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Norway's hydroelectric development 1945-1990

Torodd Jensen, Kjell Erik Stensby, Inge H. Vognild and John E. Brittain

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Authors: Torodd Jensen[1], Kjell Erik Stensby[1], Inge H. Vognild[2] and John E. Brittain[1]
[1] Norwegian Water Resources and Energy Directorate (NVE)
[2] Norwegian Agency for Development Cooperation (NORAD)

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Abstract: In the post war years (1945-1990) Norway constructed and commissioned an unprecedented number of large hydropower schemes despite considerable political, organisational, technological, environmental, and financial challenges. The purpose of these schemes ranged widely from rural electrification to providing power for energy intensive industry, while others involved international cooperation. The lessons learnt and the solutions to these challenges are described and will undoubtedly be useful in the development of renewable energy generation capacity in the partner countries of the Norwegian Agency for Development Cooperation (NORAD).

Key words: Hydropower development, politics, finance, multidisciplinary cooperation, technology development, research and development (R&D)

Norwegian Water Resources and Energy Directorate
Middelthuns gate 29
P.O. Box. 5091 Majorstuen
N-0301 Oslo
Norway

Telephone: +47 22 95 95 95
E-mail: nve@nve.no
Internet: www.nve.no

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Forord

Rapporten inneholder eksempler fra norsk vannkraftutbygging i perioden 1945-1990. I denne perioden ble det planlagt og bygd over 400 vannkraftverk i Norge med en samlet ytelse på 24 200 MW og en midlere årlig produksjonsevne på 97 TWh. Denne kraftutbyggingen var en viktig del av utviklingen i Norge etter andre verdenskrig og førte til stor økonomisk framgang for landet.

Prosjektet er i utgangspunktet gjennomført etter bestilling fra NORAD som ønsker å bruke disse erfaringene i sitt arbeid med å delfinansiere fornybare energiprosjekter i land som Norge samarbeider med. NVE ønsker også å dokumentere bakgrunnen for denne historiske utviklingen.

Rapporten inneholder beskrivelse av 14 vannkraftsystemer som inkluderer 48 kraftverk. Beskrivelsene bygger blant annet på gjennomgang av en rekke bøker om kraftutbyggingen i denne perioden. Alle disse er listet opp under referanser. Alle tekniske data er fra NVEs kraftverksdatabase. Produksjonsdata referer til 30 års-serien 1981-2010. Beskrivelsene av kraftverkene og sammendraget er forfatternes ansvar.

Gjennomføringen av det faglige arbeidet er organisert som et prosjekt med deltakere fra NVE (Torodd Jensen, Kjell Erik Stensby, John E. Brittain) og NORAD (Inge H. Vognild). Alle har flere tiår med erfaring innen ulike aspekter av vannkraftutbygging både i Norge og i utlandet. Prosjektgruppa har fått verdifull hjelp fra medarbeidere i NORAD (Knut Gakkestad) og i NVE (Knut Hofstad, Seming H. Skau, Astrid Voksø, Stig Storheil og Frode Sørskaar).

Ann Myhrer Østenby
Seksjonssjef
Energi- og konsesjonsavdelingen

Preface

This report contains several examples of Norwegian hydropower development during the post-war period (1945-1990). During this period more than 400 hydropower plants in Norway, with 24,200 MW power capacity and mean annual energy generation capacity of 97 TWh were planned and built. The hydropower development was an important part of Norwegian post-war development that contributed to major economic progress.

The project was initially carried out through a contract with the Norwegian Agency for Development Cooperation (NORAD) whose aim was to use these experiences in their partial financing of renewable energy projects in partner countries. NVE also considers it important to document the background for this historic development.

The report contains descriptions of 14 hydropower schemes that comprise 48 power plants. The descriptions are based among other things on a thorough review of several books on power development during this period. These are listed in the references. All the technical data is taken from NVE's power plant database and the production data refer to the 30-year series 1981-2010. The descriptions of the hydropower schemes and the summaries are the responsibility of the authors.

The work has been organised as a project with participants from NVE (Torodd Jensen, Kjell Erik Stensby, John E. Brittain) and NORAD (Inge H. Vognild), all of whom have extensive experience over several decades of different aspects of hydropower development both in Norway and abroad. The project team has received valuable help and input from employees in NORAD (Knut Gakkestad) and NVE (Knut Hofstad, Seming H. Skau, Astrid Voksø, Stig Storheil and Frode Sørskaar).

Ann Myhrer Østenby
Head of Section
Energy and Licensing Department

Summary

Investment in renewable energy projects such as hydro, wind and solar require special financial solutions as the main part of the expenses are during the initial investment period and only to a limited extent during operation. The technical life span of renewable technologies varies and is dependent on maintenance. Hydropower has a life of 50-100 years, solar c. 30 years and wind c. 25 years. Running costs are normally low. Thermal energy projects using coal, oil and gas have lower investment costs, but higher running costs. They have technical life similar to wind and solar, but shorter than hydro.

To demonstrate the reality behind the large-scale emphasis on renewable energy production, this report looks at the 45 years since the Second World War (WW2) when over 400 power plants were built with a collective capacity of 24,200 MW and a mean annual generation of 97 TWh. This constitutes 73 % of installed capacity and 71 % of mean annual production in today's hydropower plants in Norway. A group of 14 hydropower schemes that includes 48 power stations, has been chosen to illustrate different aspects of hydropower development during this period when aspects such as local involvement, political influence, multidisciplinary cooperation, technological development through research and financial solutions are described for each individual hydropower scheme.

The report also gives a brief insight into the situation before WW2. The legislation regarding the harnessing of Norway's waterfalls was in place during the first 20 years after the dissolution of the Union with Sweden in 1905. Already then and later during the years between the Wars experience was gained through the construction of many small and some large hydroelectric power plants, of which the Vemork and the Såheim power plants in Telemark County were among the largest in the world when they were inaugurated. A national basis of power companies, consultants, contractors, and suppliers was thus established in Norway. This provided good background experience for further development regarding organisation, implementation, and technical development after WW2. The earlier power plants were constructed by municipalities, counties, and private power companies. The heavy involvement of the State in power development only came after 1945.

In the first decades after WW2 many large power plants were built to provide energy to large scale industrial development. These large-scale stand-alone systems were obtained through the option to establish large reservoirs for water storage, giving the power plants the possibility to deliver stable power according to the needs of industry. These power plants could deliver the same reliable amount of power as traditional coal-fired power plants. Coal-fired power plants were the economic comparison for the identification of Norway's hydropower potential. Because of technological advances, improved mapping and climate change Norway's technical and economic hydropower potential has increased from 107 TWh in 1946 to almost 216 TWh in 2020.

Other large power plants were also built to meet an increasing domestic market with a requirement for power when it was needed. This entailed greater flexibility for these power plants compared to plants that supplied electricity to industry. At the start of the post-war development period environmental and social consequences were largely considered in the planning itself and clearly poor solutions were avoided. Gradually environmental consequences became more thoroughly considered in the licencing process. At the same time several watercourse conservation plans were approved. These plans prevented hydropower development in such watercourses, while other watercourses were developed. The descriptions of, for example, the Tokke, Lærdal and Orkla developments illustrate this. The overall national conservation plans are also summarised.

A summary table of the 14 hydropower schemes.

Scheme	No. of power plants	Total Capacity MW	Total Generation GWh	Main objectives
Aura	2	310	1 964	Large industry and public electricity supply
Åbjøra	1	95	474	Public electricity supply in other counties and districts
Porsa	2	14.5	69	Supplying nearby town and local rural electrification
Røssåga	2	525	2 902	Large industry and local rural electrification
Nea	2	207	837	Households and miscellaneous industry. Country cooperation
Røldal-Suldal	9	606	3 293	Large industry
Skogfoss	1	48	289	Local industry and local electrification. Highlights cooperation with neighbouring country (the then Soviet Union)
Tokke	8	997	4 832	Local and county electrification, miscellaneous industry
Tussa	1	64	272	Rural electrification and local electricity supply
Øvre Namsen (KØN)	4	231.5	1 078	Households and miscellaneous industry. One plant is in Sweden. Highlights international cooperation
Sira-Kvina	7	1 760	7 115	A mix between large industry, miscellaneous small industry and households
Lærdal	3	300	1 327	Public electricity supply in another county than the host county
Siso	1	180	916	Large industry and local public electrification
Orkla	5	320	1 398	Households and miscellaneous industry
Total	48	5 685	26 766	

Based on experience from the period 1945-1990, it can be concluded that financial problems and political cooperation were the dominant themes in all decisions. Many large power plants received, in one form or another, finance via loans with long repayment periods and low interest rates. The State developments were financed over the annual state budgets. The country was to be developed such that the increased expertise necessary for the utilisation of hydropower was a driving force in itself and gave rise to a focus on multidisciplinary cooperation. Most of the hydropower projects contained elements of R&D, and this increased level of knowledge led to innovative solutions that had a long-term perspective and contributed to increased profitability.

The 14 hydroelectric schemes that are described in this report represent different types of solutions and objectives, some tailored for supplying large energy intensive industry alone, some developed for electrification of households and miscellaneous industry, and some a mix of objectives. Together they give a picture of the activities and the political and economic goals that were achieved, and they are still as valuable today as when they were inaugurated.

All data that are used in the report are taken from the current Hydropower Database of the Norwegian Water Resources and Energy Directorate (NVE) and not from the time when the plants were constructed. The annual generation capacities are based on NVE's simulations using discharge series for the period 1981-2010. This means that the increase of runoff during the period 1990-2010 is included. For more information on each hydropower scheme, the reader is referred to the respective chapters with details of each scheme.

The location of the 14 Norwegian hydropower schemes.

Sammendrag

Investeringer i fornybare energiprosjekter som vannkraft, vindkraft og solkraft trenger spesielle finansieringsløsninger fordi hovedtyngden av kostnadene er knyttet til investeringsperioden. Bare en liten del av kostnadene er knyttet til driftsperioden. Teknisk levetid for fornybare energiteknologier varierer og avhenger også av vedlikehold. Vannkraft kan ha fra 50 til 100 års levetid, solkraft ca. 30 år og vindkraft ca. 25 år. Driftskostnadene er som oftest lave. Termiske energiverk med bruk av kull, olje og gass har lavere investeringskostnader, men høyere driftskostnader. Teknisk levetid er på linje med solkraft og vindkraft, men kortere enn vannkraft.

For å få fram et bilde av storskala satsning på fornybar energiproduksjon i Norge er det i denne rapporten sett på 45 år fra siste verdenskrig til 1990. I denne perioden ble det bygd mer enn 400 kraftverk med en samlet ytelse på 24 200 MW og en midlere årlig produksjonsevne på 97 TWh. Dette utgjør 73 % av installert effekt og 71 % av midlere årlig produksjon i dagens vannkraftverk. Det er beskrevet 14 kraftverksystemer med til sammen 48 kraftverk som belyser ulike sider ved vannkraftutbygging i denne perioden. Temaer som lokal medvirkning, politiske aspekter, tverrfaglig samarbeid, organisering, teknologiutvikling ved forskning, finansieringsløsninger og tekniske og økonomiske forhold er beskrevet for hvert enkelt kraftverksystem.

Rapporten gir et kortfattet innblikk i forholdene fra før den andre verdenskrigen. Lovverket om utnyttelsen av Norges vannfall ble vedtatt i løpet av de 20 første årene etter unionsoppløsningen i 1905. Allerede da og også i mellomkrigstida ble det vunnet erfaring gjennom bygging av mange vannkraftverk, også noen som absolutt kan betegnes som store. Kraftverkene Vemork og Såheim i Telemark var blant de største i verden da de ble satt i drift. Det ble etablert en norsk basis med kraftselselskaper, konsulentfirmaer, entreprenører og leverandører av teknisk utstyr. Dette ga et godt erfaringsgrunnlag for organisering, gjennomføring og teknisk utvikling for det som skulle komme etter 1945. Kraftverkene ble bygd av kommuner, fylker og private kraftselskaper. Det store statlige engasjementet kom først etter 1945.

I de første tiårene etter krigen ble det bygd mange store vannkraftverk som ga energi til storskala industriutvikling. Noen store vannkraftsystemer uten tilknytning til nett kunne bygges fordi det var mulig å etablere store vannkraftmagasiner. Dette muliggjorde at kraftverkene kunne levere stabil kraft etter industriens behov. Disse kraftverkene kunne da levere samme påregnelige kraftmengde som tradisjonelle kullkraftverk. Kullkraftverk var da den økonomiske sammenlignbare faktoren for identifiseringen av Norges vannkraftpotensial. På grunn av teknologiutvikling, bedre kartgrunnlag og klimaendringer har det påregnelige potensialet økt fra 107 TWh i 1946 til nesten 216 TWh i 2020.

