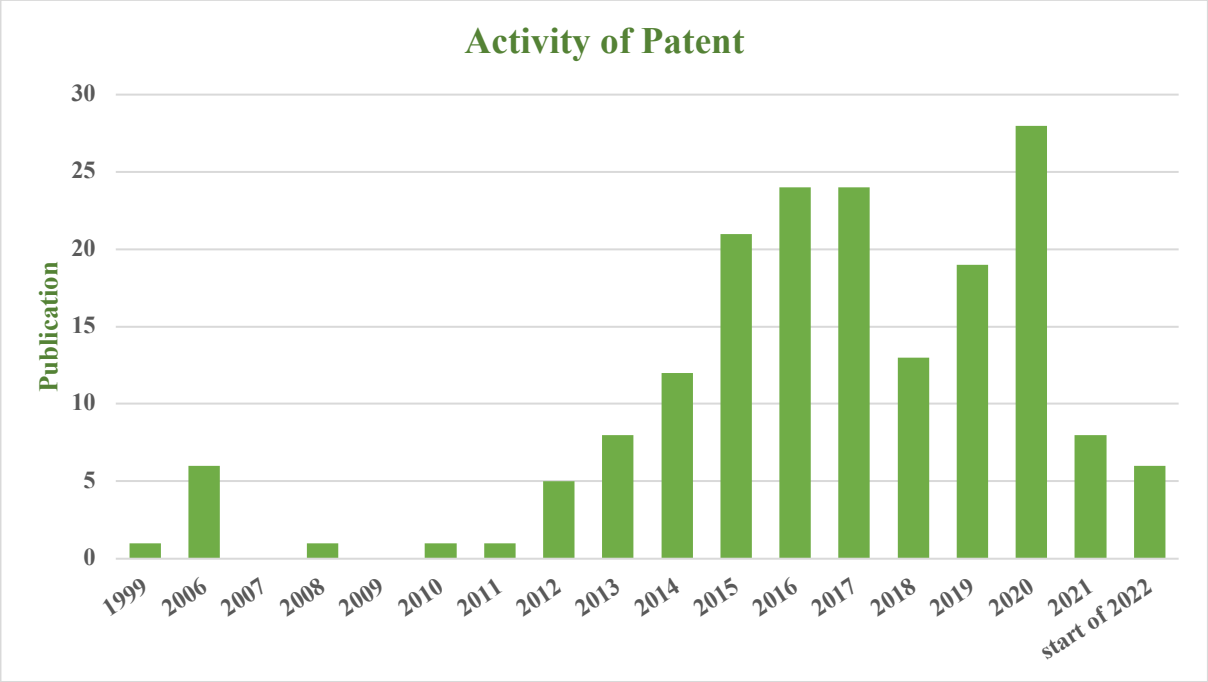


Figure 3.2.1. The total number of patents granted for inventions related to small hydroelectric power plants and their management system from 1999 to early 2022 on Espacenet.

Conclusions on the conducted patent research
Almost all the patents found related to small hydroelectric power plants on the European Patent Office (EU) "Espacenet" platform were registered for residents of China.
The number of patents has been growing over the years, there has been a drop in the number of publications, which may be related to the lockdown associated with the new coronavirus infection covid 19, but we can observe that research and new inventions do not stop and perhaps in the near future we can observe a new peak of publications in view of global support for green energy.

As managers, we clearly understand that objects under construction for many decades, such as small hydroelectric power plants during construction or renovation, should not use old technologies when new ones already exist. Next, innovations in the field of small hydroelectric power plants that use new technologies to manage the plant are considered.

Recommendations that can be used for the management of small hydroelectric power plants:

It is necessary to facilitate access to industrial equipment and technologies for small hydroelectric power plants.

To create and improve the equipment industry and the necessary components in order for the overall development of the SHP sector.
For countries with insufficient local technology, it is necessary to establish access to foreign imports, for example by reducing import taxes or establishing preferential duties

3.3. Analysis of government influence on small hydropower plant
3.3.1. Legislative regulation in electricity production

This subsection examines which legislative regulation in the field of small hydroelectric power plants should be studied by the manager before and during the decision-making process. And also, which legislative regulation stimulate the development of the small hydropower sector, and which, on the contrary, restrict.

Legislative regulation for hydropower was originally created in order to regulate the production of electricity from the state, wholesale electricity supply networks and electricity supply to the end user.

Government intervention in the electric power industry varies from country to country. At the initial stages in the XIX century, the electric power industry was practically not regulated, since electricity production and consumption were carried out only at the local level. The first legal regulation of relations in the energy sector can be considered the first contracts concluded internationally, which became the first step for the common work of European countries within the framework of communities within the European Union. And then the EU authorities were given the rights to develop the EU energy program, which should be directed at securing the functioning of the national energy exchange, securing energy supplies to the EU, promoting energy efficiencies and energy conservation, the development of new and renewable types of energy, as well as the conservancy and strengthening of the surrounding environment. Moreover, a substantial part of the European Union energy law relates to the promotion of trans European power grids as a key condition for achieving a policy of security of energy supplies and energy carriers, the development and support of renewable energy resources, improving energy efficiencies and promoting energy conservation, as well as the creation of a sufficiently exacting ecological regulation of energy interrelation.

In addition to regulating the basic energy sectors, an important point in the development of European Union energy law is regulation in the field of the environment. Thus, the legal basis for the production of energy from renewable sources was Directive 2001/77/EC of 2001, the purpose of which is to develop an increase in the contribution of renewable sources to energy production in the domestic electricity market. Energy safety and energy efficiency issues are also important part of the development of EU energy law.

The European legislative regulation of origin and development is based on the approuch of creating a competitive electroenergy market concern about security of energy supplies, ecological protection and consumer safety.

The objectives of legislative regulation are to ensure consistent and environmentally sound management of water resources, to promote an efficient energy market and cost-effective energy systems, as well as to promote the economical use of energy.

In Russia, the corporate regulatory document defining the technical and organizational requirements for the creation and reconstruction of hydroelectric power plants aimed at ensuring reliable, safe and efficient operation of the facility is the Standard 2010 "Hydroelectric power plants. Conditions of creation. Norms and requirements".

This Standard is intended for organizations performing the functions of the customer of design, construction, installation works during the creation of new and reconstruction of hydroelectric power plants in operation; design, engineering, research organizations that develop projects and conduct research to substantiate design solutions; construction, installation and industrial organizations involved by the customer in the creation of new and reconstruction of existing hydroelectric power plants; specialized organizations that carry out expert analysis of hydroelectric power projects.

All legislative regulation regardless of origin country can be divided into two types. The first can be described as a right to produce electricity from hydropotential in conditions of state restrictions.

The following table describes the resemblance in regulations of small hydropower plants in different courtiers.

Table 3.1.1 Legislative regulation in electricity production of small hydropower plants

Act's general prepose	Act's name	Decryption of the act
1) The main legislatic acts to secure sustainable manageme of the waterfalls and riv system	The Watercourse Regulation Act	Licenses to establish reservoirs and to transfer wate
	The Water Resources Act	Licenses regarding all kind of measures in the riv system
	The Acquisition Act	Licenses to acquire waterfalls and shares in pow utilities
	The Energy Act	Licenses for transmission lines and electric equipme
	The Planning and Building Act	A general law, maintained by the municipalit governing all kind of construction activities and land use. Handlir procedures, notifications to government.
The procedures inclu co-ordination with t pollution from industry	The Industrial Licensing Act	Regulations relating to acquisition of waterfalls, min and other real property.
	Pollution Control Act and The Cultural Heritage Act	Regulations relating norms of pollution
Quality of outflow water	The Watercourse Regulation Act	Regulations relating to the adjustment of license fe annual compensation and funds, pursuant to wat resources legislation. Watercourse Regulation A mainly contain: • regulations relating to the adjustment of licence fee annual compensation and funds etc.; • delegation of competent authority pursuant to T Watercourse Regulation Act; • delegation of authority related to stipulation of t threshold of payment to business development fund.
Secure energy on each	The Energy Act	Regulations relating to the generation, conversio transmission, trading, distribution and use of energ Regulations within the Energy Act contain: • regulations concerning the generation, conversio transmission, trading, distribution and use of energy • security provisions for the power supply system; • regulations relating to notification of investme projects of interest to the Economic Area in t petroleum, natural gas and electricity sectors; • regulations governing the planning a implementation of requisitioning of power a enforced reductions in supply in connection wi electricity rationing; • regulations governing metering, settlement a coordinated action in connection with electrici trading and invoicing of network services; • regulations governing financial and technic reporting, income caps for network operations a transmission tariffs • regulations governing the payment of a levy on t grid tariff into the Energy Fund

		• instructions for the Power Supply Preparedne Organization; • regulations relating to the system responsibility in t power system; • regulations relating to contingency planning in t power supply system; • regulations relating to energy planning; • regulations relating to the quality of supply
relating to river systen and groundwater	The Water Resources Act	Regulations within the Water Resources Act contair • regulations governing qualifications for tho undertaking the planning, construction and operatic of watercourse structures • regulations governing filing requirements for we drilling and ground water surveys • regulations governing the safety and supervision watercourse structures • regulations governing internal quality control comply with the Act relating to river systems a ground water; • regulations relating to the adjustment of licence fee annual compensation and funds etc., pursuant to wat resources legislation

Second type of legislative regulation conditionally can be described as state support for small hydropower production for stimulation of development of the sector. Some of the governances do not provide forms of support for small hydropower production. Some governments are developing strategies only in condition of new power generation in rural areas with aim of to contribute to the development of SHP plants. Strategies for these prioritized areas can be in form of:

- establishment of a certificate market for new power production;
- covering part of the payment for the rehabilitation of old small hydroelectric power plants;
- payment for research in the field of small hydroelectric power plants;
- tax-based economic incentives;
- simplification of the licensing process;
- green electricity purchase tariff;
- grants and other types of state support.

Certificates

Sweden and Norway reached the next level of certificate market setup when they decided to merge into a single electricity certificate market in 2012. The certification system of Sweden was taken as a basis, which has been in operation for 9 years. The essence of the electricity certificate scheme is that approved power plants receive one certificate for each MWh they produce for 15 years. And the certificate has a high demand in the market, it can be sold on the market regardless of the sale of electricity, since there is a requirement of the law that all electricity consumers purchase certificates equal to the quota obligation (the share of their electricity consumption). With the help of the certificate scheme, the goal of increasing the annual electricity production from renewable sources in the countries of Norway and Sweden by 28.4 TWh together by the end of 2020 has been achieved. This type of support from the States will contribute to the achievement of the countries' goals in accordance with the European Union Directive on Renewable Energy Sources and has been extended

until 2035. (World Small Hydropower Development Report 2016. United Nations Industrial Development Organization; International Center on Small Hydro Power, 2016)

In addition to the certificate scheme in Norway and Sweden, the state and industry are investing in hydropower. For example, as a result of the successful implementation of a large number of small projects in 2019, in 2020 in Norway the capacity of small hydroelectric power plants increased by 134 MW and in Sweden the efficiency by 200 GWh. Sweden also sets goals for 2023 to add 600 MW to its capacity by upgrading old hydroelectric power plants. Meanwhile, the support of the state of Norway and the UK contributes to the construction of the North Sea Link and NordLink, projects to ensure the trade of renewable electricity between the countries(“Hydropower Status Report Sector trends and insights,” IHA 2021)

Feed-in tariff for renewable energy

Another relatively popular support for renewable energy sources of the state is Feed-in Tariff. This is a provision on preferential tariffs for the purchase of electricity to those power plants that run on biogas, wind, hydro, fuel based on wood or wood chips and meet the prescribed conditions prescribed in the legislation. The amount of the subsidy varies based on the three-month market price for electricity or the market price of emission quotas for electricity production.

The Ministry of Economy and Employment of Finland, like many European countries, approves a law on subsidizing the production of electricity produced from renewable energy sources. According to WSHPDR 2019, at least 22 European countries and 50 countries around the world determine a preferential tariff for renewable energy sources to support the operation of small hydroelectric power plants. Asia (16 countries) before the pandemic saw an increase in the spread of state support for Feed-in Tariff for small hydroelectric power plants. Countries that have adopted Feed-in Tariff for small hydroelectric power plants in their public administration are marked in green on the map (Figure 2.2.13). The governments of these countries plan to introduce Feed-in Tariff for small hydroelectric power plants in the near future: Angola, Gambia, Zambia, Zimbabwe, Lesotho, Malawi, Mozambique, Sudan, Senegal, Sierra Leone and Ethiopia (WSHPDR 2019).

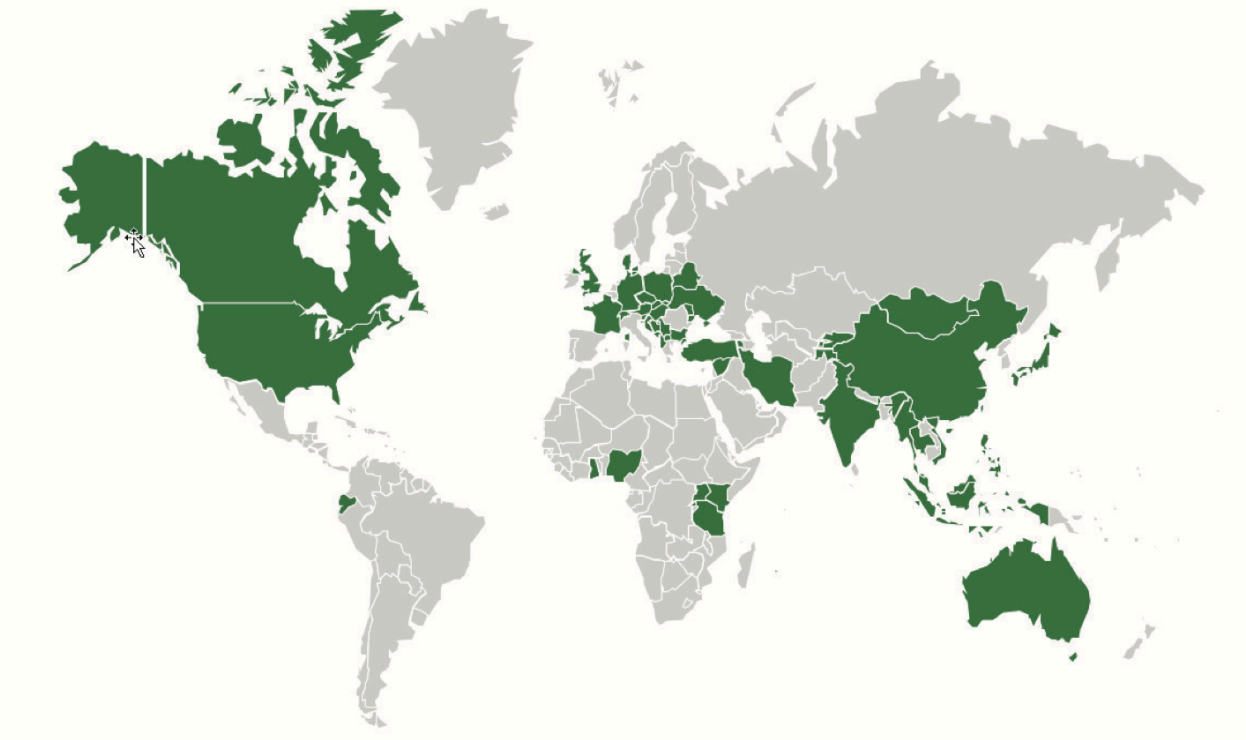


Figure 3.3.1 Countries with existing feed-in tariffs for SHP. Sourse: WSHPDR 2019

Russia can serve as an example of a country that has introduced grants for small hydropower. As a result of the competition, the best projects can provide some compensation for investment costs.

Finland's Climate and Energy Strategy defines goals to increase electricity production through hydroelectric power, for this Purpose Besides Feed-in Tariff Small hydropower is promoted by means of the existing investment support scheme and the Ministry of Employment and the Economy has established the guidelines for granting support so that it is possible to grant support for plants with the capacity 1 MW-10 MW (Finland's National Action Plan For Promoting Energy From Renewable Sources Pursuant to Directive 2009/28/EC Energy Department TYÖ-JA Elinkeinoministeriö Arbets- Och Näringsministeriet Ministry Of Employment And The Economy, 2019).

Summing up the current situation with small hydropower, it can be concluded that in order to manage small hydropower in our time, it is necessary:

- comprehensively study and continue to study legislative regulation in electricity production;

- comply with all legislation at all stages of the implementation of a small hydropotential;

- to pay attention to innovations and new technologies and also new policies related to them and particular environmental standards.

- to participate and initiate state support in the sphere.

State bodies for the development of small hydropower in the country in due time need:

- establish clear goals for the development of hydroelectric power plants in the legislative order;

- simplify the licensing process by creating a single center for obtaining standard permits and contracts.

- ensure that all relevant policies and regulations have been developed regarding the construction and operation of small hydroelectric power plants.

- provide inventory of small hydropower plants of all the regions.

-take into account local conditions and support cooperation between institutions responsible for the environment and electricity, water resources.

- provide periodic analysis of hydropower potential.

- expand financial incentives for hydroelectric power plants, as well as for other renewable energy sources together and simultaneously.

3.3.2. Results of survey

According to the described methodology, a survey was conducted among owners/managers of small hydroelectric power plants in the Nordic countries. The purpose of the survey was to find out the current state of small hydroelectric power plants in the region on the basis of those who agreed to take part in the survey, the age of the structure, capacity, how many hydroelectric power plants require rehabilitation, and whether these hydroelectric power plants have permanent equipment suppliers, as well as opinions about composite materials and what method of financing they would prefer with the necessary rehabilitation.

According to the results of the survey, the results were obtained, which are reflected in Appendix 2.

In this paper, it was interesting to pay attention to the following response statistics:

About 60 percent of the respondents are connected to the central power supply (figure 3.3.2.).

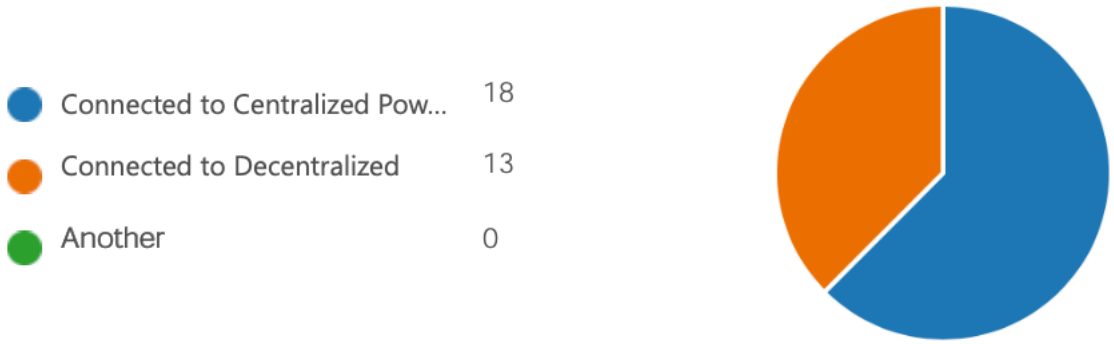


Figure 3.3.2. Distribution of answers to the question concerning Hydroelectric plant grid connection

The votes of those participating in the survey were equally divided on the issue of the need to install fish passages (figure 3.3.3.).

Figure 3.3.3. Distribution of answers for the availability of fish ways

On the question of how often a hydro power plant stops equipment for replacement and repair, the most popular answer was 2 times a year. There is variety in answers, this suggests that each hydro power plant is unique, and the chosen management strategy differs from one hydro power plant to another (figure 3.3.4.).

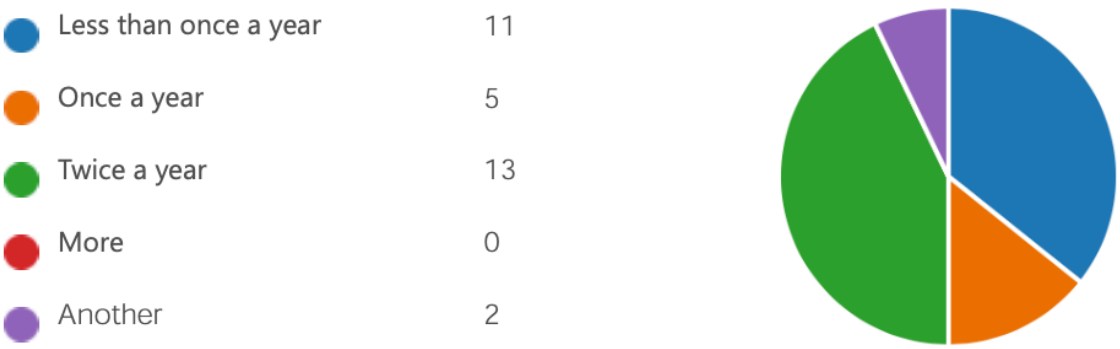


Figure 3.3.4. Distribution of answers for how frequently the power plant equipment are stopped for repair and replacement

When asked what breaks most often among the proposed equipment, half of the survey participants answered turbine (figure 3.3.5.).

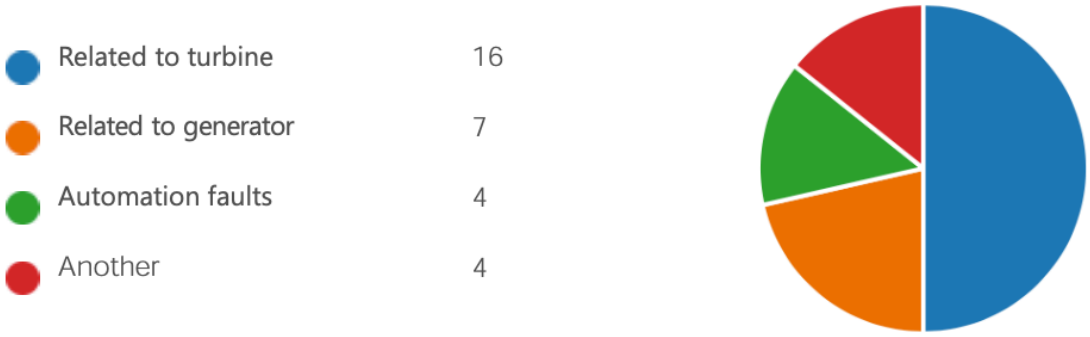


Figure 3.3.5. Distribution of answers on what types of damage is most common in hydropower plant equipment

Most respondents to the survey do not resort to assistance in installing equipment from the manufacturer (figure 3.3.6.).

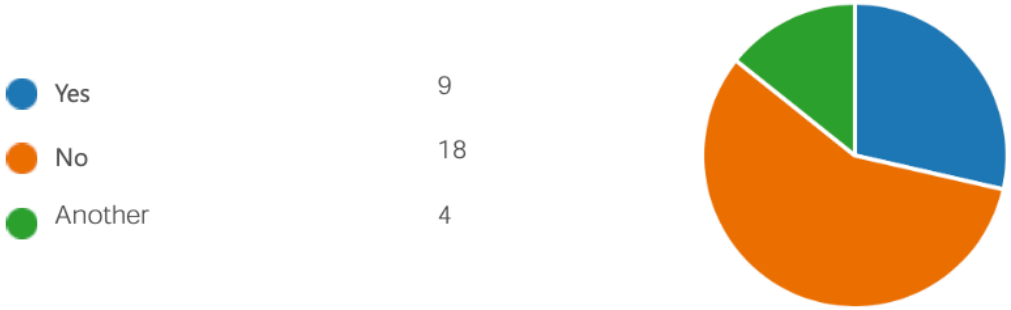


Figure 3.3.6. Distribution of answers on the question of does the respondent involve manufacturer in the repairing of the equipment

Half of the owners/managers who answered the survey questions want to rehabilitate or install a new hydroelectric power plant within the next two years (figure 3.3.7.).

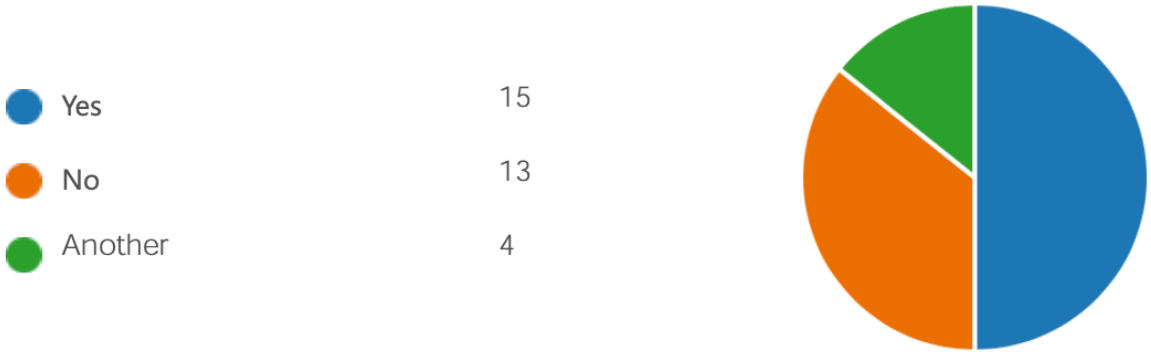


Figure 3.3.7. Distribution of answers on plans to rehabilitate the hydroelectric plant by equipment replacement or to build a new hydropower plant within the next 2 years

The votes were divided equally between those who answered that the current operating conditions of a small hydroelectric power plant satisfy all environmental standards and between

those who answered that they do not (figure 3.3.8.).

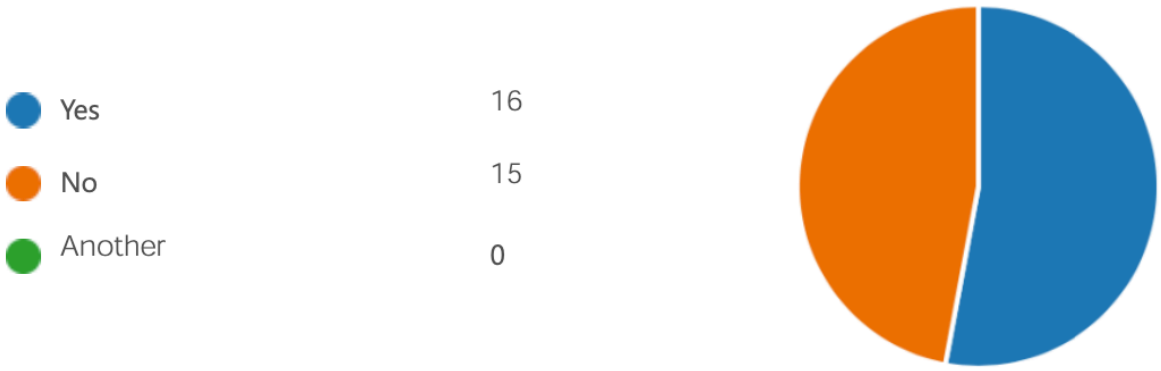


Figure 3.3.8. Distribution of answers for the question on does the hydropower plant currently meet the environmental requirements

More than half of respondents to the survey are ready to consider a technical and commercial proposal for the replacement of existing hydro turbine equipment on an equal basis with other proposals if the proposed equipment will be partially made of Composite. Only about 10% of all survey participants categorically refer to the installation of a composite turbine. It may follow from this that an ambiguous understanding and skeptical attitude both in one direction and in the other is not supported by a sufficient amount of research and publicity regarding the new technology (figure 3.3.9.).