Det ble også bygd mange store kraftverk for å møte energibehovet i et voksende forbruksmarked, og med krav om leveranse når det var behov for energien. Dette betydde større fleksibilitet for disse kraftverkene enn for kraftverkene som skulle levere elektrisitet til industrianlegg.

I starten på oppbyggingsperioden av landet etter siste verdenskrig ble konsekvenser for naturmiljø og sosiale forhold hovedsakelig vurdert i selve planleggingen. Dermed ble bare helt åpenbare dårlige løsninger unngått. Etter hvert ble miljøinngrepene grundigere vurdert i konsesjonsbehandlingen. Samtidig ble det også vedtatt en rekke verneplaner for vassdrag, samtidig som andre vassdrag ble utbygd. Utvalget av prosjekter viser dette i noen grad, som i beskrivelsene av Tokkeutbyggingen og utbyggingene i Lærdal og i Orklavassdraget. Det er også oppsummerte data fra verneplaner for vassdrag.

Basert på erfaringer fra perioden 1945-1990 kan det konkluderes med at finansieringsproblematikk og politisk samarbeid var dominerende temaer for alle beslutninger. Mange store kraftverk fikk en eller annen form for finansiering gjennom lån med lang avdragstid og lav rente. De statlige utbyggingene ble finansiert gjennom de årlige statsbudsjettene. Landet skulle også utvikles slik at oppbygging av kompetanse for å utnytte vannkraftressursene var en drivkraft i seg selv og ga unike gjennomføringer med fokus på tverrfaglig samarbeid. De fleste av de store vannkraftprosjektene hadde elementer av FoU. Dermed økte kunnskapsnivået slik at det ble oppnådd innovative løsninger som hadde langsiktig levetidsperspektiv og som bidro til økt lønnsomhet.

De 14 vannkraftsystemene som er beskrevet i denne rapporten representerer forskjellige løsninger og formål. Noen er skreddersydd for kraftleveranser hovedsakelig til energikrevende industri, noen er bygd for elektrifisering av husholdninger og lokal småindustri, og andre igjen for en blanding av formål. Til sammen gir de valgte eksemplene et bilde av aktiviteter og politiske og økonomiske mål som ble nådd. Kraftverkene er like verdifulle i dag som da de ble planlagt, bygd og satt i drift.

En tabell med de 14 vannkraftsystemene og kart med deres geografiske plassering er vist i det engelske sammendraget (Summary).

Alle data som er brukt er hentet fra dagens kraftverksdatabase i NVE og ikke fra den gang kraftverkene ble bygd. De gjennomsnittlige årlige produksjonskapasitetene er basert på NVEs produksjonssimuleringer med vannføringsserier for perioden 1981-2010. Dermed er økt tilsig i perioden 1990-2010 inkludert.

Introduction

This report describes the implementation history, political targets, organisation, financing and technology challenges for 14 hydropower schemes that comprise 48 hydropower plants. All the plants were developed in the first four decades after the Second World War (WW2). The authors have had access to many literature sources that are listed in the reference list for each hydropower scheme. The work was initiated by the Norwegian Agency for Development Cooperation (NORAD) that wished to highlight experiences gained from the intensive post war hydropower development in Norway whereby 400 different large hydropower schemes were implemented during a period of 45 years. It is believed that these experiences can be used in NORAD's endeavour to cut CO_2 emissions by contributing to developing renewable energy generation capacity in Norway's cooperation countries. The work was undertaken by the International Office in the Norwegian Water Resources and Energy Directorate (NVE). All present capacity and generation data used in this report have their origin in NVE's databases. The authors have discussed the different examples with the employees of some hydropower companies, but the description of each plant and its history is solely the responsibility of the authors.

Hydroelectric power development prior to the Second World War

Resources for hydropower development are determined by climate and topography. Rainfall at high altitudes, topographical facilities for storage and favourable geology are the primary prerequisites behind the 135 years of experience with hydroelectric development in Norway.

Norway´s electricity history started at the end of the 19th century. This was the period where waterfalls and rapids in large and small rivers powered sawmills, flour mills and belt-driven machinery as illustrated in Fig. 1. The technological development from the 19th century took the mechanical devices from water wheels for direct mechanical work to Francis turbines that could provide the mechanical solution for power dynamos (generators) to produce electricity. It all started with small units that powered mines and the wood-processing industry and could also deliver for example streetlights in towns. In 1885 the city of Skien in Telemark County in the south of Norway, got electric lighting from Laugstol wood-processing plant on the Skien River. Hammerfest is a northernmost town in Norway that was among the first towns in the world that, on its own, developed hydropower produced electricity and used it for streetlights in 1890.

During the two first decades of the 20th century important decisions on the legal framework were made to secure national control of the hydropower resources. The time also saw the start of the co-existence between large hydropower developments and large energy intensive industry, where one large hydroelectric power plant with reservoirs could guarantee firm power for sustainable development of industry and thus create both local and national progress. Foreign investors were keenly aware of the opportunities that lay in Norway´s large hydropower resources. The prospect of profitable hydroelectric development gave water rights a new value and made them rather suddenly the object of trade and speculation.

In 1906 the "Panic Law" was introduced by the government to make acquisition of rights dependent on a license, normally based on a Royal Decree. Only municipal bodies and the State would be exempted from the demands of a license. Private developers needed licenses. The license could be made conditional on certain obligations for the licensee. After termination of the license, 80 years at the most, the rights together with any installation would revert to the State.

Fig. 1. Illustration of different technologies for harnessing energy in waterfalls in the 19th century (Source: Nordfjord Folkemuseum, Sandane, Norway).

The Watercourse Regulation Act of 1917 came to be the most important act in large scale hydroelectric power development. Without the right to regulate water flow by seasonal storage, development for regular hydroelectric power generation is not possible. The set of acts, their content mainly established during the first half century of development, regulate the legal context of hydropower development. This was also a period when the municipalities together with local businessmen managed to start development of small streams for rural electrification. The activities had a clear sense of pioneering, where manufacturers of equipment, construction companies and operators of the plants had to learn as they went along. Communication with foreign resources both in technology and economy proved valuable for the development of competency.

The Norwegian Water Resources and Energy Directorate (NVE) has its origins from the 19th century, being originally a body for developing canals and investigating hydrology. However, in May 1921 NVE was established also as a governmental tool for electrifying the country.

Before WW2 hydropower development in Norway was mainly organized by private, municipal, and county decision makers. The large hydropower plants were normally linked to privately owned industrial development. The State was involved in a few large plants only and the Nore hydropower scheme is one example. The municipalities and the counties owned most of the mini, small, and medium sized plants. However, most of the micro hydropower plants with capacity under 100 kW were built and owned by farmers and owners of local workshops. Between the First World War (WW1) and Second World War (WW2), there was a political discussion on if and how the State should be involved. However, after WW2 the large hydropower development in Norway ended up being a state task supported by all parties in the Parliament. NVE became the instrument to fulfil the Parliament's decision on developing the country by harnessing the rich hydropower resources.

Hydroelectric power development after the Second World War

After WW2 an expansive rebuilding of Norway´s infrastructure, industry and living standard for inhabitants was possible because of access to large hydropower development projects that provided electricity for implementing the rebuilding plans. Norway had the natural resources for hydropower development. Rainfall at high altitudes, topographical facilities for storage and favourable geology are the primary prerequisites for hydroelectric development in Norway.

During the first four decades after WW2 NVE was a powerful governmental body that encompassed the national hydrology centre, watercourse maintenance and flood control, the planning, construction and operation of hydropower plants and high voltage transmission lines and finally the handling of the licensing procedures. However, from 1986 the planning, construction and operation of the state-owned hydropower plants and the high voltage network was outsourced in a new State-owned company, Statkraft SF. Six years later in 1992, the planning, construction and operation of high voltage transmission lines were transferred from Statkraft SF to Statnett SF (the Norwegian TSO). Today the Norwegian Water Resources and Energy Directorate (NVE) is the National centre for hydrology, has tasks linked to watercourse flood control, watercourse protection plans, landslides and avalanches, licensing of energy projects (generation and transmission), updating national energy resources and control of all functions in the electricity market. NVE reports to the Ministry of Petroleum and Energy (OED).

In 1946 the overview of Norwegian hydropower showed a technical and economic viable potential of approximately 107 TWh mean annual generation, based on screening projects that could regulate the seasonal waterflow. At that time, the total capacity was calculated to be 12,300 MW. 11 TWh electric energy was developed (~10 % of the viable potential) including 2,200 MW electric capacity (~17 % of viable potential). In addition, 85 MW non-electric capacity was linked to direct use in factories etc. The table below shows the sum of micro, mini, small, medium and large hydroelectric power plants.

Table 1 shows the distribution in relation to capacity of Norwegian hydroelectric power plants in 1946 (Source: NVE). There were 2,009 hydroelectric power plants with total capacity of approximately 2,300 MW and 11 TWh mean annual generation capacity in Norway when the post-WW2 period started. By 1990, the capacity had increased to around 27,000 MW, and the mean annual generation was some 108 TWh. The number of power plants had decreased, but the power plants were considerably larger than in 1946.

Installed capacity	Number	Sum MW
0 – 0.1 MW (micro)	1 463	37.2
0.1 MW – 1 MW (mini)	355	121.2
1 MW – 10 MW (small)	146	454.3
10 MW – 50 MW (medium)	35	753.2
>50 MW (large)	10	935.3
Sum	2 009	2 301.2

Table 2 shows the development of hydropower from 1946 to 2021 (Source: NVE). From 1946 to 1990 the main focus was on development of hydropower with capacity over 10 MW, and a total of approximately 400 hydropower plants were built. This number includes the expansion of approximately 60 plants that were already in operation in 1946.

Year	No. of plants 0-1 MW	No. of plants ≥1 MW	Capacity (MW)	Generation Capacity (TWh)	Reservoir Mm^3	Reservoir (TWh)
1946	1 818	191	2 300	11.6		
1968		367	10 700	57.4		33
1990		533	26 500	108		79
2021		1 690	33 000	137	65	87

Parallel to the political decision concerning large scale hydropower development in the first four decades after WW2 a comprehensive survey of hydropower resources was carried out. The Government established a working group after the war to identify options for priority of projects. This work was included in the Norwegian Water Resources and Energy Directorate's (NVE) continuing tasks from mid-1960 and is still ongoing. The continuous development of improved maps and hydrology knowhow, the technology development both within electro and mechanical equipment as well as construction technology gave a picture of growing hydroelectricity resources.

From Vidkunn Hveding's "Hydropower in Norway" it is stated: Hydropower development has the potential to upset the existing balance between man and his environment, sometimes on a quite dramatic scale. Agriculture and settlement tend to be concentrated along the river valleys. Outside settled areas, water is still the basis for wildlife, and an important element of scenery.

In the early days of hydropower development, a negative impact on the environment tended to be overlooked as insignificant relevant to the benefits to society offered by development. In more recent times, studies of landscape, river flows and biodiversity have provided valuable information to enable the developer to design remedial measures and to work with the environment, rather than against it. Nevertheless, large dams, dry riverbeds, hydropeaking, roads, and transmission lines bring biological and visual changes to the environment which are not always acceptable. From the 1970s watercourse protection plans were introduced to keep whole watercourses untouched by hydropower development. One combined activity was the Master Plan for Hydropower Development (also called Master Plan for Watercourses) that started in 1981 and came with its main results in 1985 and 1993. The Master Plan was terminated as a political instrument in 2017.

Norway has many natural lakes in the mountains, and implementation of Norwegian reservoirs has seldom led to resettlement of people. The negative impacts on fish, wildlife and recreation have become more important for NGOs and their resistance to hydropower development. This resistance has led to the mentioned research and development and to an extensive licensing procedure for any company that wishes to apply for a license for hydropower development in Norway. NVE is the regulatory body concerned with electric power development, both transmission and generation plants.

Due to the negative impact on watercourses and the need to conserve areas for the future without technical structures, environmental protection plans have been carried out. From 1973 to 2009 six protection plans with 388 watercourses were approved. The resource mapping has all the way delivered knowhow used in developing the protection plans.