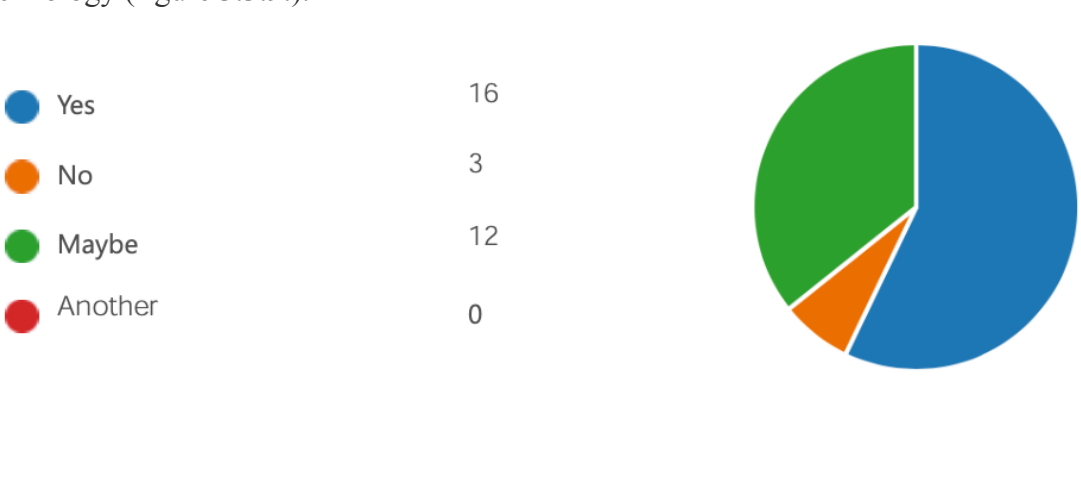
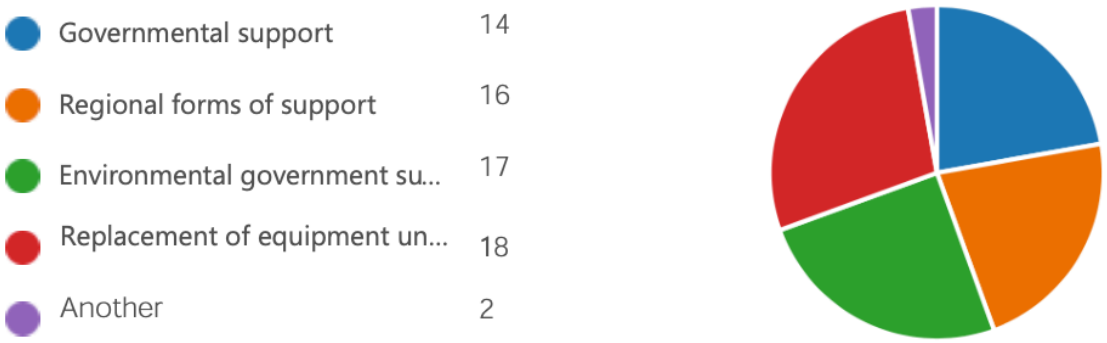


Figure 3.3.9. Distribution of answers on whether the respondent is ready to replace their current hydro turbine equipment with turbines partially made of composite material

The interest of owners/managers of small hydroelectric power plants in determining what kind of support from the state they would be interested in was also the purpose of the survey. Participants could choose several answers to this question. The results of the selected responses showed a relative equal distribution between the proposed types of support. This result may mean that there is no one state support that satisfied everyone with its conditions, because not one option did not score 100% of the choice of all participants. And also this result may say that in the region selected for the survey, namely in Norway and Sweden, the proposed types of support are evenly distributed and take place (figure 3.3.10.).



3.3.10. Distribution of answers for the question on what kind of financial support tools the respondent is interested in

Summing up all of the above, at present it can be concluded that there is an unused potential of small hydroelectric power plants in the Northern Europe region, which can replenish their potential through renovation. The changing climate in view of global warming, according to experts, will contribute to more precipitation in this region. The system of regulation and support of the state is available and is functioning adequately, there is an affordable green tariff. And the sphere of new technologies in the region has a wide offer, there is a trend for the registration of patents in the field of management of small hydroelectric power plants.
And the question of how long it takes to pay off investments in the rehabilitation of old small hydroelectric power plants, as well as what the rehabilitation project process includes, will be discussed in the next chapter.

4. RECOMMENDATIONS FOR DEVELOPING FEASIBILITY STUDY OF REHABILITATION OF THE ASKOLA SMALL HYDROPOWER PLANT IN FINLAND

4. 1. General characteristics of the Askola small hydropower station in Finland

An analysis of the market and the state of affairs in the small-scale energy industry shows the need to use the hydropotential through the construction of new and restoration of old small hydroelectric power plants. The trend towards the development of renewable energy sources, as well as contributes to the improvement of hydropower, in view of its relatively inexpensive installation and the cost of electricity (Strielkowski, 2020), also contributes to the development of other modern sources of renewable energy such as solar and wind power plants, etc., which do not depend on the state and position of rivers. For the same reasons, the economic problems of investing in small hydroelectric power are superimposed. As a result, the regulatory terms of operation of power equipment are violated everywhere, renovation processes are slowed down, as a result, increased aging of equipment. Environmental standards are being tightened everywhere in view of the transition to green electricity. In connection with these events, among the already functioning small hydroelectric power plants, the question arises of developing and implementing a new optimal management strategy and maintenance and repairs.

The management strategy of small hydroelectric power plants should be built in accordance with the requirements and meet the set goals for obtaining benefits from the sale of electricity. Small hydropower should give priority to the use of new technologies, continue the process of improvement and receive support from the state.

Recommendations for changing the strategy in this paper are developed for the small hydroelectric power station "Askola" in Finland, taking into account local conditions.

General information about Askola Hydropower plant is presented below.

Askola Hydropower plant is located on the Porvoo (Porvoonjoki) river in Askola is a municipality of Finland. It is located in the Uusimaa region Southern Finland. The Vakkola Rapids on the Porvoo (Porvoonjoki) river have been used for agricultural work since the Middle Ages. At the turn of the 20th century, a sawmill and planning mill were built on this site, and the construction of the power plant was completed in 1909. Today, the hydroelectric power station has 5 hydroelectric units with a total capacity of 750 kW, net heat 9 meters. The average annual output of the power plant is about 3,000,000 kWh of electricity. Maximum flow rate of HPP through all units 15 $м^3$/s. Net head – 9 м. Discharge of Porvoonjoki river on Vakkolan rapids 1 – 140 $м^3$/s.

A photo of the Askola small hydroelectric power station can be found below (Figure 4.1.1).

Figure 4.1.1. Askola SHPP, Finland. Source: Finnrunner Oy

Askola has two horizontal Francis turbine each 125 kW capacity installed in the 60s of the 20th century, Hydraulic units have a common outdoor wooden penstock length of approximately 65 m.; 2 turbines each capacity 210 kW and 1 turbines 90 kW Tube turbine installed in the 90s of the 20th century Hydraulic units have a common/ segregated underground metal penstock length of approximately 115 m. Two existing water intake are equipped manual inlet gate and trash mesh. On the right bank there is an active fishing way and a functioning spillway with automatic gate.

Porvoo River is a small river in Finland. The Mediaeval town of Porvoo is situated in the river delta. It is the main river of the Porvoonjoki drainage system, the sources of which are located on the southern slopes of Salpausselkä in Kärkölä, Hollola and Lahti. The river flows through Orimattila, Pukkila, Askola and Porvoo into the Gulf of Finland. The agricultural landscape of the Porvoo River with its ancient settlements, villages and manors together with the old town of Porvoo is part of the national landscapes of Finland.

Parameters of Askola SHPP:

Length 143 km;

Basin size 1,271 km^2;

Average discharge 1 to 200 m3/s;

Discharge of Porvoo river on Vakkolan rapids 1 – 140 $м^3$/s.

To collect information about the management strategy of the Askola small hydroelectric power plant,

The main issues were the basics of Askola management, the desire to improve the existing strategy for managing the operation of the station.

The following data in addition to the main physical characteristics of Askola were obtained during the interview:

All requirements are met, including an environmental impact assessment (EIA), an environmental license is available, flood protection is installed, there is gradient control;

Environmental standards established by the Energy Department of the region: ISO 140001;

The owner of the object is one (full ownership);

The autonomy of the object: a separate enterprise;

Technical and managerial potential: one turbine is not working properly;

Political stability and transparency in cost management: at a high level.

During data analysis these main reasons for the development of a new strategy were conclude:

- The owner admitted that the hydroelectric power plant is not working at full capacity, and wants to increase revenue and profitability, as well as reduce operating and maintenance costs.

- The owner wished to compare the existing management and maintenance with international best practices;

- A potential investor in the upcoming reconstruction project wants to see an assessment of the owners' capabilities in the field of operation and maintenance to ensure the sustainable operation of facilities;

- In the near future, it is planned to conduct an inspection by regulatory authorities on compliance with legal requirements and safety regulations.

Management and maintenance and repair strategies apply to all activities necessary for the operation and maintenance of hydropower facilities, including repairs and reconstruction.

After analyzing the available information obtained during interviews with the owners of Askola and official documents, the following conclusions were made about the necessary recommendations for the management of a small hydroelectric power plant with the focus on the following key components:

- improving the efficiency and reliability of hydropower by taking into account the full life cycle of a hydroelectric power plant: design, construction, commissioning, operation and reconstruction itself, as well as decommissioning at the end of its service life;

- protection of the environment, including aquatic inhabitants and water quality, personnel involved and the population of nearby areas;

- maximizing benefits for stakeholders, including the provision of low-cost, reliable, renewable energy.

4. 2. Methodology of project management for small hydropower plant rehabilitation

Before starting the renovation of a small hydro power plant, the manager needs to clearly understand that with the help of it, it will eliminate safety threats, ensure labor safety, increase the efficiency of electricity production, ensure the economic efficiency of work and improve operation and maintenance.

The proposed methodological approach of performing the renovation of a small hydro power plant allows providing the necessary conditions for its technically configured management with minimal costs and environmental impact.

According to the rules of the circular economy, the existing and sufficiently functioning facilities or equipment should be fully utilized. Everything that no longer fulfills its mission is liable to be replaced by matured new technologies. New technologies are also existed as new processes, new equipment and new materials in order to improve energy conservation or other technical /financial/environmental sides of the hydropower station (better all together) and which ultimately meet the protection requirements. Outdated technologies should not be used.

If a hydroelectric power plant has an element that does not handle its functions, the choice should be made against repairing of it and utilization and replacement of new equipment or component if the objects or machinery have significant defects, and their safety cannot be insured even after multiple repairing or it is forecasted that the repair will cost over 60% of the cost of the new equipment.

According to the Development of Small Hydroelectric Power Plant Management documentation, before starting physical work on a hydroelectric power plant, an analysis and assessment of the condition, determination of the safety of the equipment and the facility (if there are signs of non-safety) must first be performed. The next stage is a feasibility study to determine the necessary measures of technical renewal. Comprehensive attention should be paid to environmental and social effects (in particular, the release of environmental wastewater and protection of environment), it must be remembered that the design of the fish passage should be installed in accordance with the actual position of the power plant. The project for the reconstruction of a small hydroelectric power plant should not contradict the provisions of local and national regulations for the project (Technical Guidelines for the Development of Small Hydropower Plants Management Part 3: technical Renovation, 2019).

The manager's algorithm was compiled (see Figure 4.2.1), with the help of answers to these questions, the manager and his working team can navigate whether the renovation of a small hydroelectric power plant system is needed or renovation is not a solution to a specific case.

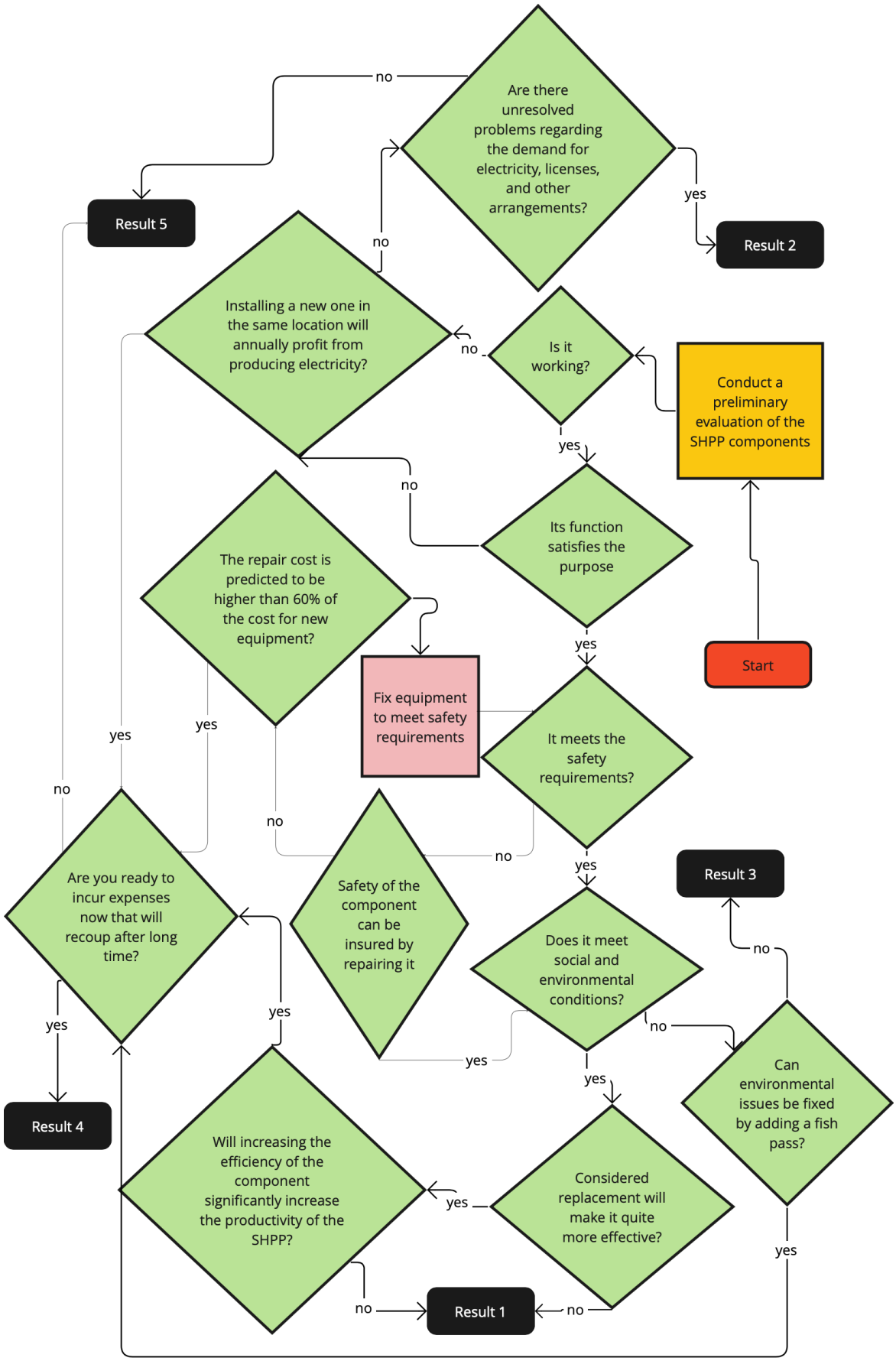


Fig. 4.2.1. An algorithm for determining the need for rehabilitation of a small hydroelectric power plant or its irrelevance

Table 4.2.1. Explanation to figure 4.2.1

Result 1	According to the concept of a circular economy, where consumption and production occur in a closed cycle with 3 conditions: resources are used to the maximum; waste does not accumulate; there is no negative impact on nature. If you have "Result 1" as a outcome of the passage, congratulations, it means that you do not need to renovate this element yet, but on the contrary, you do not need to fully use the existing one. Tip: Use existing equipment, carry out periodic assessment, maintain its condition with regular technical support. Monitor changes in regulatory documents in order not only to make a profit, but also not to harm nature and, in particular, people.
Result 2	If you have "Result 2" as a outcome of the passage, this means that renovation may not be your solution to all the problems. Tip: Firstly, it is necessary to make sure that the electricity produced is in demand, there is appropriate documentation: license, sales contract, certificates of state support and others.
Result 3	If you have "Result 3" it is necessary to conduct an environmental audit of a small hydroelectric power plant with the help of the environmental management service. During the audit, experts may identify inconsistencies or notifications in detail. Inconsistencies are classified as insignificant or significant. For each nonconformity, the manager should develop corrective actions, as well as analyze the causes of nonconformities.
Result 4	"Result 4" shows that you are set up for the rehabilitation of a part or parts of a small hydroelectric power station, nothing stops you, you have a clear understanding of what is subject to renovation, the goals of renovation and the necessary funds, and beyond that, perhaps not with a immediate payback. Good luck!
Result 5	If you have come to the 5th "Result", unfortunately, you do not have the necessary permits, resources, desire or even understanding to rehabilitate a small hydroelectric power plant. Tip: additionally involve an expert for a detailed assessment and search for solutions, or sell a small hydroelectric power plant.

Only after the maneuvers aimed by clarifying the goals of rehabilitation of a small hydroelectric power plant (for example, using the scheme presented earlier), the mandatory conditions of the rehabilitation project should proceed to the next stage.

If research proceeded further, in addition to operation and maintenance management strategy, factors that also need to be paid attention to while to investment decision making process for the construction/renovation of a small hydroelectric power plant showed in a table 4.2.2.

Table 4.2.2. Key qualitative and quantitative factors small HPP for making a decision in renovation

Qualitative Factors	Quantitative Factors
Availability of qualified specialists in the field of hydroelectric power plants with work experience, construction companies.	The amount of remuneration of qualified workers for the construction / renovation of a small hydro power plant depending on the complexity of the work and the location region.
Distributed supply chain of basis power equipment, auxiliary components, materials and raw materials. Their remoteness.	The costs of materials and equipment used for the construction/ reconstruction of a small hydroelectric power plant (including VAT, which may vary from region to region and state subsidies).
Affordable financing, loan permits, government support in the form of grants, certificates (if it is interested in landscaping).	The cost of electricity, the electricity purchase tariff (compliance and agreement on "green" tariff), depending on the attractiveness of the region's electricity production.
The underlying demand within the enterprise /country/region or international demand for electricity, which is important in finding the location of production facilities.	The amount of necessary capital, financial security, credit and interest.
The development of transport logistics (including large-sized transport) for access to the construction of equipment and materials.	The cost of equipment, transportation, remoteness, altitude of the location of a small hydroelectric power plant.
Formation of industry infrastructure (specialized universities, research and design organizations, integrator companies, international knowledge exchange)	The cost of currency, commissions, maintenance, taxation, fee, license cost, depending on the region of a small hydroelectric power plant location.

Figure 4.2.3 represents the order and the required number of stages of renovation management of a small hydroelectric power plant.

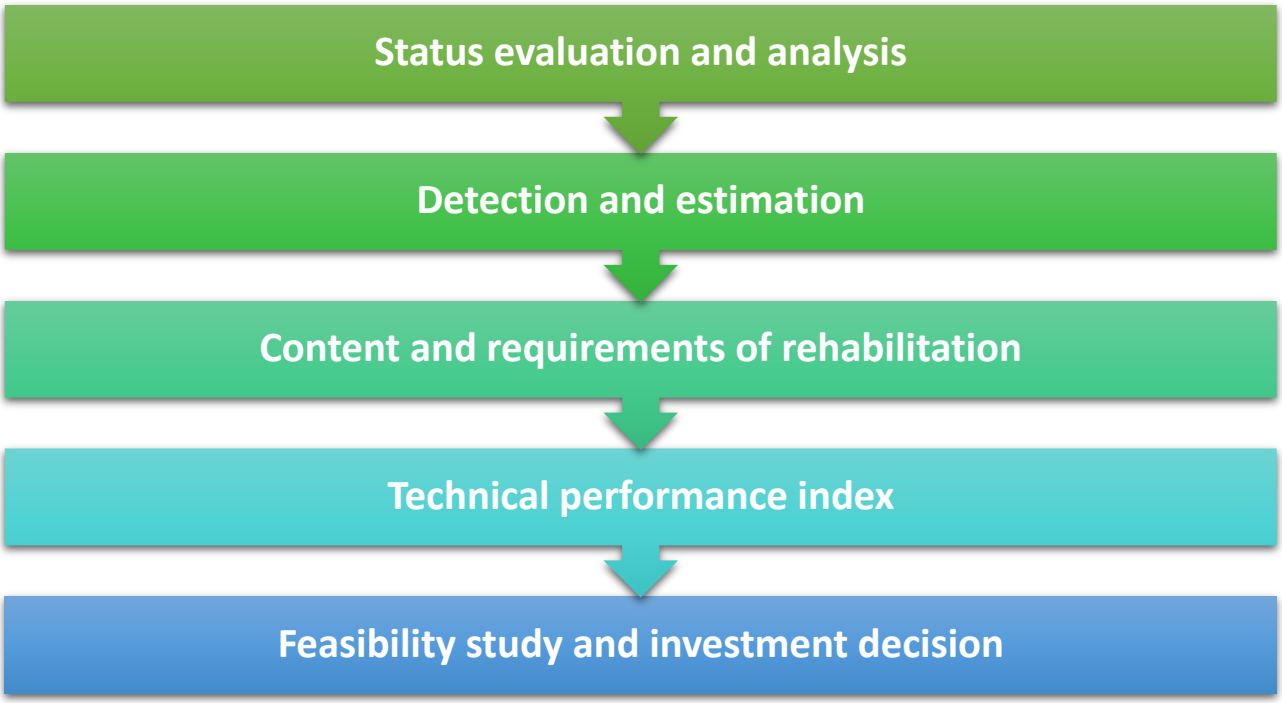


Figure. 4.2.2. Stages of renovation of a small hydroelectric power station

The next paragraph will be devoted to the financial assessment of the rehabilitation of a small hydroelectric power plant "Askola"

Further, each stage of renovation will be considered in more detail. For this purpose, a practical checklist for the rehabilitation management of a small hydroelectric power plant (table 4.2.3) was compiled separately for each stage.

Table 4.2.3. Practical check list for rehabilitation management of small hydroelectric power plant

Status evaluation and analysis		
1	Following data is collected:	
	engineering design of the power station	☐
	data on completion and performance	☐
	maintenance records of all previous years	☐
	hydrological data and precipitation data	☐
	Other relevant data such as safety detection and performance assessment	☐
2	Hydraulic engineering structures, electromechanical and hydromechanical equipment and other equipment are evaluated in terms of safety and performance:	
	performance dimension	☐
	safety in accordance of the preventive testing	☐
	performance testing	☐
	safety assessment	☐
	operation and maintenance data	☐
3	River planning and hydrologic data is studied:	☐
	water head	☐
	water flow	☐
	sediment concentration	☐
	downstream and upstream water level	☐

	The available runoff and the design flood are reviewed The SHPP is analyzed for floods that have occurred (if any) The SHPP is being analyzed for the renewal of hydraulic structures (by increasing the volume of water intake or increasing the height of the dam/dam) The impact of climate change for the safe spillway capacity is checked The runoff is checked by updating or deleting the capacity Ecological flow reviewed Suitability usable abandoned water is studied Existence of any conditions which may increase/reduce the flow studied Existence of conditions that may decrease or increase the working head studied Conditions for reducing the head loss and the reduced flow loss studied	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
4	Possible environmental and social impacts of the SHPP rehabilitation is evaluated	☐
5	The necessity of updated or deleted of power station capacity is considered	☐
6	Demonstrated the necessity of renovation and feasibility of the it	☐

The next stage after status analysis and evaluation is the Detection and estimation of rehabilitation of a small hydroelectric power station, the manager's checklist related to this stage is discussed below.

	Detection and estimation	
1	Before rehabilitation project is started the power station is inspected for: hydraulic safety of structure project quality and operation and management conditions	 ☐ ☐
2	During the inspection, the structures are also checked at the time of operation in abnormal conditions	☐
3	The comparison test is performed (to measure before and after the technical renovation economic performance and effects of changes the particular part) The method of assessing and conditions are selected, as well as the set of instruments and meters (in order to repeat the test after renovation in the same conditions)	☐ ☐
4	According to the certain case the performance of the turbine is executed, either performed in compliance with the related regulation of International Standard *Hydraulic Machines-Acceptance Tests of Small hydroelectric Installations* (IEC62006-2010)	☐
5	All electromechanical equipment influencing safe operation such as exceeding the design service life or issue in abnormal condition is evaluated. The major constructional elements are examined for: erosion strength and rigidity deformation and cracks	☐ ☐ ☐ ☐
6	The penstock, specials gate and hoist members are inspected for:	☐ ☐ ☐ ☐

	corrosion	
	deformation/cracks/twisting	
	erase of the all-constructional members strength and rigidity	
	The welds are inspected (non-destructive testing) for:	
	defections	
	strength and rigidity	
7	There are results of performance test of the main electrical equipment (either performed in compliance with the related regulation of International Standard *High-voltage Test Technique- Part 3: Definition and Requirements for On-site Testing (IEC60060-3-2006)*:	
	results of past preventive test	☐
	current test results before renovation	☐
8	The evaluation and detection of the results are applied as the foundation for defining the necessity of rehabilitation and future renovation technical plan	☐

After a comprehensive assessment of the current state, the next stage is the elaboration of the optimization of the necessary elements and evaluation and technical planning. The checklist for the next step Content and requirements of rehabilitation continues below.