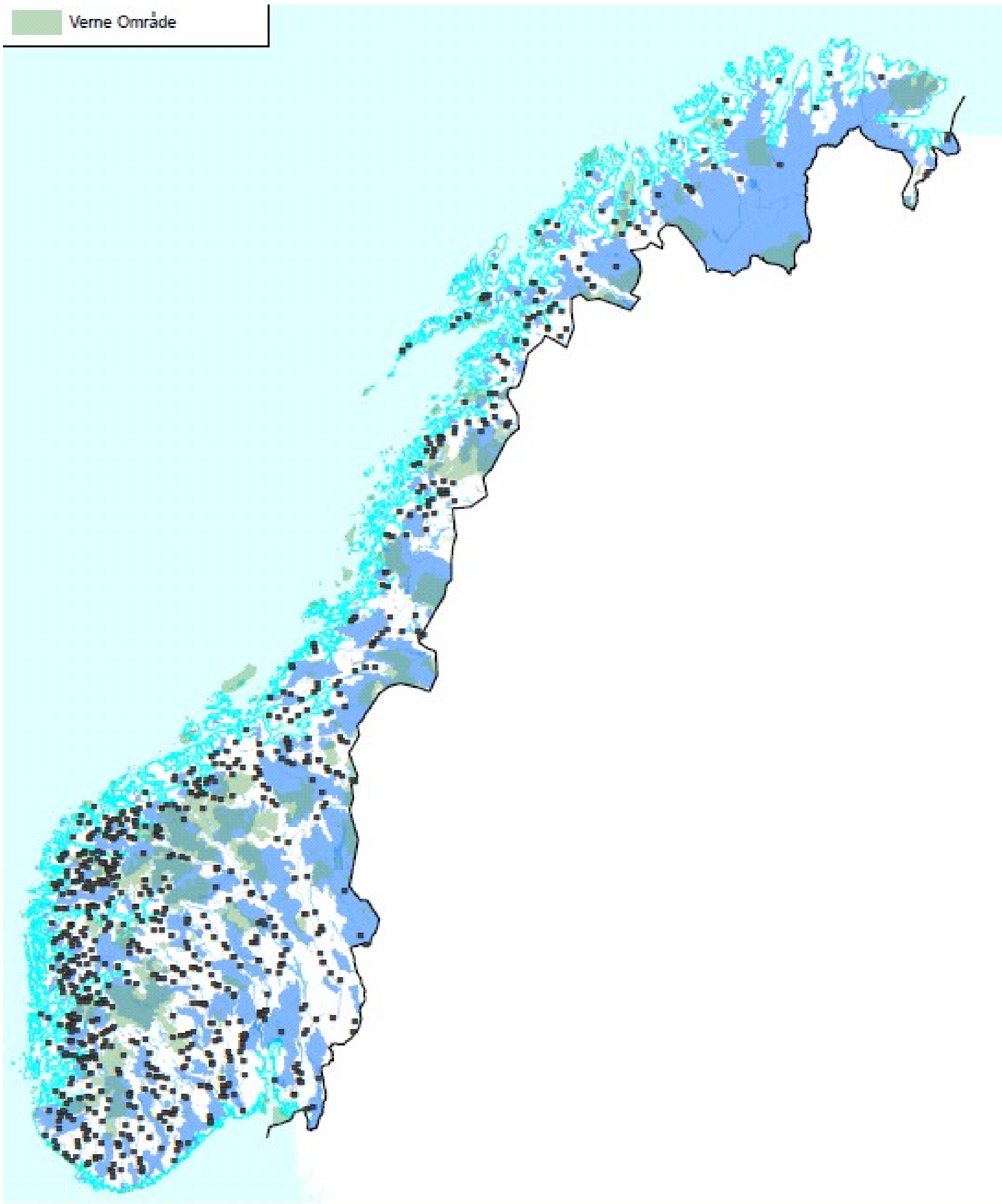

Fig. 2. Location of hydropower plants in operation and the different conservation areas and protected watercourses (Source: NVE).

Norway has more than 1,500 hydropower plants in operation with capacity over 1 MW. They generate 136 TWh at a very low cost and have a climate footprint between 2 and 4 g CO_2-ekv/kWh according to the research institute Østfold Forskning's life cycle analyses on the Skjerka storage HPP in the Mandalselva watercourse and Embretsfoss river HPP in the Drammenselva watercourse.

The CEDREN R&D programme and other studies support the low emission from Norwegian hydropower.

More than 60 % of the country's area has limitations for hydropower development because of National Parks (dark green), Special Wildlife and Fauna Protection areas (light green) and the 6 specific hydropower watercourse protection plans (blue).

The respective hydropower potential that is conserved is about 50 TWh.

Table 3. Illustration on the development of hydropower resources, construction of hydropower plants, resources for license application and watercourse protection plans since WW2 (Source: NVE).

Year	Calculated Technical/ Economic potential (TWh)	Developed Hydropower (TWh)	Conserved Water-courses (TWh)	Master Plan for Water-courses (TWh)	Under Construction (TWh)	Available for License Application (TWh)
1946	107	11	-	-	-	-
1990	172	108	21	24	3	16
2002	187	118	37	10	1	21
2020	215.6	136.4	49.5	-	2.3	27.5

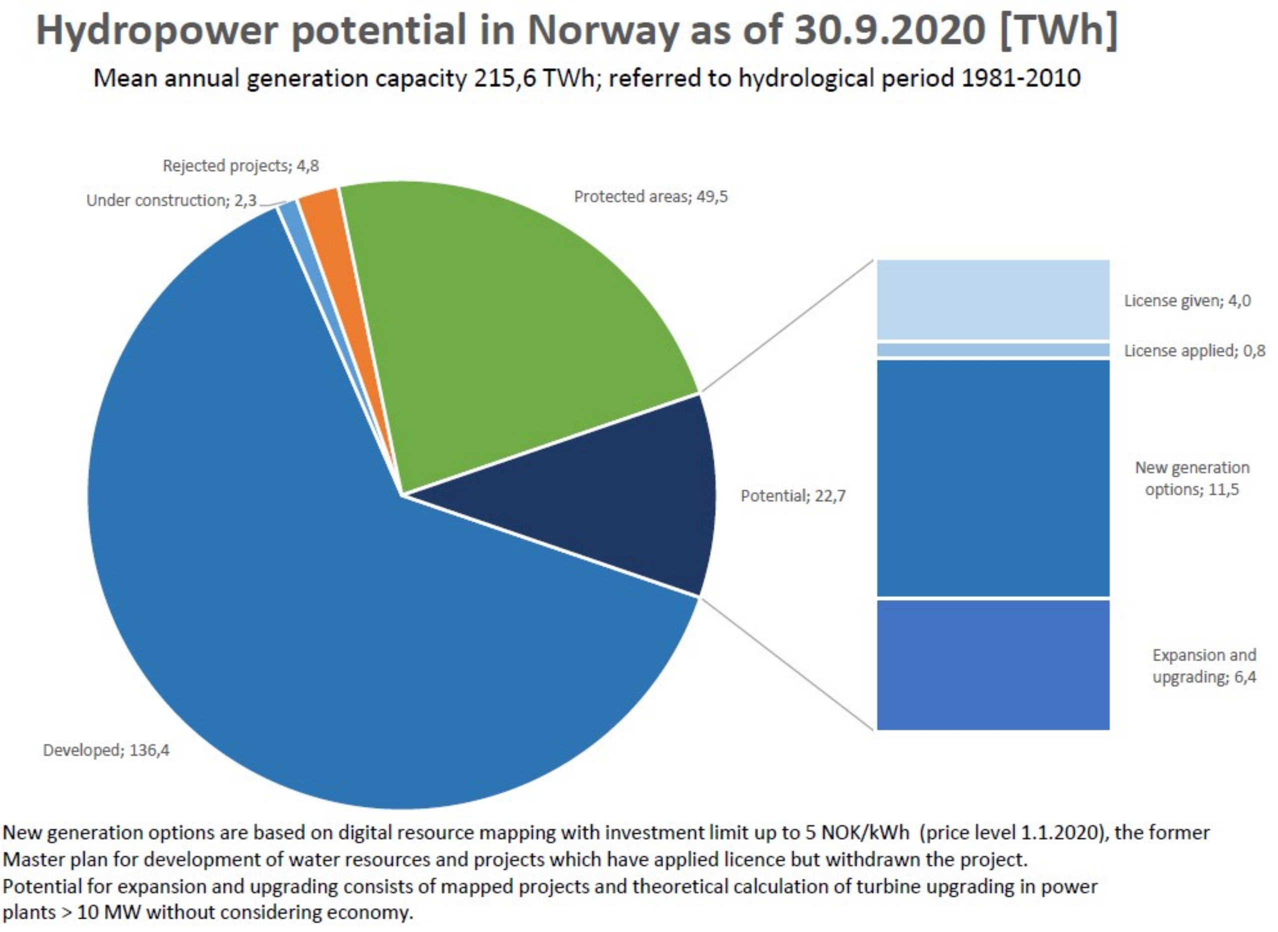

Fig. 3. Illustration of the data in Table 3 for the year 2020.

Issues relevant for the 14 hydroelectric power plant systems

License revisions

Most hydropower licenses in Norway are granted for public development and are time unlimited. The right to claim a revision of a license provisions is an important statuary right in Norwegian watercourse legislation. A few revisions are completed or are in progress. Three of the ongoing revisions are mentioned in this collection of examples. The claims and the processes are referred to here, but not the outcome. Furthermore, several revisions are in the pipeline and more than 400 licenses for generation of hydroelectric power in Norwegian watercourses can come up for revision by 2022.

It is possible to improve the environmental requirements for the operation of hydropower plants through revision of the licensing provisions. It is a prerequisite that the revision is claimed by representatives of public interests such as concerned municipalities or organisations within outdoor recreation and nature conservation. On basis of the claim, NVE decides whether the revision process shall be implemented. A revision of the provisions opens for a weighting of the societal benefits of the hydropower production against the impact of the regulation on the environment and public interests, such as recreational use and landscape experience. At the same time, the revisions are the principal instrument to improve the environmental conditions in regulated watercourses, and thus to implement the intentions of the European Water Framework Directive in Norway.

Other EU directives call for technologies that will enhance reaching the target of CO_2 free energy generation by 2050. Hydropower with storage capacity is an example of such technology. Norway's hydropower reservoirs include an energy storage of 87 TWh, which is equivalent to EU's storage capacity. The value of hydropower reservoir energy capacity for development of variable energy generation in the EU must be included in the coming revisions.

Watercourse Associations

In accordance with the Watercourse Regulation Act, it is compulsory to establish a Watercourse Association where there are hydropower plants with different owners in the same watercourse. The objective of Watercourse Associations is to take care of the owners' common interests as to use of reservoirs in the watercourse. The Watercourse Associations have their history back to the end of the 19th century. Watercourse Associations have been established in most large watercourses in Norway, and are important parties in the application for license, construction, operation and maintenance of dams, reservoirs and diversions. Hence the associations have a key role in the Norwegian hydropower system. The associations cooperate with the owners of the power plants in the watercourses, and the owners are also members of the associations. The Åbjøra power plant is an example.

Prerequisites in licenses to purchase Norwegian manufactured products and services

For hydropower licenses in Norway in the first four decades after WW2 there was a provision demanding that the licensee should preferably use Norwegian products and services for the construction works and operation. A precondition was that the Norwegian supplies should be of a quality as good as foreign supplies, on time and at a price which did not exceed foreign prices by more than 10 %. A premise was also that there were no conflicting interests. This clause was a national policy to raise Norwegian competence and supported the Norwegian supplier industry. Many large projects were in the pipeline, and hence there was a promising market for suppliers. Norwegian suppliers were competitive in the Norwegian market and were gradually awarded a considerable share of the contracts in the next decades. When the intensive development period decreased in the 1980s some suppliers tested the international market, and in particular the turbine manufacturer Kværner was awarded challenging contracts in other countries.

This clause is also mentioned in the license for the Siso hydropower project (1960), the Røldal-Suldal hydropower scheme (1960), the Orkla hydropower scheme (1980) and the Tussa hydropower scheme (1957). The Tussa hydropower scheme was among the first and the owners of Tussa hydropower scheme wanted to support the building of expertise in Norwegian industry and decided to include two units in stage 1 where one generator was from the Norwegian company National Industri. Similar provisions were also included in licenses for other developments in this collection of examples. The conclusion is that the clause was of great importance and the impression is that the provisions were, as far as possible, followed.

Strategic cooperation between stakeholders in Norway

The huge natural hydropower resources and the need to develop the country in direction of modern industry and technology development in combination with the positive political atmosphere for hydropower development resulted in close stakeholder cooperation. These circumstances secured the primary national target, namely employment for all. The stakeholders included central and local authorities, banks, other financing institutions, industry, manufacturers of equipment, consultants, contracting companies, research investors (mainly the State, municipalities and counties, private large energy intensive industry), and research units in the universities. For example, the development of the Tussa hydropower plant involved cooperation between the construction company and the researchers at the Norwegian University of Science and Technology (NTNU) in Trondheim for 27 m deep tapping of the lake Tyssevatn. The tunnel was 50 m under the natural water level and there were not many similar solutions at that time.