	Content and requirements of rehabilitation	
1	Rehabilitation is carried out if even one of these items after assessing the current condition:	
	poses a security threat	☐
	have been noticeable geological changes	☐
	large variation in the hydrological characteristics of the upper and lower reaches	☐
	the existing water pressure is not used	☐
	other energy resources are not used	☐
	performance of the hydroelectric power plant decreased due to equipment	☐
	poor technical condition of the equipment and/or structure	☐
	environment is exposed to a significant negative impact from SHPP	☐
	another reason why rehabilitation is necessary	☐
2	The efficiency coefficient of the working part of the equipment is calculated	☐
3	If it is decided to carry out the replacement by increasing the capacity, the scale of the installed capacity should be revised at the time	☐
	of structural strength	☐
	sufficiency of equipment	☐
	strength of hydraulic transients	☐
	water intake	☐
	pressure losses	☐
4	Mandatory requirements for rehabilitation:	
	potential security threat has been eliminated	☐
	low risk of flooding/consequences of flooding	☐
	The design is convenient	☐
	The process of water drainage for rehabilitation has been established:	
	Channels have been laid to another zone	☐
	Environmental requirements for the drain are met	☐

5	possibility of raising the height of the dam to generate more pressure and more electricity generation is checked	☐
6	possibility of removing sediments in the riverbed and reducing the level of the tail water of the installation is checked	☐
7	height of the turbine thrust is observed	☐
	The rehabilitation of the water drainage system was carried out as follows:	
	Deposits and debris were removed	☐
	install additional equipment for garbage collection	☐
	possibility of self-washing of deposits is facilitated	☐
	means for storing garbage and unloading ice added	☐
	dredging and anti-sewage treatment are performed on the forebay, tunnel and channel of the diversion structure	☐
	wastewater has been cleared of barriers	☐
8	The capacity of the tunnel and channel has been rechecked	☐
9	Flood control unit improved	☐
10	the strength of the generator support and crane beam revised	☐
	the strength of the floor slab with an increase in load revised	☐
11	project class revised	☐
	construction class revised	☐
	flood standard revised	☐
12	means of protection against freezing (ice-retaining bar and ice-retaining rack) for cold regions are installed	☐
13	The gate meets the requirements	☐
	The drain gate lift is equipped with a reliable backup power supply	☐
14	For the emergency lock bulkhead on the water intake of the installation and the lock bulkhead of the tail stroke, means for balancing the pressure and the level of filling with water are installed	☐
15	Technical re-equipment of the rod meets the requirements	☐
16	The control of threats to the safety of the dam reservoir has been revised and improved	☐
17	The hydraulic power and regulatory parameters of a tap-type pressurized water supply system equipped with one common pump servicing several turbines have been tested to achieve the expected goal of updating the capacity expansion.	☐
18	The selected turbine impeller is improved in terms of energy index, has excellent cavitation characteristics and good stability of operation	☐
19	The turbine is adapted to changes in pressure and flow to improve operating conditions and increase stability and efficiency	☐

20	With a high sediment content, the hydraulic and structural design of the turbine is improved in accordance with the volume of deposits	☐
21	The characteristic parameters, such as the operating power of the regulator is revised in accordance with the turbine parameters when changing the pressure, flow rate or diameter of the impeller	☐
22	The regulator is equipped with a fully manual control system in case the device requires starting in black mode	☐
23	A pressurized oil source is provided for the automatic braking device, provided that the requirements are met (if necessary)	☐
24	The repaired hydraulic turbine control system fully meets the requirements of:	
	emergency shutdown	☐
	of fast synchronization	☐
	to start and stop	☐
	increasing/decreasing the load	☐

To evaluate the planned rehabilitation actions, the next stage is the Index of technical characteristics. Its checklist is presented below.

	Index of technical characteristics	
1	After the technical upgrade of the power plant, the power of the unit and the efficiency of the unit meet the following requirements:	
	The output power of the installation must reach or exceed the design requirements for technical upgrade	☐
	In the nominal state, the efficiency of the unit should not be lower than the following indicators, which should be taken from high to low depending on the power of the unit	☐
2	The distribution of electromechanical equipment should be reasonable; the proportion of equipment in good condition should reach 100% for part of the technical upgrade	☐
3	After technical repairs, the noise of the turbine and generator during normal operation meets all the requirements	☐
4	Water leakage should not exceed 0.3% of the nominal flow rate of the turbine when the new non-conical guide blade is completely closed	☐
	At nominal pressure, the water leakage should not exceed 0.4% of the nominal flow rate of the turbine when the new conical guide blade of the jet turbine is completely closed	☐

If research proceeded further, in addition to rehabilitation management, factors that also need to be paid attention to while to investment decision making process for the construction/renovation of a small hydroelectric power plant showed in table 4.2.3.

Table 4.2.3 c Key Qualitative and Quantitative Factors small HPP for making a decision Manufacturing /Renovation

Qualitative Factors	Quantitative Factors
Availability of qualified specialists in the field of hydroelectric power plants with work experience, construction companies.	The amount of remuneration of qualified workers for the construction / renovation of a small hydro power plant depending on the complexity of the work and the location region.
Distributed supply chain of basis power equipment, auxiliary components, materials and raw materials. Their remoteness.	The costs of materials and equipment used for the construction/ reconstruction of a small hydroelectric power plant (including VAT, which may vary from region to region and state subsidies).
Affordable financing, loan permits, government support in the form of grants, certificates (if it is interested in landscaping).	The cost of electricity, the electricity purchase tariff (compliance and agreement on "green" tariff), depending on the attractiveness of the region's electricity production.
The underlying demand within the enterprise /country/region or international demand for electricity, which is important in finding the location of production facilities.	The amount of necessary capital, financial security, credit and interest.
The development of transport logistics (including large-sized transport) for access to the construction of equipment and materials.	The cost of equipment, transportation, remoteness, altitude of the location of a small hydroelectric power plant.
Formation of industry infrastructure (specialized universities, research and design organizations, integrator companies, international knowledge exchange)	The cost of currency, commissions, maintenance, taxation, fee, license cost, depending on the region of a small hydroelectric power plant location.

To provide a financial accounting of all costs that will be associated and required to develop, produce, deploy, sustain and dispose of a rehabilitation project was developed Life Cycle Cost (figure 4.2.3).

Life cycle cost (LCC) is an approach that assesses the total cost of an asset over its life cycle including initial capital costs, maintenance costs, operating costs and the asset's residual value at the end of its life (Sesana and Salvalai, 2013).

When considering the life cycle of a small hydroelectric power plant, it can be seen that building structures are manufactured for a period of 50 to 100 years, during preventive maintenance to replace mechanical and electromechanical systems (which last from 20 to 50 years) and replace electrical wiring and control systems every 10-20 years.

Figure 4.2.3. Life-cycle cost of small hydropower plant

Life-cycle benefits of small hydropower plant are shown in figure 4.2.4 below.

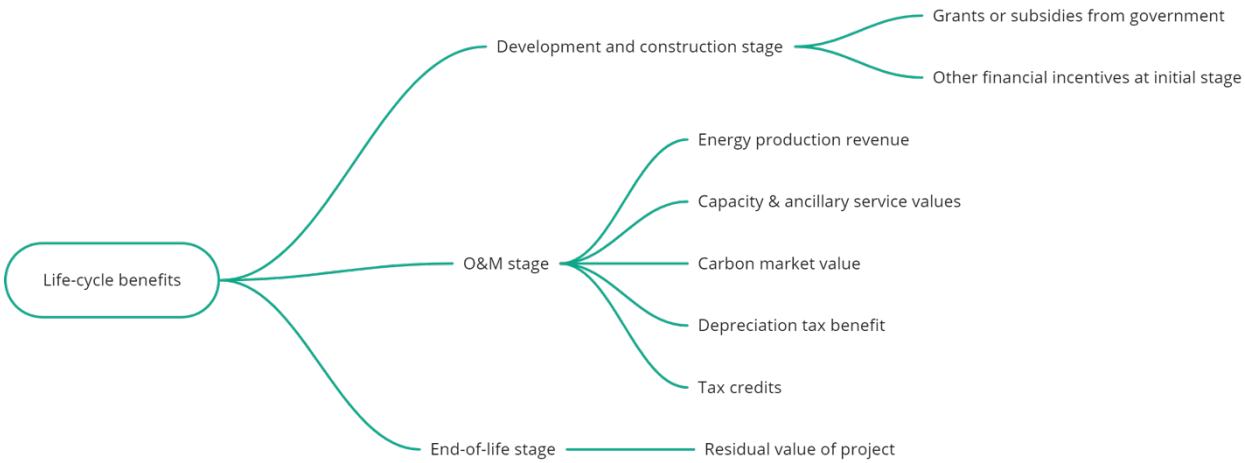


Figure 4.2.4. Life-cycle benefits of small hydropower plant

Life Cycle Cost Calculation (LCC) helps a hydroelectric power plant to be aware of where a plant is located on its life cycle, because the life cycle can have a huge impact on the profits and costs generated.

The final step is the construction of a feasibility study and an investment decision. Next, the paper will present the economic planning of a project for the rehabilitation of a small hydroelectric power station on the example of Askola in Finland

4. 3. Economic planning of rehabilitation for the Askola small hydroelectric power station in Finland

Finnrunner Oy, with the support of Business Finland and possible financing from the state, plans to reconstruct the Askola hydroelectric power station. Additional capacity will be achieved by installing a new hydraulic unit instead of the old turbine of the power plant. Also, a new water intake and a new water intake will be built for the new turbine.

Finnrunner will supply for the Customer a classic construction with implementation of the steel flow part of hydraulic turbine - for the generation electricity. In addition, Finnrunner will supply composite set flow part for the turbine, runner blades, guide vane - for R&D and pilot testing of the implementation composite materials in manufacturing turbine parts.

Implementation composite materials will be produced as an alternative, more environmentally friendly and modern material.

The Proposed Project

The proposed project would support the scaling up of power generation capacity by adding 150-210 kW to the total capacity of the hydropower plant. This would maximize use of water reassures, existing facilities, provide the additional power for the Grid and restore the historic power house building. New unit will generate approximately additional 700 000 kWh of electricity utilizing the same water flows at a very low cost compared to alternative generation from thermal or other hydropower projects, that is because all other infrastructure such as dam and power house are already constructed. Most importantly the gestation period of the project is short (8 months from the start of construction).

The primary components of the Project are:

- New Intake and manual gate equipment
- New composite penstock pipe line

- Powerhouse
- Rehabilitation Tailrace
- New auxiliary electrical and mechanical equipment for new DG set.

Another important advantage in development of this Project is that power generation part of the project will be free of problems in obtaining permits for the construction of hydroelectric power plants, which are often major causes of delay in hydro-electric projects. Environmental and social issues are relatively minor, since most of the infrastructure is already in place.

Scope of Works and Services

Finnrunner offers a full scope of works on the extension of the hydroelectric power station on EPC basis, these works include but are not limited:
Design, Manufacture, Supply, Constriction, Erection, Testing, Commissioning and and handing over to Employer of Turbines, Generators, Associated Accessories and Auxiliaries, Auxiliary Electrical Equipment, Mechanical Equipment – Penstock, Water intake and intake gates.
The scope shall include training of Employers personnel in operation and maintenance of all new equipment
The scope of work shall include complete set of documentation including: design drawing supported with thorough design reports, installation drawings, as-built drawings, operation and maintenance manuals and a complete set of quality documentation for manufacturing and testing of all the equipment.

Standards, Codes and Design

All design, materials, goods, plant, manufacture, testing and performances of the works shall comply with the latest current ISO / IEC / EN or DIN standards / codes where applicable, and/or other approved standards or codes.
If the Contractor proposes deviations from the specified or approved standards and codes or desires to use materials or equipment not covered by these standards and codes, the Contractor shall state the exact nature of the change, the reason for making the change and proof that these equipment or materials are equivalent or better, in every significant respect, to those specified.
The International System of Units (SI) will be used consistently for this Works, and all materials, fittings, components, items of equipment supplied for the works shall be standardized accordingly.
If after making diligent enquiries, the Contractor is unable to obtain an item standardized in SI units, written approval shall be obtained from the Employer to supply non-standard materials.
SI units will be used in all correspondence, documentation, calculations, drawings, measurements etc. If reference has to be made to non-standard items, the SI units shall be quoted followed by the non-standard units in brackets.

Description of new turbine

• Kaplan tubular turbine with horizontal shaft
• Kaplan-runner 4-blade
• Performed as S-turbine
• designed and hydraulically designed for the following data (table 4.3.1):

Table 4.3.1. Description of new composite turbine for Askola SHPP

Number of Units	1
Type of turbine	Kaplan S

Shaft arrangement	horizontal
Direction of rotation	clockwise
Rated turbine discharge (Q_R)	3.0 m^3/s
Rated head (H_R):	7 m
Design head (H_d):	7 m
Minimum net head (H_{min})	6 m
Rated turbine output (P_R):	191 kW
Synchronous speed (n):	500 rpm
Runner diameter:	approx. 768 mm

Cross-section turbine and generator illustrated on figure 4.3.1.

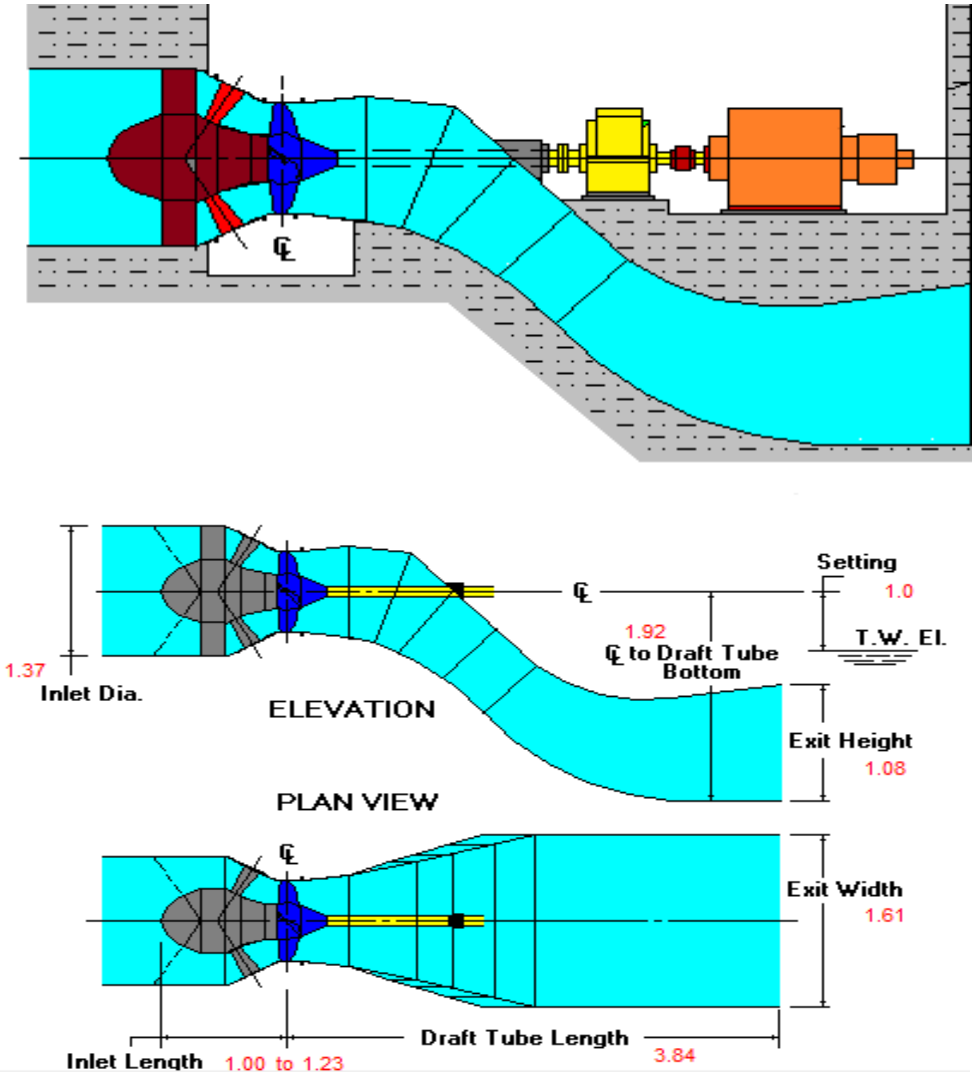


Figure 4.3.1. Askola small hydroelectric power station turbine layout. Source: Finnrunner Oy

The data for the Economic planning of rehabilitation for the Askola small hydroelectric power station in Finland, which was provided by the Finnrunner Oy, which is engaged in the rehabilitation of Askola, are presented below in the table 4.3.2.

Table 4.3.2. Data Askola small hydroelectric power station in Finland and rehabilitation costs by Finnrunner Oy

Parameter	**Number**	**Measure**
Installed capacity of composite turbine	200	kW
Estimated annual output*	1576,8	MWh
It is presumed that the price of the electricity will increase every year one point less than the inflation rate.		
The estimated cost of the project in € is as follows:		
1. Feasibility study	6100	€
2. Project design and management	60000	€
3. Civil works	132000	€
4. Electromechanical equipment	274000	€
5. Auxiliaries: Cabling Electrical cabinets Gates	70000	
6. Installation	51600	€
In the analysis, it is presumed that the project will be developed in whole development is finished and paid	8	month
Unforeseen expenses	4	%

Source: Finnrunner Oy Data.
*Annual output will be 1576,8 only if new turbine will be installed in the front part of the tube, according to the contract between the customer Askola and the Finnrunner company.

Calculations displayed further.

Sub-Total would be:

Feasibility study + Project design and management + Civil works + Electromechanical equipment + Auxiliaries (such as Cabling, Electrical cabinets, Gates) + Installation.

Sub-Total for Askola SHP is: 6100+60000+132000+274000+70000+51600= €593700

Finnrunner company suggests 4% as unforeseen expenses what is 593700*4%= 23748

Total investment for installation of composite turbine for Askola SHP by Finnrunner company can be calculated as Sub-Total + unforeseen expenses =593700+23748= **€617448**

According agreements between electricity buyer and owner, Tariff for 1 MWh will be €78,32. First year annual revenue then will be annual output multiplied by tariff what for Askola will be equal 1576,8*78,32 = €123489.

Estimated annual output = 12* month output =12*131,4 =1576,8

The investment cost per annual MWh produced by new composite turbine is: 617448/200= €3087.

Investment return time = Total investment /Year annual revenue* Tariff per MWh.

Investment return time = 617448/123489*78,32 = less then 5 years.

A table with deducted values is presented below.

Table 3.3.2. The final results of the calculation for the investment of the project for the rehabilitation of the small HPP Askola

Parameter	**Number**	**Measure**
First year annual revenue	123489	€
Tariff per MWh	78,32	€
Sub-Total	593700	€
Unforeseen expenses (4%)	23748	€
Total investment	617448	€
The investment cost per installed kW	3087	€/kW
The investment cost per annual MWh produced is:	392	€/MWh
The operation and maintenance cost per year, estimated at 4% of the total investment	24698	€
Investment return time	5	years

According to calculations, it is expected that the rehabilitation project will be ready to fully functionate after 8 months. The planning process and feasibility study will be given the first month, as well as the planning and approval process. In total, at the end of the first month, the cost of the feasibility study and 50% of the cost of project design and management will be paid to the construction company. The remaining half of the project design and management costs will be transferred by the customer before the end of four months. 60% of the construction work will be completed and 50% of the electromechanical equipment including auxiliary devices will be paid for by the end of half year from the beginning of project. The time of completion of construction and payment of 100% of the project is planned for the end of 8 months. Further in the work, the Gantt chart of the rehabilitation of the Askola small hydropower station project is presented on figure 4.3.1.

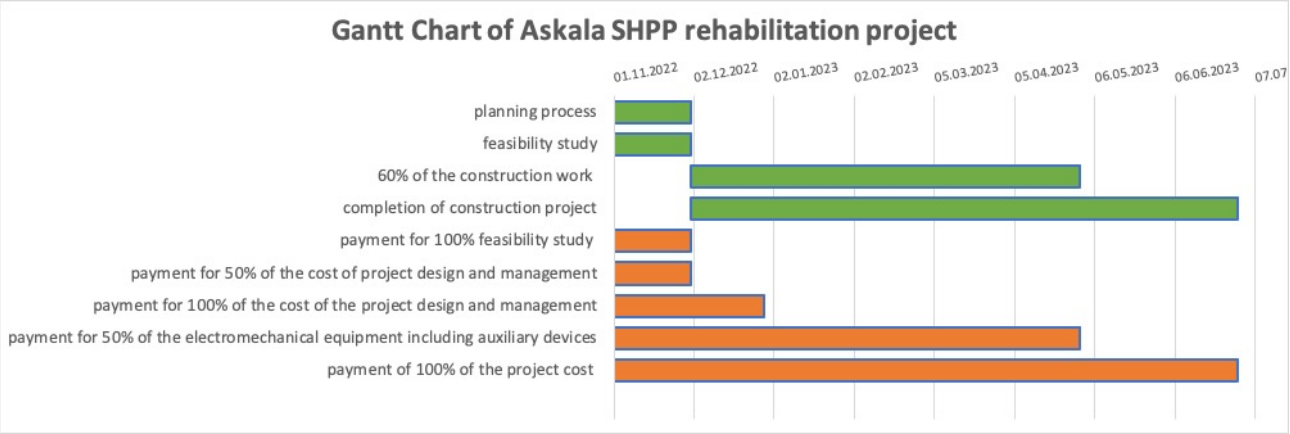


Figure. 4.3.1. Gantt chart of the rehabilitation of the Askola small hydropower station project

The construction with a new composite turbine is going to operate from the start of 9th month (the starting point of the zero year of operation of the hydropower plant after rehabilitation). From the first year of operation at the end of each year, are starting to calculate . At the same time, as mentioned earlier, calculations are made taking into account the fact that the inflation rate is growing by one point more than electricity prices.

The main conclusions obtained during the calculations carried out on the rehabilitation project as part of operational and maintenance management for the Askola small hydroelectric power station in Finland are as follows:

The required funding is = €617448;

Duration of the rehabilitation project = 8 months;

The payback period of investments* = 5 years.

*when installing a new turbine made of composite materials, it will be in the front part of the tube according to the contract between the customer Askola and the Finnrunner company.

Results of Economic planning of rehabilitation for the Askola small hydroelectric power station in Finland: recommendations on the management of the “Askola” small hydropower plant in Finland were made, recommendations on the rehabilitation project as part of the operation and maintenance management were given, and a justification of the renovation of a small hydroelectric power plant using the example of the Askola small hydropower plant in Finland was presented.

5. RESULTS

Awareness of the possibilities of the modern world and priority issues are part of the goals of scientific work. In this paper, the problem of the ambiguity of the decision on the rehabilitation of an old small hydroelectric power plant is considered. The paper also considers modern solutions that can be used as part of the rehabilitation of an old small hydroelectric power plant.

In the scientific field, there was a shortage of works on the topic of small hydroelectric power plants. As part of this work, an analysis of the literature on Hydropower generation energy was made. The advantages and disadvantages of small hydroelectric power plant were collected and briefly described. Also, the paper considered hydroelectric power plants in the context of sustainable development.

Finding successful examples to strive for in relation to the management of small hydropower is a help for the development of less developed cases. The analysis of current installed and potential capacity of hydroelectric power plant was carried out in the work. “Working” ways to support small hydropower from the state were found. Modern solutions for the modernization of small hydroelectric power plants were collected and described, such as new technologies, modern materials, digitalization and interconnection in the network.

On the practical side, the collected information and its analysis were applied to develop the methodology of project management for small hydropower plant rehabilitation. An algorithm, created to facilitate the decision on the need to make a decision on the rehabilitation of a small hydroelectric power station or its irrelevance, has been developed. The qualitative and quantitative factors small HPP for making a decision in renovation were collected into a single table. The work included clarify stages of renovation management of a small hydroelectric power plant, and a managers’ practical checklist for the for the rehabilitation management of a small hydroelectric power plant was compiled.

Regarding the economic component, there is a shortage of works in the scientific community on the payback of rehabilitation of old small hydroelectric power plants. In this work, financial aspect of the replacement of one old turbine with a new composite alternative was calculated, its payback have defined approximately 5 years of operation of this turbine.

6. DISCUSSION AND CONCLUSION

Electrical capacity of Nordic countries is estimated as 206 thousand MW, and their hydropower capacity equal 60 thousand MW. 4,4 thousand MW is installed small hydropower plants (<10 MW). Potential of SHPP (economic potential suitable for industrial use) is more than 10.8 thousand MW. This shows that hydropower is an important asset for energy Nordic countries, and this potential should be used. This thesis showed that the payback of rehabilitation and modernization projects can pay off within a few years, but they are justified, due to the long-life cycle of small hydroelectric power plants.

In this study, it was analyzed that the world is in a transitional period in terms of electricity production and consumption, when all-known technologies with burning of natural resources are recognized as causing irreversible harm to nature. To solve this as a global problem, the world is now looking for certain solutions, one of which is to obtain energy from renewable energy sources. Hydroelectric power is one of the promising aspects of the transition to renewable energy sources, given its long history, self-sufficiency, low cost of unite energy and other advantages. The results of the study showed that only small proportion of the world's hydro potential is used. Greater extent of world energy capacity can be done not only through the construction of new hydroelectric power plants, but also through the restoration and rehabilitation of old ones. Due to proper management, the existing small hydroelectric power plant can achieve its goals for electricity production without harming nature for up to 100 years. The work justify rehabilitation and recommend steps for building the feasibility plan for small hydroelectric power plants for rehabilitation management that is suitable for Nordic SHPPs the realities of the modern world.

Summing up, we can draw the following conclusions.

The network of small hydropower has a great potential for providing the population due to its advantages. Management of existing and new develop small hydropower plant should be mainly focused on long-term sustainability, that is, it should take into account not only economic profit, but also the satisfaction of social needs and compliance with environmental standards. That's why justification of small hydroelectric power plant rehabilitation important before the investing. The work justify rehabilitation with changing not working turbine to composite turbine "Askola" small hydroelectric power plant in Finland. This situation shows how while one of the turbines is not functioning due to old age, the hydroelectric power plant receives less electricity and becomes less cost-effective despite the natural potential and the available equipment and buildings. This situation can continue for many years. Presented on the example of Askola, the economic calculation of replacing an old turbine with a new one made of composite material shows that for about 5 years after the installation of the turbine, observing all agreements, the cost of the rehabilitation project (including all costs from the development of a feasibility study to the installation and configuration of related electrical equipment) is fully paid off. In addition, the advantage of composite material is not only its weight and erosion resistance, but also a lower carbon footprint during production and operation, which makes a small hydroelectric power plant more stable in the future.