Similar cooperation between NTNU and the electro and mechanical industry materialized during the expansive period and allowed companies such as Kværner to grow and be among the biggest hydropower turbine suppliers in the world. NTNU and Kværner cooperated and financed test laboratories already from 1920 onwards in order to train students and implement advanced scientific experiments. To meet a particular Norwegian challenge focus was on technology for high pressure hydropower plants.

In the same period different stakeholders created their own associations. One of the obligations was to present challenging technological solutions which were developed by the construction of new plants. In this way they contributed to bring knowledge to all parties by using R&D reports in cooperation with NTNU and SINTEF, as well as by arranging seminars and conferences. This open information on advanced technological developments resulted in high quality hydropower development on a broad scale. Elements of the lessons learned are still in use today.

Financing

The projects were financed in different ways by using a mix of national and foreign loans, equity, and state support.

Municipalities, local banks, and miscellaneous industry often cooperated when the aim was public electrification. These projects often had constraints with customers and the owners had to work hard to connect enough customers to the electricity supply to secure a basic income. Many small private schemes and local small industrials had periods with low income from their activities. For example, the power company Tussa Energi needed both bank loans and state support. NVE set acondition for State support that the involved municipalities should cooperate so that the development was beneficial for the entire region. Hence, Tussa Energi could not commence any development before there were sufficient customers for utilising the large electric energy potential. This meant construction of transmission lines to supply the new customers.

Some schemes like the Tokke hydropower scheme were tailored for region electricity consumption financed through loans raised from a customer subscription arrangement (49 %), a World Bank (WB) loan (36 %) and allocations over the State Budget (15 %). The WB loan was referred to as the “Marshallhjelpen” (The European Recover Program (ERP), the US help programme for Europe after WW2). The municipalities that would benefit from the development also increased their tariffs to pay for the share of equity. Lærdal hydropower scheme was a similar case some years after Tokke. The developer, Østfold County, had to increase the tariffs to raise the equity.

A few schemes had direct foreign investment like the Nea hydropower plant that had 71 % Swedish investment and the rest in equity and Norwegian loans. This project also included a license for export to Sweden for electricity generated in high flow periods. Another scheme with high foreign investment was Røldal-Suldal where 2/3 were loans from banks in other countries.

The Røssåga hydropower scheme was implemented by the State through NVE and had then special treatment and was financed through ordinary State budget allocations, which were approved by the Parliament. In the parliamentary debate some representatives put forward a proposal for financing through loans, but the proposal was voted down.

The Skogfoss project was financed entirely by domestic resources. The financing also included transmission lines. The shareholders were the mining company A/S Sydvaranger (energy consumer) and the power company Varanger Kraftlag (energy producer). Each of the shareholders financed 50 % of the power plant, while Varanger Kraftlag financed the transmission lines. The power company received financial support from State banks.

These brief examples of financing in general give some introduction to financing. For other examples and more comprehensive descriptions the reader is referred to the presentations of the 14 hydropower schemes.

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1 The Aura Power Scheme (1946-1962)

Highlights

- The power project was developed as a part of the State's energy intensive industrial policy
- The post-WW2 political context provided a favourable financing opportunity
- The power project also targeted general supply in the surrounding districts
- The transmission lines associated with the power project became important building blocks in the future national transmission backbone system
- The aluminium smelter project, facilitated by a foreign loan, influenced the technical design of the power plant
- A long headrace pressure tunnel and a long shaft with tailored cross sections for the needs of the aluminium smelter implied constraints for later upgrading of the plant
- A diversion tunnel with many stream intakes conveys water to a large reservoir
- A large rockfill dam at an early stage of national competence building for this type

Project Information

The Aura and the Osbu power plants are in Møre and Romsdal County with the power stations located in the Sunndal Municipality. Møre and Romsdal is the south-western part of mid-Norway with border to the present Trøndelag County in the east and north. The power plants exploit hydro resources in the Aura (Eira) and the Litledalselva (Litledal River) watercourses. The origins of the two rivers are in the same mountainous area at 800-900 m a.s.l. The Litledal River flows northwards to the sea near Sunndalsøra, the centre of the Sunndal Municipality, while the Aura River flows north westwards to the sea in the neighbour municipality Nesset.

The Aura power plant was Norway's largest when commissioned and is an example of early technology for underground power stations. The largest units had also the highest capacity in Norway at that time. The implementation was a formidable work and was important for NVE and other developers as to knowledge and experience for future large power plants.

There were only relatively small lakes in the Litledal River's catchment area, and the costs for establishment of large reservoirs would be high. The Aura watercourse includes Lake Aursjøen,which permitted a much cheaper large reservoir. The solution was therefore to transfer the runoff from Lake Aursjøen to the lower located lakes in the upper part of the Litledal watercourse and establish smaller intake reservoirs there. The plan was strongly disputed but was approved.

The Aursjøen reservoir is on the border between Møre and Romsdal County (Sunndal Municipality) and the present Innlandet County (Lesja Municipality).

The two power plants were implemented in the period 1946-1958. The license was finally granted in 1953. The Parliament decided already in 1947 that NVE should start construction of the Aura power plant with 120 MW capacity. The capacity was later increased to 290 MW. The objective was then to supply both public consumption and the planned nearby aluminium smelter.

An additional license in 1959 gave the right to transfer water from rivers and streams (tunnel and intakes) to the main reservoir in Lake Aursjøen. The construction work was finished in the early 1960s.

The power scheme was developed by NVE (the State Power Utility by then). The present owner is Statkraft Energi, which is 100 % owned by Statkraft.[1] Statkraft was split off from NVE in 1986 after political debates for years. The data for the two power plants are shown in the table below.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Aura	290	46	783	1 852	1953
Osbu	20	46	56	112	1958
Sum	310			1 964	

Data from NVE's Hydropower Database, December 2020.

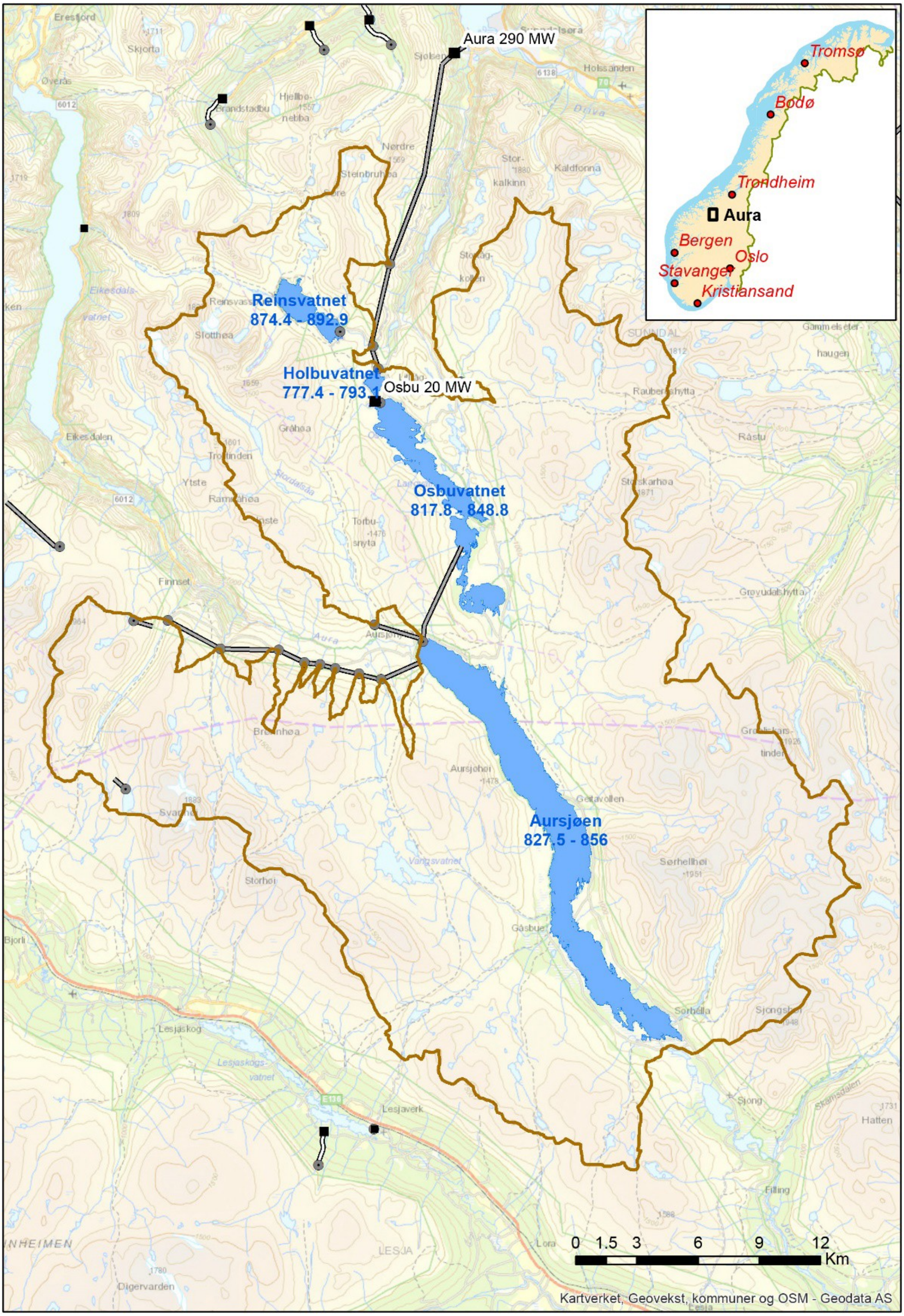
The capacities are the same as in the 1950s. The two power plants and the main reservoir Lake Aursjøen is an example of a cascade development. The Aura power plant utilises the head between the intake reservoir Lake Holbuvatnet and sea level on Sunndalsfjorden (Sunndal Fiord) at Sunndalsøra. The Osbu power plant exploits the head between the intake reservoir Lake Osbuvatnet and the tailwater in Lake Holbuvatnet. The total reservoir capacity is 720 Mm^3. Lake Aursjøen with 561 Mm^3 is crucial for the development. The total reservoir capacity is equal to about 75 % of the average annual inflow.

A headrace tunnel of length 16 km and a cross section area of 27 m^2 leads the water from Lake Holbuvatnet to seven Pelton turbines in the underground power station. The outlet to the sea permits flexible operation.

The Aura power plant was refurbished in 2006. It was by then considered whether to design the power plant for peaking purposes. However, the considerable costs associated with the increased cross-section area of the long headrace tunnel, or the construction of a new tunnel did not make this economically feasible.

A revision of the license provisions for two of the granted regulation licenses has been in process since 2003. The licenses in question were granted in 1953 and 1959. The revision was claimed by three concerned municipalities in October 2003 in a letter to NVE. In accordance with resolutions in the three municipal councils in November 2004 the steering committee for license revisions claimed the revision. Statkraft prepared a revision document in January 2006 as a basis for the public hearing. The hearing has been terminated. NVE has evaluated the comments and submitted their recommendations to the Ministry of Petroleum and Energy in December 2019. The Ministry's review is ongoing. Please refer to the Åbjøra hydropower project for a brief introduction to the background for a revision.

[1] The name was NVE-Statskraftverkene when included in NVE.



Overview of the Aura hydropower scheme.

The construction of hydropower plants has been important for the development in Norway during the last century, with extended effects to the society. Statkraft owns several power plants with high cultural heritage value. Statkraft has in cooperation with the Directorate for Cultural Heritage (Riksantikvaren) (and NVE in the period 2008-2010) prepared a protection plan for its cultural-historical properties to take care of these values. The Directorate adopted the conservations of parts of six of Statkraft's power plants. This was notified to Statkraft in August 2020. The selected power plants were constructed in the period from 1920 to1961 and show the development from surface power plants and surface penstocks to high technological underground power stations, tunnels, and shafts. The Aura power plant is one of the six selected power stations. Parts of two other power plants from this period are also included in the list. These power plants are the Nedre Røssåga power plant (commissioned in 1955) and the Tokke power plant (commissioned in 1960). The protection is authorized in the Cultural Heritage Act.