REFERENCES

"18 2021 Hydropower Status Report Sector trends and insights" (2021).
"2021 Hydropower Status Report Sector trends and insights" (2021).
"WSHPDR 2019 Case Studies" (2019).
Aboagye, B. *et al.* (2022) "Investigation into the impacts of design, installation, operation and maintenance issues on performance and degradation of installed solar photovoltaic (PV) systems," *Energy for Sustainable Development*, 66, pp. 165–176. doi:10.1016/j.esd.2021.12.003.
Abubakar Tadda, M. *et al.* (2020a) "Operation and Maintenance of Hydraulic Structures," in *Hydraulic Structures - Theory and Applications*. IntechOpen. doi:10.5772/intechopen.91949.
Abubakar Tadda, M. *et al.* (2020b) "Operation and Maintenance of Hydraulic Structures," in
Adepoju, Omoseni. (2022). Internet of Things (IoT). 10.1007/978-3-030-85973-2_8.
Barbier, E.B. (1987) "The Concept of Sustainable Economic Development," *Environmental Conservation*, 14(2), pp. 101–110. doi:10.1017/S0376892900011449.
Barr, J. (no date) "Improving Maintenance of Micro Hydropower Systems in Rural Nepal-A qualitative study evaluating problems affecting micro hydropower maintenance and their possible solutions."
Belagoune, S. *et al.* (2022) "A Discrete Chaotic Jaya algorithm for optimal preventive maintenance scheduling of power systems generators," *Applied Soft Computing*, 119. doi:10.1016/j.asoc.2022.108608.
Belsnes, M.M. *et al.* (2016) "Applying successive linear programming for stochastic short-term hydropower optimization," *Electric Power Systems Research*, 130, pp. 167–180. doi:10.1016/j.epsr.2015.08.020.
Bernardes, J. *et al.* (2022) "Hydropower Operation Optimization Using Machine Learning: A Systematic Review," *AI*, 3(1), pp. 78–99. doi:10.3390/ai3010006.
Betti, A. *et al.* (2021) "Condition monitoring and predictive maintenance methodologies for hydropower plants equipment," *Renewable Energy*, 171, pp. 246–253. doi:10.1016/j.renene.2021.02.102.
Bhandari, R., Saptalena, L.G. and Kusch, W. (2018) "Sustainability assessment of a micro hydropower plant in Nepal," *Energy, Sustainability and Society*, 8(3). doi:10.1186/s13705-018-0147-2.
C, A.K. (no date) *ENVIRONMENTAL AND SOCIAL SAFEGUARD ISSUES IN KALIGANDAKI A HYDROPOWER PLANT REHABILITATION PROJECT*. Available at: https://www.researchgate.net/publication/306904628.
Dalzochio, J. *et al.* (2020) "Machine learning and reasoning for predictive maintenance in Industry 4.0: Current status and challenges," *Computers in Industry*. Elsevier B.V. doi:10.1016/j.compind.2020.103298.
Deighton, M.G. (2016) "Maintenance Management," *Facility Integrity Management*, pp. 87–139. doi:10.1016/B978-0-12-801764-7.00005-X.
Dekker Dekker, R. and Scarf, P.A. (1998), "On the impact of optimization models in maintenance decisionmaking: the state of the art", Reliability Engineering and System Safety, Vol. 60 No. 2, pp. 111-9.
Edmondson, A.C. and Mcmanus, S.E. (2007) "Methodological fit in management field research," *Academy of Management Review*, 32(4), pp. 1155–1179. doi:10.5465/AMR.2007.26586086.
EFNMS (no date). Available at: http://www.efnms.eu/ (Accessed: June 5, 2022).
Finland's national action plan for promoting energy from renewable sources pursuant to Directive 2009/28/EC Energy Department TYÖ-JA ELINKEINOMINISTERIÖ ARBETS-OCH NÄRINGSMINISTERIET MINISTRY OF EMPLOYMENT AND THE ECONOMY (no date).
Finnland Työ- ja elinkeinoministeriö (no date) *Finland's integrated energy and climate plan*.
Fossil Fuels | EESI (no date). Available at: https://www.eesi.org/topics/fossil-fuels/description (Accessed: June 18, 2022).

Garbea, Razvan & Scarlatache, Florina & Gheorghe, Grigoras & Neagu, Bogdan. (2021). Integration of Data Mining Techniques in SCADA System for Optimal Operation of Hydropower Plants. 1-6. 10.1109/ECAI52376.2021.9515045.

Garg, A. and Deshmukh, S.G. (2006) "Maintenance management: Literature review and directions," *Journal of Quality in Maintenance Engineering*, pp. 205–238. doi:10.1108/13552510610685075.

Global Overview Disclaimer (2019). Available at: www.smallhydroworld.org.

Guide on How to Develop a Small Hydropower Plant ESHA 2004 (no date).

Haas R, Ragwitz M. Resch G.Faber T.Held A. Status of the internal market, success factors in different markets for RES-E Copenhagen, 12th November 2006: pp. 352-365.

Haas, R.R. Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources, Lessons from EU countries. Energy. 2011. Vol. 36, No. 4, pp. 2186-2193.

Hans-Josef Fell Feed-in Tariff for Renewable Energies: An Effective Stimulus Package without New Public Borrowing. German Bundestag, Energy and Technology Policy Alliance 90/The Greens. Berlin 2009: pp. 226-238.

Hoes, O.A.C. *et al.* (2017) "Systematic high-resolution assessment of global hydropower potential," *PLOS ONE*, 12(2), p. e0171844. doi:10.1371/JOURNAL.PONE.0171844.

Huang, J. *et al.* (2019) "A maintenance and energy saving joint control scheme for sustainable manufacturing systems," in *Procedia CIRP*. Elsevier B.V., pp. 263–268. doi:10.1016/j.procir.2019.01.073.

I. Ahmad, A. Rashid, On-line monitoring of hydro power plants in Pakistan,Inf. Technol. J. (2007) 919–923.

Ierace, S. and Cavalieri, S. (2009) "An ahp based model for the selection of decision categories in maintenance systems," in *IFAC Proceedings Volumes (IFAC-PapersOnline)*. IFAC Secretariat, pp. 1591–1596. doi:10.3182/20090603-3-RU-2001.0438.

Islam, M. R. Mekhilef S. Saidur.R Progress and recent trends of wind energy technology. Renewable and Sustainable Energy Reviews 21, 2013: pp. 456- 468.

Israel, D. (2007). Research methods for graduate business and social science students. Raeside and David White Response Books, A Division of Sage Publications, New Delhi, 2007, Pages: 270; Price: Rs. 395: pp. 157-163.

Kassem, Gamal & Zenker, Niko & Turowski, Klaus & Jamous, Naoum. (2016). Collaborative Network Platform Solution for Monitoring, Optimization, and Reporting of Environmental and Energy Performance of Data Center. 10.1007/978-3-319-25153-0_8.

Kishor, N., Saini, R.P. and Singh, S.P. (2007) "A review on hydropower plant models and control," *Renewable and Sustainable Energy Reviews*, pp. 776–796. doi:10.1016/j.rser.2005.06.003.

Kumar, D. and Katoch, S.S. (2015) "Small hydropower development in western Himalayas: Strategy forfaster implementation," *Renewable Energy*, 77, pp. 571–578. doi:10.1016/j.renene.2014.12.058.

Kumar, K. and Saini, R.P. (2022) "A review on operation and maintenance of hydropower plants," *Sustainable Energy Technologies and Assessments*, 49. doi:10.1016/j.seta.2021.101704.

Liszka, D. *et al.* (2022) "Alternative Solutions for Small Hydropower Plants," *Energies*, 15(4). doi:10.3390/en15041275.

Littlewood, D. and Holt, D. (2018) "How social enterprises can contribute to the sustainable development goals (SDGs) - A conceptual framework," in *Contemporary Issues in Entrepreneurship Research*. Emerald Group Publishing Ltd., pp. 33–46. doi:10.1108/S2040-724620180000008007.

Ma, T. *et al.* (2022) "Anomaly detection for hydropower turbine based on variational modal decomposition and hierarchical temporal memory," *Energy Reports*, 8, pp. 1546–1551. doi:10.1016/j.egyr.2022.02.286.

Mikkonen, H & Lahdelma, Sulo. (2015). Remote monitoring allows new operating practices in condition monitoring. Condition Monitor. 6-9.

Mikkonen, H. and Lahdelma, S. (2014) *Remote monitoring allows new operating practices in condition monitoring*. Available at: https://www.researchgate.net/publication/312033874.
Nations, U. (2005a) "Resolution adopted by the General Assembly on 16 September 2005 60/1. 2005 World Summit Outcome."
Ocean and hydropower (no date). Available at: https://energy.ec.europa.eu/topics/renewable-energy/ocean-and-hydropower_en (Accessed: June 1, 2022).
Ordean, M., Chiorean, D., Rogoz, I., Lehene, C., Stoian, I., Stancel, E. (2006) "SCADASystems-Support for the Maintenance Management of Hydro Power Plants", IEEE In-ternational Conference on Automation, Quality and Testing, Robotics, vol.1, pp.238-242, Cluj, Romania.
Paidipati, J. *et al.* (2017) *Workforce Development for Hydropower*.
Pavlakovič, B. *et al.* (2022) "Small hydropower plants in Western Balkan countries: status, controversies and a proposed model for decision making," *Energy, Sustainability and Society*, 12(1). doi:10.1186/s13705-022-00335-7.
Pinciroli, L. *et al.* (2022) "Optimization of the Operation and Maintenance of renewable energy systems by Deep Reinforcement Learning," *Renewable Energy*, 183, pp. 752–763. doi:10.1016/j.renene.2021.11.052.
Pintelon, L. and Puyvelde, F.V. (1997), "Maintenance performance reporting systems: someexperiences", Journal of Quality in Maintenance Engineering, Vol. 3 No. 1, pp. 4-15
Pintelon, L., Gelders, L. and VanPuyvelde, F., (2000). Maintenance Management, second ed. Acco Belgium, Leuven: pp.231-239.
Policy Guidelines Small hydropower projects in the Energy Community DRAFT FOR PUBLIC CONSULTATION (no date). Available at: https://energy-community.org/news/Energy-Community-News/2018/011/13.html.
Poudel, B. *et al.* (2021) "Factors influencing the sustainability of micro-hydro schemes in Nepal," *Renewable and Sustainable Energy Reviews*, 151. doi:10.1016/j.rser.2021.111544.
Renewable Energy Definition and Types of Renewable Energy Sources | NRDC (no date). Available at: https://www.nrdc.org/stories/renewable-energy-clean-facts (Accessed: June 18, 2022).
Ristić, B., Bozic, I. and Božić, I. (no date) *Digital technologies emergence in the contemporary hydropower plants operation Artificial Intelligence and Nature Inspired Optimization in the Function of Sustainable Water Management View project Research and development anemometry probes, measuring, calibration and optical methods for the technical practice measurement View project Digital technologies emergence in the contemporary hydropower plants operation*. Available at: https://www.researchgate.net/publication/356377723.
Rodríguez, J.A. *et al.* (2021) "Accelerating Benders decomposition for short-term hydropower maintenance scheduling," *European Journal of Operational Research*, 289(1), pp. 240–253. doi:10.1016/j.ejor.2020.06.041.
Sakib, N. and Wuest, T. (2018) "Challenges and Opportunities of Condition-based Predictive Maintenance: A Review," in *Procedia CIRP*. Elsevier B.V., pp. 267–272. doi:10.1016/j.procir.2018.08.318.
Sesana, M.M. and Salvalai, G. (2013) "Overview on life cycle methodologies and economic feasibility fornZEBs," *Building and Environment*, pp. 211–216. doi:10.1016/j.buildenv.2013.05.022.
Shuffleton, D.. (1998). Outage management - The way ahead?. 39. 88-92.
Singh, P. *et al.* (2020a) "Sustainability of maintenance management practices in hydropower plant: A conceptual framework," in *Materials Today: Proceedings*. Elsevier Ltd, pp. 1569–1574. doi:10.1016/j.matpr.2020.04.842.
Singh, P. *et al.* (2020b) "Sustainability of maintenance management practices in hydropower plant:
Singh, V.K. and Singal, S.K. (2017) "Operation of hydro power plants-a review," *Renewable and Sustainable Energy Reviews*. Elsevier Ltd, pp. 610–619. doi:10.1016/j.rser.2016.11.169.

Somberg, J. *et al.* (2021) “Tribological characterisation of polymer composites for hydropower bearings: Experimentally developed versus commercial materials,” *Tribology International*, 162. doi:10.1016/j.triboint.2021.107101.
Strategic Infrastructure Steps to Operate and Maintain Infrastructure Efficiently and Effectively Prepared in collaboration with The Boston Consulting Group Industry Agenda (2014).
Strielkowski, W. (2020) “Renewable energy sources, power markets, and smart grids,” in, pp. 97–151. doi:10.1016/B978-0-12-817770-9.00004-3.
Technical Guidelines for the Development of Small Hydropower Plants ManageMent Part 3: technical Renovation (2019).
THE 17 GOALS | Sustainable Development (no date). Available at: https://sdgs.un.org/goals (Accessed: April 29, 2022).
Tong, Colin. (2019). Advanced Materials and Devices for Hydropower and Ocean Energy. 10.1007/978-3-319-98002-7_7.
Torres, C. *et al.* (no date) *REHABILITATION OF HYDROPOWER-An introduction to economic and technical issues*.
Tsang, A.H.C. (1998), “A strategic approach to managing maintenance performance”, Journal of Quality in Maintenance Engineering, Vol. 4 No. 2, pp. 87- 94.
turbine - History of water turbine technology | Britannica (no date). Available at: https://www.britannica.com/technology/turbine/History-of-water-turbine-technology (Accessed: June 2, 2022).
Vagnoni, E. *et al.* (2021) “Digitalization in hydropower generation: Development and numerical validation of a model-based Smart Power Plant Supervisor,” in *IOP Conference Series: Earth and Environmental Science*. IOP Publishing Ltd. doi:10.1088/1755-1315/774/1/012107.
Vardoulakis, S. *et al.* (2015) “Impact of climate change on the domestic indoor environment and associated health risks in the UK,” *Environment International*. Elsevier Ltd, pp. 299–313. doi:10.1016/j.envint.2015.09.010.
Walczak, N. (2018) “Operational evaluation of a Small Hydropower Plant in the context of sustainable development,” *Water (Switzerland)*, 10(9). doi:10.3390/w10091114.
Wang H. (2002), “A survey of maintenance policies of deteriorating systems”, European Journalof Operational Research, Vol. 139 No. 3, pp. 469-89.
What is Climate Change ? | Climate Change Knowledge Portal (no date). Available at: https://climateknowledgeportal.worldbank.org/overview (Accessed: June 18, 2022).
What is climate change? | Australian Academy of Science (no date). Available at: https://www.science.org.au/learning/general-audience/science-climate-change/1-what-is-climate-change (Accessed: June 18, 2022).
What Is Sustainability in Business? | HBS Online (no date b). Available at: https://online.hbs.edu/blog/post/what-is-sustainability-in-business (Accessed: June 3, 2022).
Widén, Å. *et al.* (2021) “Let it flow: Modeling ecological benefits and hydropower production impacts of banning zero-flow events in a large regulated river system,” *Science of the Total Environment*, 783. doi:10.1016/j.scitotenv.2021.147010.
World Small Hydropower Development Report | UNIDO (no date a). Available at: https://www.unido.org/our-focus-safeguarding-environment-clean-energy-access-productive-use-renewable-energy-focus-areas-small-hydro-power/world-small-hydropower-development-report (Accessed: June 1, 2022).

Appendix 1. Questionnaire survey

QUESTIONNAIRE

TECHNICAL AND ECONOMICAL MODELING OF SMALL HYDRO POWER PLANTS REHABILITATIONS IN CONDITIONS OF IMPLEMENTING UNIFIED SOLUTIONS AND REDUCING THE ENVIRONMENTAL IMPACT

The Survey aims to obtain information on the conditions of equipment of hydroelectric power plants and the possible needs for their modernization or reconstruction.

We work hard to develop new environmental friendly World and products for Global Hydro market and hope you could help us to do it better with filling out this short questionnaire.

This Survey is being conducted under support of Finnrunner Oy

https://finnrunner.fi/
getinfo@finnrunner.fi

1.Please indicate what functions you hold in the Company you represent?

- Management
- Engineering
- 50/50
- another

2.Name the Company you represent

3.Please indicate how many hydro electric plants your Company own or operate?

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- another

4.Please indicate the names of the hydroelectric power plants and the following information in brackets (...):

- the year of construction
- total output power, kW
- output power per Unit, kW
- quantity of the Units in operation and out of operation

- designed head, m
- flow, m3/s
- year of last reconstruction

Fill an answer

5.Fill this space if you have any additional comments to the previous question

Fill an answer

6.Hydroelectric plant grid connection

- Connected to Centralized Power Grid
- Connected to Decentralized (autonomous) Power Grid
- another

7.Water supply to the units

- Open channel derivation
- Run-of-river power house
- Wooden tube
- Composite tube
- Metal tube
- another

8.Availability of fish ways on sites

- Yes
- No
- another

9.How often do you have to stop the equipment to carry out unforeseen repairs on hydropower plants (avarage per HPP)?

- Less than once a year
- Once a year
- Twice a year
- More
- another

10.What equipment breaks down the most and leads to the longest downtime?

- Related to turbine
- Related to generator
- Automation faults
- another

11.Do you involve the manufacturers of installed equipment in repairs?

- Yes
- No
- another

12.Is it planned to make rehabilitation of your hydroelectric plants for the nearest 2 years?

- Yes
- No
- another

13.Do you have plans to make rehabilitation of any HPP you own with equipment replacement or construct new hydroelectric plant in nearest 2 years? (you may enter details in comment)

- Yes
- No
- another

14.Does the current conditions of the HPPs meet environmental requirements?

- Yes
- No
- another

15.Is it needed to install fish passages on your HPPs?

- Yes
- No

16.Does actual environmental requirements have strong/significant influence on your power generation business?

- Yes
- No

17.In which direction do you see the future development of small hydropower?

- Is expected development of new HPPs and reconstruction of existing HPPs
- Is expected mostly rehabilitation with replacement of equipment and maintenance of existing HPPs
- Companies are open for new solutions for HPPs that allow to add output power and rise generation
- Power sector is mostly focused on wind and solar energy and will stay on that
- another

18.When you hear about the use of composite materials in the production of small turbines up to 1MW, the first thing you think about is ...

Fill an answer

19.Are you ready to consider a technical and commercial proposal for the replacement of existing hydro turbine equipment on an equal basis with other proposals if the proposed equipment will be partially made of composite?

- Yes
- No
- Maybe
- another

20.What financial support tools for purchasing new equipment, for construction HPP or even fish passages might you be interested in?

- Governmental support
- Regional forms of support
- Environmental government subsidies to cover partial of the new technological equipment purchase

- ☐ Replacement of equipment under power purchase agreement with provider of solutions
- ☐ another

21.What instruments of financial support for the purchase of new equipment does your Company use?

Fill an answer

22.What is your Company's tariff per kWh of electricity sold?

Fill an answer

23.Please provide your Contact details (email, phone).

Fill an answer

Thank you!

Lappeenranta-Lahti University of Technology (LUT) presents the survey for Master's thesis

31 Answer 09:57 Avarage time

1. Please indicate what functions you hold in the Company you represent?

Management	14
Engineering	6
50/50	11
Another	0

2. Name the Company you represent

31
Answer

Last answers

"Umeå Energi Elnät AB"

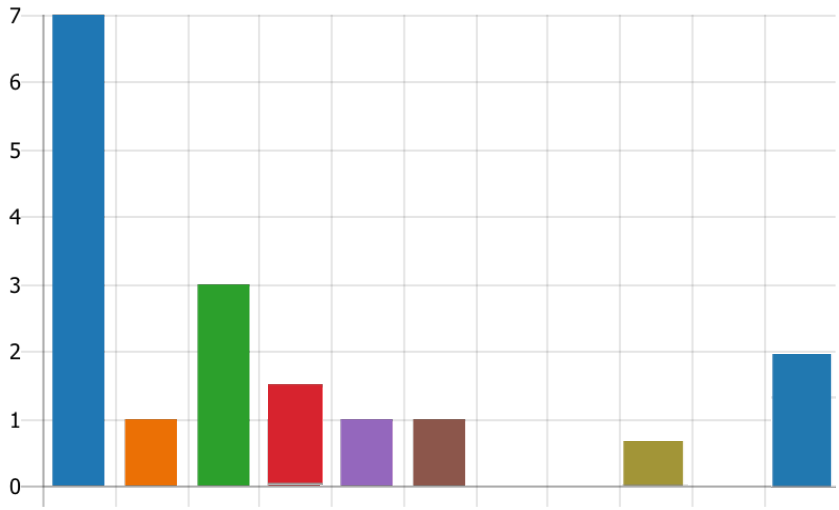
"Skogskvarn Kraft AB"

"Barsbro Kraft AB"

3. Please indicate how many hydro electric plants your Company own or operate?

1	19
2	1
3	3
4	1
5	1
	1

6	1
7	0
8	0
9	1
10	0
Another	3



4. Please indicate the names of the hydroelectric power plants and the following information in brackets (...):
   - the year of construction
   - total output power, kW
   - output power per Unit, kW
   - quantity of the Units in operation and out of operation
   - designed head, m
   - flow, m3/s
   - year of last reconstruction

31
Answer

Last answers

"1994 0,253 MW 1,4 GWh 34m no reconstruction"

"1902 0,4 MW 1,7 GWh 7 m 1987"

"2009 0,13 MW 0,656 GWh 3,1 m -no reconstruction"

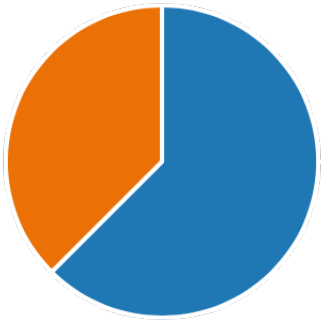
5. Fill this space if you have any additional comments to the previous question

5

Answer Last answer

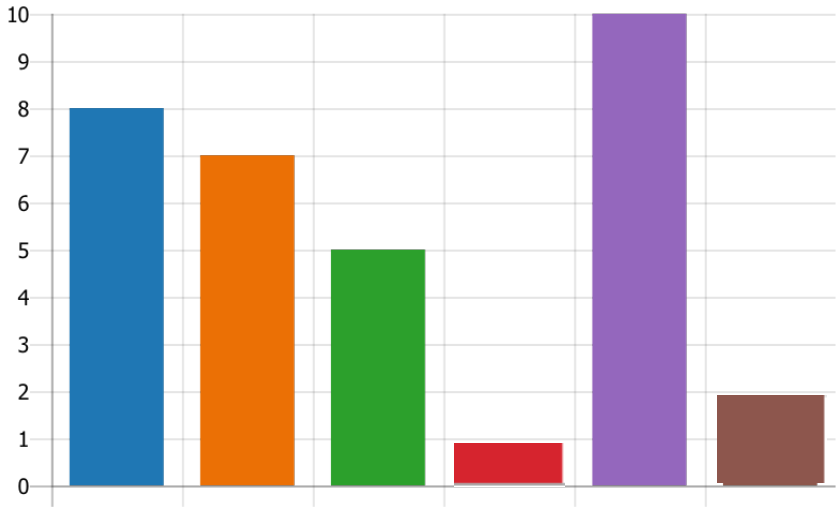
6. Hydroelectric plant grid connection

Connected to Centralized Pow...	18
Connected to Decentralized	13
Another	0



7. Water supply to the units

Open channel derivation	13
Run-of-river power house	15
Wooden tube Composite	7
tube	1
Metal tube	24
Another	2



8. Availability of fish ways on sites

Yes	15

No	16
Another	0

9. How often do you have to stop the equipment to carry out unforeseen repairs on hydropower plants (avarage per HPP)?

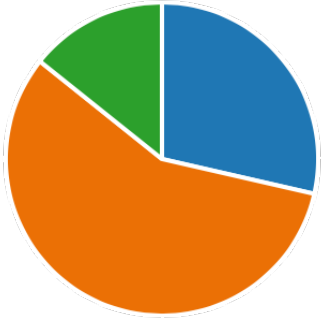
Less than once a year	11
Once a year	5
Twice a year	13
More	0
Another	2

10. What equipment breaks down the most and leads to the longest downtime?

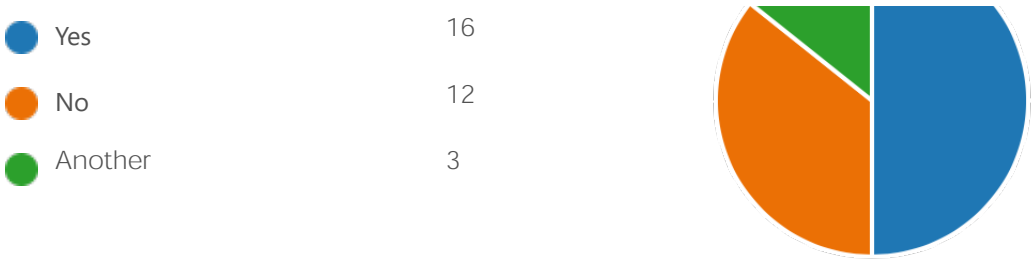
Related to turbine	16
Related to generator	7
Automation faults	4
Another	4

11. Do you involve the manufacturers of installed equipment in repairs?

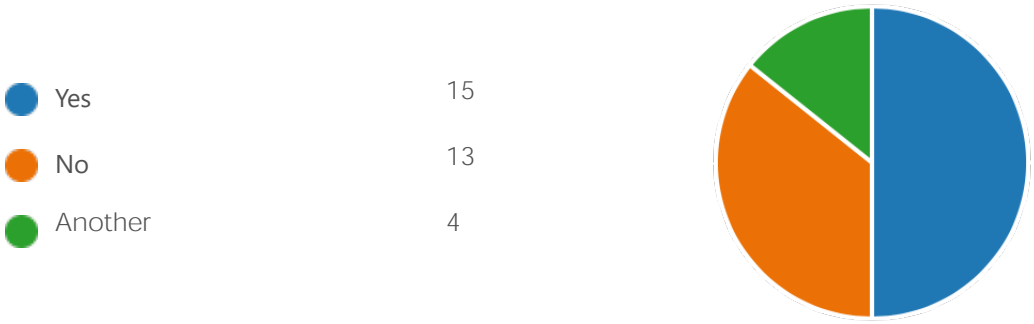
Yes	9
No	18
Another	4



12. Is it planned to make rehabilitation of your hydroelectric plants for the nearest 2 years.



13. Do you have plans to make rehabilitation of any HPP you own with equipment replacement or construct new hydroelectric plant in nearest 2 years? (you may enter details in comment)



14. Does the current conditions of the HPPs meet environmental requirements?

15. Is it needed to install fish passages on your HPPs?

16. Does actual environmental requirements have strong/significant influence on your power generation business?

on your power generation business?

Yes	26
No	5

17. In which direction do you see the future development of small hydropower?

Is expected development of n...	6
Is expected mostly rehabilitati...	23
Companies are open for new s...	24
Power sector is mostly focuse	10
Another	2

18. When you hear about the use of composite materials in the production of small turbines up to 1MW, the first thing you think about is ...

31
Ответы

Последние ответы

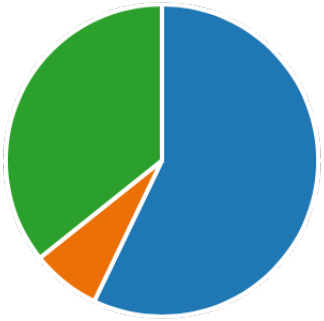
"wow, very nice"

"good"

"good, but does is safe?"

19. Are you ready to consider a technical and commercial proposal for the replacement of existing hydro turbine equipment on an equal basis with other proposals if the proposed equipment will be partially made of composite?

Yes	16
No	3
Maybe	12
Another	0



20. What financial support tools for purchasing new equipment, for construction HPP or even fish passages might you be interested in?

Governmental support	14
Regional forms of support	16
Environmental government su...	17
Replacement of equipment un...	18
Another	2

21. What instruments of financial support for the purchase of new equipment does your Company use?

7
Answer

Last answer

22. What is your Company's tariff per kWh of electricity sold?

11
Answer

Last answer

23. Please provide your Contact details (email, phone).

31
Answer

Last answers

"+46 90 16 00 00 umea.energi@umeaenergi.se"

"Kuppramåla Björkelund 365 94 Skruv"

"Telephone and e-mail Växel: 0771-765 765 Plant vis...

24. Please evaluate the form filling process

Positive

Negotive

6

25. Please leave here any comments related to this survey

5
Answer

Last answer