The Aura power plant from the early 1950s represents the State's hydropower development and industrial policy during the first decade after the war. Aura was the first State power plant with an underground machine hall (in fact there are two halls in parallel) and has a representative contemporary architectural design. Those protected comprise the underground power station, the valve chamber and the guard's house. The power station is in the underground rocks behind the portal building, while the valve chamber is located high up in the steep mountain side above the portal building. The purpose is to preserve parts of the Aura power plant which is an important cultural-historical example of a large State hydropower development in the early post-war period. The elements comprise the room sectioning with the original building elements, the wall panels and the use of materials, armatures, and illumination.

Project Background

The development of the Aura power plant has a long and laborious history.

The Norwegian founder Ragnvald Blakstad bought the fall rights in the Aura and the Litledal rivers in 1907 and established the company Aura Ltd. Mr. Blakstad intended to construct one or more power plants. In 1912 Aura Ltd. submitted a license application for an overall development of the two rivers. In 1913 his company, financed mainly by British capital, was authorised by the State to develop the hydro potential in the Litledal and the Aura rivers.

However, their proposal to divert Aura to Litledal and construct a single power station was not approved. Then it was decided to exploit only the potential in Litledal River in a 70 MW power plant. The company anticipated using the power for production of calcium carbide and cyanamide in a planned factory near the power station at Sunndalsøra. The works were soon started, and 2,000 employees were rapidly involved. When the First World War began in 1914 the work was temporarily halted but was soon taken up again until 1919 when it came to a stop for many years.

As mentioned, the license application in 1912 for an overall development was rejected. A new application was submitted in 1927 and was approved by the Parliament. However, Aura Ltd. was hesitant to adopt the license because there were uncertainties as to future power sale. During the German occupation of Norway in Second World War (WW2) the Germans started construction works to use the power for aluminium production. The progress was minimal, and the project was abandoned in 1943.

Political Aspects

After the liberation, the Norwegian State took over the plant as war booty. In October 1947, the Norwegian Parliament decided that the Aura power plant should be completed by NVE and granted a fund for the purpose. The preparation of the plans was delegated to NVE for later processing by Parliament. The plan was approved in July 1949. The development was then planned with four units with 30 MW capacity, with two units in the first stage.

During the Second World War the Norwegian Government in London discussed the use of hydropower after the war. Fredrik Vogt, a prominent civil engineer, and professor at the Technical University in Trondheim was central in the programme work. He emphasised that Norway should facilitate for high power demanding industry. In 1947 Professor Vogt was appointed to General Director in NVE. This initiated a radical change in the State's power engagement and the relation to the power demanding industry. NVE was at that time strongly influenced through many years with no progress in the State's hydropower development. However, General Director Vogt raised NVE's ability, and with support in the Labour Party's industrial policy several large State power schemes were implemented for supplying heavy industry during the following years. Normally the power plants were also constructed for public supply within the respective regions. Hence, hydropower contributed strongly to industrialisation, public electrification, and the Norwegian welfare state. The Aura power scheme and the aluminium smelter in Sunndal is one such example.

In 1951 the Parliament approved the construction of the aluminium factory at Sunndalsøra. To provide power for aluminium production the power plant had to be enlarged, which also was approved by the Parliament. The capacity was increased from 120 MW to 288 MW, with three additional units, each of 56 MW. Besides selling power to the industry the Aura plant also generated for public supply within the Møre and Romsdal County and two other counties, both northwards. NVE completed the construction of the Aura power plant and constructed a 132 kV transmission lines to neighbouring districts. A smaller power plant (Osbu) with capacity 20 MW was commissioned in 1958 and exploited the head between two reservoirs.

The power plant and the aluminium smelter were constructed simultaneously. The smelter was in operation in 1954 and was a flagship in the Labour Party's industrial policy. The associated aluminium smelter project must be seen in the light of the political situation after WW2. In 1948, the U.S. Government launched the European Recovery Programme (ECA, often referred to as the Marshall Plan). The purpose was to stabilize the political situation in Western Europe by stimulating economic growth. Self-sufficiency in aluminium was strategically important for Europe, and the ECA provided an opportunity for the Norwegian Government to realize its industrial policy.

Project Organisation

The hydropower scheme was implemented as a NVE project. NVE used its own staffs in the engineering and construction tasks. Aura was NVE's first hydropower project since the Nore hydroelectric power project in the 1920s and the early 1930s and was a challenging task. In the first years after WW2 NVE's organisation was strongly influenced by many years with limited employment in power engineering and construction, and a staff of aged engineers. However, the organisation was gradually strengthened with budgets that allowed for employing skilled, innovative engineers and construction workers. Many skilled persons were employed in NVE for decades, and their companionship was an important factor in NVE's success.

The new technology also made it possible to carry out many tasks mechanically instead of manually. Thanks to improved technology the Aura development became the most modern in Norway so far. The methods for rock excavation were totally changed. It was possible to excavate tunnels, shafts, and power stations cheaper and faster than earlier. Large rockfill dams were also a new experience. Although there was much competence in NVE, there was also a need of external experience. In Norway the Technical University, consultant companies, contractors, mechanical and electrical suppliers, and power companies were useful advisers. Study tours were made to Sweden (tunnel excavation) and USA (rockfill dams) in particular. As time went on it was obvious that Norway at least was on par with other countries regarding competence and experience in the construction of hydropower plants.

There was also rationing and lack of equipment and building materials hampered the work progress. NVE also organised procurement of turbines, generators, and transformers. Norwegian suppliers were in an establishment stage, and they were not yet ready for these large deliveries. Four turbines in German possession had been taken over by the Norwegian State as war booty, while the other machinery was mainly purchased from other countries.

However, the Aura project and other large Norwegian hydropower projects developed a considerable supplier market in which also competent Norwegian suppliers would have a promising future. The governing powers therefore encouraged relevant Norwegian suppliers to strengthen their capacity, and within a few years Norwegian manufactures of high quality made up a considerable share of the Norwegian hydropower market. This was also caused by a license clause requiring that the licensee preferably should apply Norwegian equipment and services for the construction works and operation. Norwegian suppliers, in particular the turbine producer Kværner, increased their competence and strengthened their economy.

Economic and Technical Aspects

Due to the ECA loan and approval of the aluminium smelter project, NVE designed a larger power project than originally planned. Given that the main purpose was to supply the aluminium smelter, the Aura power plant was designed with a high load factor (i.e. the installed capacity is low compared to the annual electricity generation).

As part of the project, 132 kV transmission lines to Trondheim (Norway's third largest city) and Molde (the administrative centre of Møre og Romsdal County) were constructed. This was a strategic choice for providing stable electricity supply as well as creating a larger market for the power from Aura. These transmission lines also formed a building block of the future national transmission backbone system.

The Aura power plant consists of the intake in Lake Holbuvatnet, headrace tunnel, surge chamber, valve chamber, two parallel shafts with two penstocks in each of them, an underground power station and a tailrace tunnel.

The headrace tunnel is 15.9 km long. During the first construction period in 1913 the tunnel was designed to conduct water from the Litledal River only. The tunnel was given a cross section of 14 m^2 and a length of 17.9 km and was planned to be excavated by use of 14 adits, but only 2.5 km was completed. In the revised project the tunnel cross section was enlarged to 27 m^2 since the discharge increased with water from both rivers. On the other hand, the improved tunnel technology made it possible to reduce the number of adits to four. This enabled the tunnel alignment to be straightened and its length to be reduced to 15.9 km. Only a small part of the tunnel which was excavated during WW1 could be used.

The power station was constructed with two machine halls. From the valve chamber there was one shaft down to each machine hall. Two penstocks in each shaft led the water to the turbines. The length of the shafts was around 1,100 m. The shafts were excavated with a declination of 45° and a cross section of 32 m^2.

The northern machine hall accommodated four units, each of them with 30 MW capacity. The Pelton turbines for these units were ordered by the Germans during WW2 for another plant which was never constructed. The turbines were taken over by the State as war booty at the time of liberation. In the southern hall there are three Pelton turbines, each of them with a capacity of 56 MW, giving a total capacity of 288 MW. The units in the southern hall supplied the furnaces in the aluminium smelter, while the units in the northern hall were allocated for public supply.

The tailrace system included a 575 m tunnel with a cross section of 29 m^2 and a 190 m channel to the outlet of the sea.

The facilities in the regulation area are also important. The line of production and reservoirs is as follows: Aursjøen reservoir – diversion tunnel to the Osbuvatnet reservoir – the Osbu power plant - Holsbuvatnet – the Aura power plant. The data for the reservoirs are:

Reservoir	Natural level (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Capacity (Mm^3)
Aursjøen	831	856	827.3	561
Osbuvatnet	825.7	848.8	817.8	150
Holbuvatnet	777.4	793.1	777.4	8.5
Sum				720

The reservoirs Aursjøen and Osbuvatnet include submersions of upstream lakes with higher natural and LRWL levels than given in the table.

There is in addition a reservoir in Lake Reinsvatnet in a tributary river to the Litledal River. The reservoir volume is 38 Mm^3 between 892.0 m and 874.4 m a.s.l.

The last license in 1959 included diversion from catchment areas northwest of Lake Aursjøen. A tunnel with a length of 14 km conveys water from many rivers and streams to the Aursjøen reservoir. The diversion was completed in 1962. This tunnel is in Norwegian named "Takrenne" (gutters). The name has later been used as a standard term for tunnels which gather runoff from rivers and streams along a valley side. The facilities are regarded in context as to the economy of the scheme. The diversion tunnel provided more water and gave the option for larger capacity in the Osbuvatnet reservoir which was created by a costly dam construction. An argument was that the solution gave an increased head and thereby higher energy production in the Osbu power plant.

Today, the Osbu power plant exploits the mean gross head of 56 m between the Osbuvatnet and the Holbuvatnet reservoirs. The installation is 20 MW, with one unit with Francis turbine in a surface power station.

The Aursjøen reservoir is the largest in the Aura hydropower scheme. The reservoir above the natural water level was created by the construction of a rockfill dam and merges with the upstream Lake Gautsjøen when the water level is higher than the natural water level of Lake Gautsjøen. The Aursjøen dam was the first rockfill dam which was designed and constructed by NVE and was also one of the first dams of this type in Norway. There was no available moraine for a central core as seal and the dam was therefore originally constructed with two upstream layers of impregnated timber planks separated by a tarpaper seal. The dam construction was completed in 1956. The dam was nearly 1 km long with 39 m as the maximum height. The amount of blasted rock was 860,000 m^3. The upstream seal has later been rehabilitated and partly reconstructed several times and in 2005-2006 the whole impermeable seal was removed and renewed with a thick concrete lining. Measuring weirs and two metering cabins just downstream the dam to provide continuous monitoring of seepage were also established.

The five other dams in the scheme are smaller, but certainly not insignificant, neither as to construction tasks nor function. Four of them are rock fill dams and the last is a concrete dam. The dam at Osbuvatnet is a rockfill dam with an impermeable frontal concrete lining.

The acquired competence and experience of rockfill dams in Norway during the next decades were followed up. Many large rockfill dams have been constructed. This type is often cheaper and more appropriate than other dam types. Moraine has been a current material for the dam cores but had to be available not far from the dam sites. If not, a concrete slab in front was a solution. Later, rockfill dams with asphalt core have also been constructed.

Dam sites on lakes in mountainous areas are often well suited to rockfill dams, which then create large reservoirs. Additional reservoir capacity is many places is provided by lake tapping (utilisation of a reservoir below the natural water level). The high-altitude large reservoirs which have rockfill dams are important for the Norwegian electricity system. Power plants with a large reservoir in combination with a high head is a characteristic part of Norwegian hydropower development.

Project Financing

The hydropower project was financed through ordinary state budget allocations. However, the power plant was designed to secure power for the construction of the aluminium smelter, originally with a capacity of 40,000 tonnes aluminium annually. The Economic Cooperation Administration (ECA)[2] provided favourable loans for the construction of the aluminium smelter. This support helped to finance the aluminium smelter without draining the state budget.

The entire funding for the aluminium smelter was based on a loan in US and European currencies. The loan had an interest at 2.5 % and a repayment period of 10 years. The loan was paid back in deliveries of aluminium, valued in accordance with the prevailing market price.

[2] i.e. the U.S Government Agency was set up to administer the Marshall Plan.

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2 The Åbjøra Hydropower Project (1946-1960)

Highlights

- A county and an adjacent district in another county with limited energy resources within or near the respective supply areas
- Both the county and the district were owners of a public power company through the municipalities
- Power purchase versus developing own power plants – or both
- Development of a project in another county relatively far away through the respective power companies in a Joint Venture
- Limited transmission possibilities between the power plant and the supply areas
- Financial risks and liquidity constraints were mitigated through the Joint Venture
- Risks were also mitigated through project development in stages
- The Watercourse Association's role in the Åbjøra development area
- Technology development provided opportunities to increase the power plant's efficiency
- A not-yet concluded revision process of the license conditions may impose stronger environmental restrictions on future plant operation

Project Information

The Åbjøra hydropower plant is in the Nord-Aurdal Municipality and the present Innlandet County[1], about 130 km north-west of the capital Oslo. The construction works started after the regulation licenses were awarded in November 1948 and January 1949.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Åbjøra	95	24	442	474	1951

Data from NVE's Hydropower Database, December 2020.

Åbjøra HPP utilizes the head between the intake reservoir Lake Ølsjøen (also named Bløytjern) in the Åbjøra River and the regulated Lake Aurdalsfjorden in the Begna watercourse. Åbjøra River is a 60 kilometres long eastbound tributary river to Begna River, which is the main river in the valley of Valdres. The catchment area to the power plant is 837.4 square kilometres.

The first construction stage included two 27 MW units with commissioning in 1951. This phase included also a 75 km transmission line. A third unit of same size was commissioned in 1955, giving an installed capacity of 81 MW.

The power plant was upgraded in 2002. The upgrading included a new underground power station 200 m from the original underground station. The three Pelton turbines with total capacity 81 MW were replaced by one 95 MW Francis turbine.

Most hydropower licenses in Norway are granted for public development and are time unlimited. However, it is possible to improve the environmental requirements

[1] Innlandet County is a merging of the earlier Hedmark and Oppland counties from 1 January 2020. Åbjøra hydropower plant was originally located in Oppland County.

for the operation of hydropower plants through revision of the licensing provisions. It is a prerequisite that the revision is claimed by representatives of public interests such as concerned municipalities or organizations within outdoor recreation and nature conservation. On basis ofthe claim, NVE decides whether the revision process shall be implemented. A revision of the provisions opens for a weighting of the social benefit of the hydropower production against the impact of the regulation on the environment and public interests, such as recreational use and landscape experience. At the same time, the revisions are the principal instrument to improve the environmental conditions in regulated watercourses, and thus to implement the European Water Framework Directive in Norway.

The right to claim a revision of a license's provisions is an important statuary right in Norwegian watercourse legislation. A few revisions are completed or are in process. Three of the ongoing revisions are mentioned in this collection of examples. The claims and the processes are referred to here and not the outcome. Furthermore, several revisions are in the pipeline to be carried out in the near future.

A revision of the license provisions for the Åbjøra hydropower plant has been in progress since 2010. The revision was claimed by five concerned municipalities in May 2009. The public hearing has been terminated, and NVE submitted their recommendations to the Ministry of Petroleum and Energy in December 2018. As of June 2021, a final decision has not yet been made.

Åbjøra power plant has been 100 % owned and operated by Skagerak Kraft AS since 2001. Skagerak Kraft is one of Norway's largest producers of electricity, with almost 50 wholly and partly owned hydropower plants. Their mean annual generation is approximately 5.6 TWh. Skagerak Kraft was established 1 January 2001 and is owned by Statkraft (66.6 %) and three municipalities in the lower part of the earlier Telemark County (33.4 %).

The three municipalities were originally the owners of Skiensfjordens kommunale kraftselskap AS (SKK) while Vestfold Kraft[2] AS (VK) was owned by municipalities in the earlier Vestfold County. SKK and VK have a long history in the earlier Telemark and Vestfold counties respectively[3]. These two companies constructed the Åbjøra hydropower plant in a Joint Venture (JV) cooperation. The JV was the owner until 2001 when SKK and VK were incorporated into Skagerak Kraft.

The ownership changes illustrate the new situation in the energy production and support system since the early 1990s, both as to single companies as well as an overall national energy regime.

[2] The name was Vestfold Kraftselskap (Vestfold Power Company) until 1996, when the name was Vestfold Kraft.

[3] Vestfold and Telemark County is a merging of the earlier Vestfold and Telemark counties from 1 January 2020.

Overview of the Åbjøra hydropower project. The brown line shows the catchment area.

Project Background

Vestfold County faced a rapid growth in electricity demand after WW2. The county had to a large extent relied on power purchase from NVE. However, Norway faced a tight power balance in the late 1940s which reduced the options for power purchase. Thus, there was a recognition that Vestfold County, through its power company Vestfold Kraftselskap (VK), most probably had to develop its own power plants.

Vestfold is a small and a mainly lowland district with limited hydropower resources and with little developed hydropower in 1946. In total, there were around 20 private micro (lower than 100 kW) hydropower plants with summarized capacity less than 1 MW and one larger power plant with capacity 2 MW owned by a private industry company. VK owned and operated four power plants with total installed capacity 20 MW in the then neighbouring counties Telemark (3) and Buskerud (1). The plants were commissioned in the period 1912-1921, and the distances to Vestfold were a few tens of kilometres. The production could scarcely meet the then demand, and the supply situation in the ensuing years was foreseen to be difficult. VK therefore intensified its efforts to locate hydropower resources for purchasing water rights and later power plant construction in other counties. In 1946 VK acquired the water rights in the Åbjøra River in Oppland County, about 200 km north of Vestfold.

VK was established in 1920 with objective to produce and distribute power. The company was owned by several municipalities in the then Vestfold County. The county was located about 80 kilometres south of the capital, Oslo. The area is approximately 2,200 square kilometres with a population of nearly 175,000 in 1946.

The municipal power company Skiensfjorden kommunale kraftselskap (SKK) in the then Telemark County was established in 1912. The Norwegian Prime Minister Gunnar Knudsen was initiator. The owners were municipalities in the area around Skiensfjorden, a fiord district in a lower part of then Telemark County. Mr. Knudsen said: "Which possibilities are there for new business and development given a safe energy source? What about a common solution?" These ideas were the background for the Prime Minister's letter to the mayors in the involved municipalities in 1910. Mr. Knudsen was educated as an electrical engineer and had earlier been pushing for the establishment of one of the first hydroelectrical plants in Norway (1885). Many years later he combined local and national energy policy with personal authority and technical expertise.

After WW2, SKK was lacking projects to meet the increased power demand in its supply district. The company had developed two power plants in Telemark County before the war, with capacities of 18 MW (1915) and 22 MW (1933).

Both SKK and VK were engaged in power generation and sub-transmission. VK sold power to distribution companies in then Vestfold County. SKK was also directly involved in electricity distribution. Now there was a need for both companies to increase their own production for sale and thereby reduce the purchase of power.

Due to uncertainties regarding demand growth and the financial burden associated with the project, VK entered into negotiations with its neighbour SKK for a joint development of the Åbjøra project.

The Skiensfjorden district borders on Vestfold and there was a relatively short distance between VK's and SKK's supply areas. The cooperation between the companies had long traditions, and after the war it was appropriate to renew the cooperation. In 1947 the two companies agreed on a Joint Venture for the development of Åbjøra HPP, for which VK had acquired the water rights the year before.

Political Aspects

The developer of Åbjøra hydropower plant was a Joint Venture (JV) established by Vestfold Kraft(VK) and Skiensfjordens kommunale kraftselskap (SKK).

The first regulation license was awarded in November 1948. Additional licenses were awarded in 1949, 1957 and 1959, comprising one new reservoir and extensions of three others. Thus, five reservoirs were established in the regulation area with a total volume of 220 Mm^3, which is still the case today. The licensee is "Foreningen til Bægnavassdragets Regulering" (FBR). FBR is an association in accordance with the Watercourse Regulation Act. FBR's objective is to take care of the owners' common interests as to use of water in the Begna watercourse. FBR was founded in 1908. The present owner of Åbjøra hydropower plant (Skagerak Kraft) is now one of eight owners.

Similar associations to FBR have been established in most large watercourses in Norway, and are important parties in the establishment, coordination, maintenance and operating of regulation facilities as dams, reservoirs, and diversions. Hence the associations have a notable role in the Norwegian hydropower system. The associations cooperate with the owners of the power plants in the watercourses, and the owners are also members of the associations.

There was a relatively long distance from Åbjøra to the supply areas of the two JV companies. The solution was then to transfer the power to a site located closer to Åbjøra for local distribution and consumption. Hence, the construction of a long transmission line to the owners' supply areas was avoided. It was necessary to involve NVE for a power exchange agreement. The agreement stated that the JV could deliver power to the grid in a connection point and receive an equivalent amount in sub transformer stations in the respective supply district. A 132 kV power transmission line with a length of 75 km was constructed eastwards to Gjøvik. There the electricity was transformed down to 60 kV for NVE's disposition for deliveries in this district. SKK and VK received power from NVE equivalent to their respective shares of the production in the Åbjøra power plant (with deduction of an agreed loss percentage). The compensation power was transferred to transformer stations in the JV's respective supply areas. The contractual power amount was then available for local distribution.

Project Organisation

The project organization manned a construction site office, which was in close contact with VK's engineering office. A Norwegian contractor was awarded the main civil contract. The primary tasks of the site office were then control and coordination. Some small works were nevertheless carried out with the in-house workforce. The construction works took place during a period with strong economic expansion, resulting in budget overruns. The poor rock conditions at the power station site also contributed to the overruns.

The Pelton turbines were produced by an English company. The generators were also produced in England, while the transformers were delivered by a Norwegian company.

The Joint Venture (JV) was based on a fifty-fifty ownership. At the same time, the two companies also established a JV for the Hjartdøla power scheme in Telemark. Hjartdøla was commissioned in 1958. VK was responsible for the construction works in the Åbjøra project, while SSK took the same role in the Hjartdøla project. Later, the two companies also established other JVs as well as JVs with other power companies.

Economic and Technical Aspects

The Åbjøra hydropower plant was planned and constructed in the period 1947 to 1960 for utilization of the head between Lake Ølsjøen and Lake Aurdalsfjorden. The mean gross head was 420 m. The first stage in 1947-1951 included two Pelton turbines, each with capacity of 27 MW, and the mean annual production was estimated to be 420 GWh. A unit number three was commissioned in stage 2 in 1955, also with a 27 MW Pelton turbine. Then the production increased to 470 GWh. Stage 2 also included an increase of the reservoir capacity.

The runoff originates from a mountainous area of almost 840 square km between two valleys, Hemsedal in the west and Valdres in the east. Lakes at 750-870 m a.s.l. were suitable for reservoirs. Four reservoirs in addition to Lake Ølsjøen were established. The reservoir volume in stage 1 was almost 150 Mm^3. After a very dry summer in 1959 there was a poor reservoir situation in eastern Norway, and a larger reservoir capacity was considered. A new reservoir in Åbjøra's catchment area was established. The Ministry gave in addition the permission to increase three of the existing reservoirs. The total reservoir capacity included Lake Ølsjøen and was then 221 Mm^3 in 1960, which was approximately 40 % of the mean annual inflow. The reservoir capacity has been unchanged since then.

Figures for the regulation reservoirs and the tailwater (Aurdalsfjorden) are shown in the table below.

Reservoirs	Natural WL (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Volume (Mm^3)
Ølsjøen	747.97	748.97	745.97	8.1
Helin	865.83	867.83	865.83	18.7
Storfjorden-Flyvatnet	855.9	859.4	853.9	57.5
Storevatnet	824.09	824.09	821.09	13.3
Tisleifjorden	810.57	820.57	809.07	123.4
Sum				221.0
Aurdalsfjorden		307.0	303.2	9.4

The dam on Lake Ølsjøen has three sections, a rockfill dam with concrete core, an Ambursen (concrete) dam and a concrete gravity dam. The total length is approximately 750 m and the maximum height is 13.5 m.

A tunnel with a length of 4,500 meters and a cross section of 18 m^2 led the water to a surge chamber (700 m^3) and a pressure shaft. The length of the shaft is 660 m declining 43 degrees down to the underground power station. Three horizontal Pelton units were installed. The tailwater tunnel to Lake Aurdalsfjorden was 1,100 meters long. The access tunnel to the power station has a length of 576 m.

The use of Francis turbines was not an actual technical option when Åbjøra power plant was planned and constructed. However, when the power plant was upgraded in 2002 the Francis turbine technology had been developed to cater for high heads like that of the Åbjøra scheme. Francis turbines have higher efficiency than Pelton turbines and the intake in a reservoir allowed for one single unit. Due to the poor rock conditions the power station was moved to a new location 200 m further into the mountain massif. This is an example of technical solutions to modernize power plants of that age, and thereby achieve a more effective operation and increased profitability.

Project Financing

Each of the two companies raised 50 % of the necessary capital. VK raised its share of the capital through debt financing. A consortium of thirteen life insurance companies provided a loan with an interest rate of 3 %, with mortgage in the assets. The loan was converted to a bond in January 1953. There were only interest payments during the first two years, followed by a repayment period with a duration of ten years. In general, SKK raised most of the capital for its hydropower projects through loans. For the Åbjøra project, SKK's board authorized the company to increase the electricity tariff by 15 %.

Due to 33 % cost overruns, VK and SKK had to raise additional capital. For VK, somewhat more than 50 % of the additional costs were met through additional long-term loans, while the remaining share was paid by short term loans from the municipalities in the then Vestfold County.

The unit number three and the additional works in the regulation area in the late 1950s were financed through operating funds.

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3 The Porsa Hydropower Scheme (1946-1962)

Highlights

- Inter-municipal cooperation for the establishment of a power company
- Permanent and effective administration over decades
- Rebuilding of a war-torn district
- Important for meeting local electricity demands for households and industry
- Central or local transmission lines for rural electrification?
- Construction and operation in a harsh arctic area
- An example of State financing support

Project Information

The Porsa Hydropower Scheme consists of two power plants in series, Nedre (Lower) Porsa and Øvre (Upper) Porsa (see the table below). The lead time for implementation from the first years after the Second World War (WW2) to the commissioning of the power plants was long and difficult.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Nedre Porsa	12.8	7.7	215	58	1959
Øvre Porsa	1.7	6.9	55	11	1962
Sum	14.5			69	

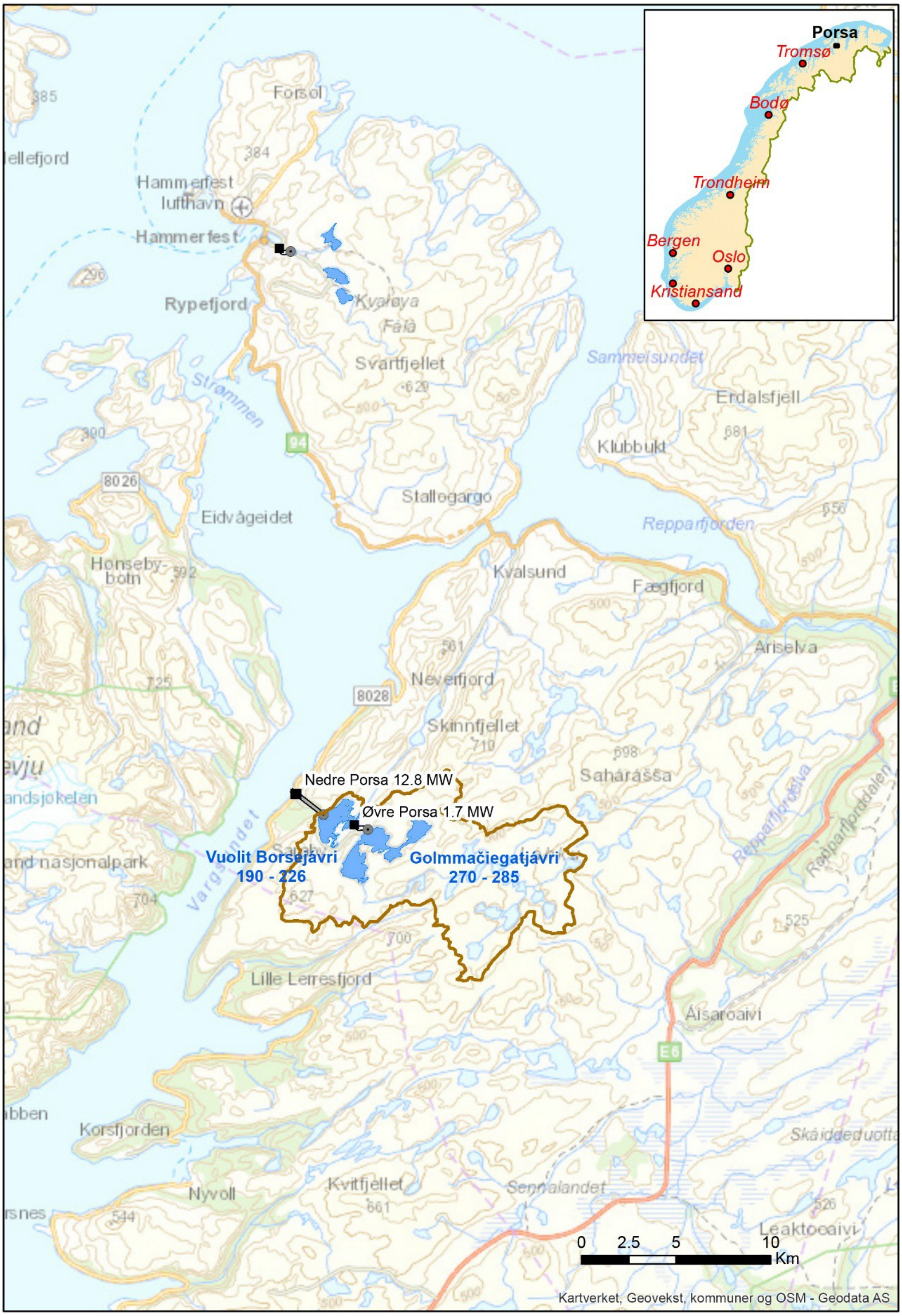
Data from NVE's Hydropower Database, December 2020.

Øvre Porsa was rehabilitated 2016-2017 (commissioning in January 2018) with new electro-mechanical equipment with less capacity than originally (2.5 MW) from 1962.

The two hydropower plants are in the Porsa watercourse in the present Hammerfest Municipality and today's Troms and Finnmark County[1]. Hammerfest is the municipal administration centre. The district is a typical northern Norwegian coastal area, located c. 70 °N latitude and has a harsh and stormy coastal climate as well as polar darkness for two months. The topography is challenging, with steep mountains, fiords and islands. Transport is therefore often difficult, particularly in the long winter. The distance by road from Porsa to Hammerfest is approximately 40 km.

The Porsa hydropower plants are owned and operated by Porsa Kraftlag AS (Porsa Power Organization Ltd). Porsa Kraftlag is owned by three municipal energy companies, in three different municipalities. Hammerfest Energi (Hammerfest Energy), Repvåg Kraftlag (Repvåg Power Organization) and Alta Kraftlag (Alta Power Organization). The shares are 70 %, 10 % and 20 %, respectively. This corporate form is the same as when established in 1956.

[1] The earlier Troms and Finnmark counties have been merged into Troms and Finnmark County from 1 January 2000. The Porsa hydropower scheme was originally in Finnmark County.



The Nedre (Lower) and the Øvre (Upper) Porsa hydropower plants. The reservoirs are here given their Sami names.

Project Background

The development was planned to increase electricity supply in a district in the western part of Finnmark County, both for households and the fishing industry in the area. Finnmark County was the northernmost county in Norway, and the largest. The area is some 48,000 km^2, with population approximately 59,000. Finnmarksvidda, a high plateau at elevations 300-500 m a.s.l.,, covers 36 % of the county. The planning and construction of the two plants in Porsa was a part of rebuilding of Finnmark County after WW2. The hydroelectric potential in Finnmark was low compared to most other counties in Norway.

The electricity supply was inadequate even before WW2. Due to substantial destruction, the situation was even more critical after the war. The Soviet Army (the Red Army) forced the Nazi Army from east to west through the county during autumn 1944 and winter 1945. The escaping Nazi Army detonated and burned most of houses, factories, and infrastructure in the county.

Finnmark was a wilderness when the war ended in May 1945. Many people had been evacuated to southern districts in Norway. Several people escaped to the high plateau area, where they spent the winter in caves or other uncomfortable places. Hence, power development in Finnmark was not only a normal process in a county with low power coverage, but also an essential part of the reconstruction of a total war-torn county. Other Norwegian counties were also affected by the war, but not as totally as Finnmark. Even so, projects in Finnmark were evaluated in a national context as to utility value and available economic resources. The southern parts of Norway had a much higher population, also with an uncovered electricity demand. Large power plants for electricity support to the metallic smelting industry were also important for the national economy.

Utilization of the resources in the Porsa watercourse was anyway considered to be an important local contribution. However, other projects in Finnmark were prioritized higher than Porsa. This meant that the first and largest of the Porsa power plants was not commissioned until 14 years after the end of the war.

There is an earlier history of hydropower production in Porsa. A private mining company built a small hydropower plant in 1918 for electricity support to their copper mining. The installed capacity was approximately 0.45 MW. Due to low copper prices the mining was terminated after a few years. A continued operation of the power plant was not relevant without the mining activities.

Hammerfest owned a small hydroelectric power plant in the town, but generation in the existing small power plant could not meet the increased demand.

At the end of the 1930s Porsa was of interest for the municipal power company, Hammerfest Energi (HEV)[2], also for a larger development than that existing plant.

[2] The company has changed name since foundation in 1891. Here we use Hammerfest Energi even though this was not the name when Porsa power plants were planned and constructed. However, the company has always been 100 % owned by municipalities, of which Hammerfest Municipality all time in a majority, with 80 % share at present.

Hammerfest Energi was founded in 1891. At the same time a small hydropower plant was constructed in a suitable waterfall (40 m) at Storvatnet in the town's immediate vicinity. A 1.1 kV transmission line transferred electricity to the town for street lighting. Hammerfest is said to be the first town in world with street lightning from hydropower generation. During the years to come the power plant was enlarged in several stages for generation in line with increasing demand, although the demand gradually exceeded the possible generation at this location.

The rights in Porsa were transferred from the mining company to HEV in 1939. HEV immediately started planning a more reliable power plant, and construction was also initiated. The works went on as planned during the autumn of 1939 and winter 1940, and partly also later. 550 kW was clarified for operation in the summer of 1941. A 22 kV transmission line to Hammerfest was also constructed and connected to the power plant. However, it was obvious that the capacity was too low to meet the rapidly increasing demand. The German occupants also initiated industry with the need for electricity. Full electricity cover was not achieved during the occupation. The Porsa power plant (550 kW) was destroyed by the German Army in late autumn 1944. The power plant was rehabilitated in 1947 and was phased out when the new Nedre Porsa HPP was commissioned in 1959. The installed capacity before commissioning of the Nedre Porsa plant was 1.3 MW after a temporary extension of the plant in 1951/52.

There are limited hydropower resources in the coastal areas of Finnmark, and a more rational exploitation of Porsa was already discussed at that time. Only a minor part of the potential was utilized, and the old power plant was always regarded as a provisional solution. After WW2 it was important to reconstruct and increase electricity production in Finnmark. Several possibilities were evaluated and prioritized in the late forties, but Porsa was not included (see also Political Aspects). Nevertheless, the local authorities continued their attempts to find acceptable prerequisites for the development of a larger power plant. However, both organization of a power company as well as financing were the main challenges.

Political Aspects

From the very beginning of the reconstruction of Finnmark after WW2 it was stressed that Porsa was important for a more sufficient and secure electricity supply for the district. The old power plant was out of function after the war.

Hammerfest is a centre in the district, and the Porsa scheme with good energy storage capacity was considered important for the town and the more rural adjacent municipalities. There was an increasing electricity demand. The municipal energy company, Hammerfest Energi, was clear in this matter. It was also concluded that it was not sufficient to rehabilitate the existing Porsa power plant. Hammerfest Energi was in forefront of promoting a new Porsa hydroelectric scheme before the war as well as in the reconstruction phase after the war. A development of both Nedre and Øvre Porsa as soon as possible was required. Planning of a higher utilization of the resources had started short before WW2, but the war hampered effective progress.

Representatives from the Norwegian Water Resources and Energy Directorate (NVE) visited Finnmark in July 1947. Other participants were representatives from the county's tribunal for electricity support. The purpose was to consider possible power plants, among them Porsa. It was concluded that NVE would recommend several power plants in Finnmark to be prioritised in an initial phase, either quite new or rehabilitation and enlargement of existing power plants. The target was that Finnmark should be electrified as near full-scale as soon as possible. Therefore, there was a hope in Hammerfest and the nearby district that construction of an enlarged Porsa power plant could be implemented within a short time. The county tribunal proposed five projects to be prioritised, all with equal priority. Porsa was one of these projects.

However, the following year, a disappointing message came to the Hammerfest district. In a White Paper in 1948 the Ministry of Industry presented a national priority list for hydropower development where only four plants in Finnmark were listed. Porsa was not included, as the only one in the list presented by the county tribunal one year ago.

One reason for the omission of Porsa was that the central energy authorities were sceptical to a development with Hammerfest Energi in the lead for both production and distribution of the electricity. Larger geographical and economical units as the future's organization of electricity support were foreseen. There was therefore limited understanding of giving priority to an independent municipal power company when there were several projects in a national context. In addition, there was also a considerable national shortage in both capital and stock. The Porsa scheme was therefore postponed for an indefinite time.

However, the plans were not discarded, and further attempts to find an acceptable inter-municipal organisation for an implementation were carried out. Hammerfest Municipality then asked other municipalities if there was a will to establish an inter-municipal power association with purpose to develop Porsa, and then meet the superior national obligations. Alternative solutions were proposed and negotiated for some years. There was broad local agreement on the development of Porsa. Despite different points of view as to the organizational structure concerned municipalities succeeded in the establishment of an association named Porsa Kraftlag in 1956.

The license for acquisition of rights for use of and regulation of the Porsa watercourse for 50 years was granted in a Royal Decree in May 1958. The license was renewed to be valid indefinitely in July 2007.

Project Organisation

An inter-municipal power company Porsa Kraftlag was established in 1956, with objective of ensuring an effective organisation for proper development of the Porsa hydropower scheme, including financing. The power company was a result of local negotiations. The organisation met the superior national obligations (see also Political Aspects).

Porsa Kraftlag was founded with three municipal energy companies as owners. Hammerfest Energi with 70 % share, Repvåg Energi with 10 % share and Alta Energi with 20 % share.
The ownership and shares have been unchanged since 1956.

Economic and Technical Aspects

The Porsa scheme has been important for the district. The electricity support has brought about industry establishment, serving the activities for fisheries in the area, employment and subsequent improved public and private economy.

An important aspect was that the overall grid systems were inadequate sixty years ago. Hence, the local supply of electricity was more dependent on local power plants and local transmission lines than today. A 66 kV transmission line from Porsa were also constructed. This was the start of the regional grid in West-Finnmark. It was also facilitated for a 22 kV outlet from Nedre Porsa, which was connected to the existing 22 kV line.

The two power plants have a relatively high reservoir capacity, with approximately 40 % of mean annual runoff for Øvre Porsa in the Golmmačiegatjávri (Bjørnstadvatnet) reservoir and approximately 70 % for Nedre Porsa with the Vuolit Borsejávri (Porsavatn (Storvatnet)) reservoir. (Golmmačiegatjávri and Vuolit Borsejávri are Sami names). The reservoirs are valuable also today but were even more so when the power plants were planned and constructed. Benefits are, both then and now, the possibility of storage of water in summertime for production in wintertime. In addition, there are small flood losses.

The reservoirs are listed below.

Reservoirs	Natural WL	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Volume (Mm^3)
Bjørnstadvatnet	270	285	270	40
Porsavatn	209	226	190	52
Sum				92

The Nedre Porsa power plant utilizes the head from Porsavatn to the sea. The reservoir was established by damming Porsavatn. The main dam is a rockfill dam with concrete core. The headrace from intake to the power station consists of a horizontal tunnel (150 m), a pressure shaft (250 m) and a horizontal tunnel (250 m). The power station, with two horizontal Francis turbines, each with capacity 6.2 MW, is located underground. A tailrace tunnel of length 140 m leads the water to an outlet in the sea.

The Øvre Porsa power plant has its intake in Bjørnstadvatnet and its outlet in Porsavatn. The reservoir was created by construction of a rockfill dam with concrete sealing on the water side. A short tunnel and a surface pipeline (wood) with length 750 m were constructed to lead the water to the surface power station. A turbine with capacity 2.5 MW was installed (replaced with 1.7 MW a few years ago).

Project Financing

The Porsa Hydropower Scheme was mainly financed from a national development bond for Northern Norway. The bond was established in 1952 and lasted ten years, when it was included in a national fund for development of rural areas throughout Norway. The idea was that this bond would improve social living standards in northern Norway and was based on decision in the Norwegian Parliament. The focus was on investment for fisheries, energy, and other industry. The credits and grants given by the bond were based on grants through the State budget.

The national development bond granted for approximately 80 % of the investment as an advance loan for Nedre Porsa. The loan was presupposed to be converted to a State bank loan. The remaining capital was raised as district grants, Sivilforsvarsnemda (Civil Defence Committee) and by military sources.

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4 The Røssåga Hydropower Scheme (1947-1962)

Highlights

- The power project was developed as a part of the State's energy intensive industrial policy
- Contribution to the economic strengthening of northern Norway by supplying power to regional industry
- The Norwegian post-WW2 political context provided a favourable financing opportunity through State allocations
- The power project also targeted public supply of electricity to the surrounding districts
- The Røssåga hydropower scheme was one of the largest hydropower developments in Norway during the first years after the Second World War (WW2)
- The implementation was challenging, and new equipment and methods for hydropower construction were introduced

Project Information

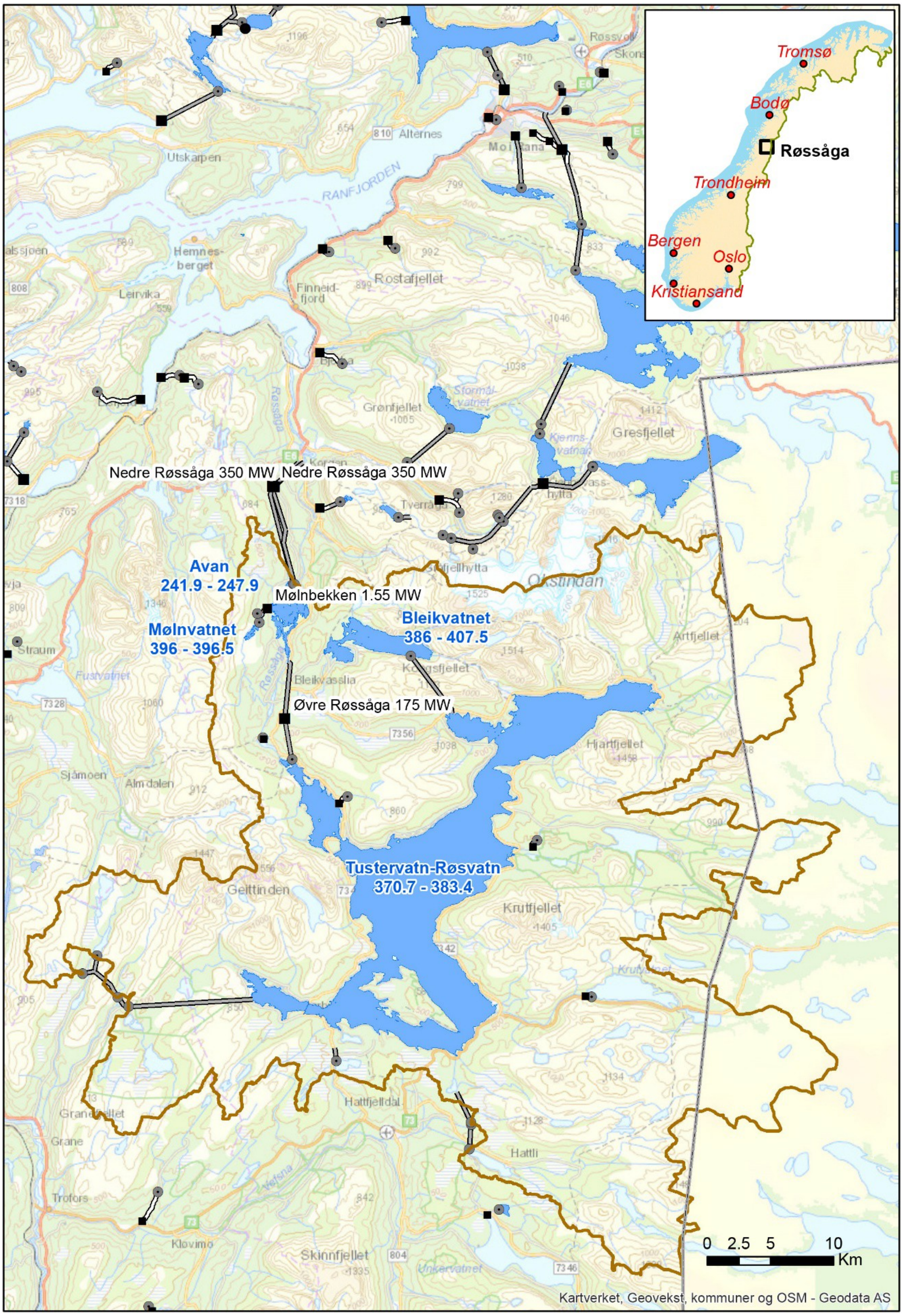
The Røssåga hydropower scheme includes the Nedre (Lower) Røssåga and the Øvre (Upper) Røssåga power plants in the Røssåga River in the Hemnes Municipality, Nordland County. The two power plants were constructed in the 1950s and the early 1960s. The power plants were constructed for power supply to heavy industry in the region, including Norsk Jernverk (smelting of iron ore from local mines and production of steel in a large factory and further processing of the steel) in Mo i Rana and the Mosal aluminium plant in Mosjøen. The hydropower development was carried out by the then NVE-Statskraftverkene (the State Power Utility) on behalf of the State. The first license was granted by the Parliament in a Royal Decree on 8 July 1954. Two licenses for diverting water from nearby rivers were granted in 1960.

The main section of the Røssåga River is around 40 km long from Lake Tustervatnet at around 372 m a.s.l. to Sørfjorden (sea level), an arm of the large fiord Ranfjorden. The catchment area to the river´s outlet in the sea is around 2,100 km^2, with a mean discharge of 115 m^3/s. Lake Tustervatnet was merged with the upstream Lake Røssvatnet into a single reservoir, Røssvatnet.

Røssvatnet is the intake reservoir for the Øvre Røssåga power plant and is regulated between LRWL at 370.7 m a.s.l. and HRWL at 383.2 m a.s.l. and has an area of 218 km^2 at HRWL. Lake Tustervatnet with natural water level 372.1 m a.s.l. was 600 m downstream Lake Røssvatnet with natural water level 373.6 m a.s.l. A dam at Lake Tustervatnet raised the maximum water level and merged the two lakes and gave a total storage capacity of around 2,300 Mm^3.

There is also a reservoir in Lake Bleikvatnet on the tributary Bleikvasselva River to the Røssåga River. The runoff is transferred to the main reservoir through a diversion tunnel and is thus the reservoir for both power plants.

The Nedre Røssåga power plant utilizes the head in the River Røssåga between a small artificial intake pond at Stormyra and the outlet some kilometers upstream of the river mouth in Sørfjorden. The production started with the first three units in 1955. Three additional units were installed by 1958. The power station is located underground.



The Røssåga Hydropower Scheme. (Avan is a local name of the Stormyra pond).
The Mølnbekken power plant with the reservoir Mølnvatnet was constructed in 2015, and is not part of the Røssåga scheme.

The Øvre Røssåga power plant has its intake in the Røssvatnet reservoir and outlet in the Stormyr pond. The two first units were commissioned in 1961 and number three in 1962, also in an underground facility.

Expansion of the Nedre Røssåga plant with a new unit and modernization of the Øvre Røssåga plant with increased efficiency of the existing units were carried out from 2012 to 2020. The present data are shown in the table below. The owner of the power plants is Statkraft Energi AS which is 100 % owned by Statkraft SF. Statkraft SF is 100 % owned by the Norwegian State.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Nedre Røssåga	350	165	135.5	2 001	1955
Øvre Røssåga	175	160	244.4	901	1961
Sum	525			2 902	

Data from NVE's Hydropower Database, December 2020.

The expansion of the Nedre Røssåga power plant started in the spring of 2012 and was finished in 2016. The works included a new headrace tunnel which was partly excavated by a Tunnel Boring Machine (TBM) as the first TBM in hydropower construction in Norway for decades. A new unit with a 200 MW Francis turbine was installed in a new power station. Three units in the old power station were upgraded and three units were taken out of operation. The capacity increased from 260 MW to 350 MW and the increased mean annual generation is around 150 GWh.

An important change was a shorter tailrace tunnel, with outlet longer up in the river than earlier. This gave a positive impact, with better conditions for migrating salmon and sea trout. The river "got back" a natural section which is the basis for around 30 % of the salmon spawning in Røssåga River.

The maximum discharge of the Øvre Røssåga power plant is 160 m^3/s. Before the expansion of the Nedre Røssåga power plant the discharge was lower, around 130 m^3/s. The Nedre Røssåga power plant has only a small intake pond, and the lower maximum discharge hindered an optimal coordination of the operation of the power plants. The maximum discharge is now 165 m^3/s, which has improved the operational conditions.

The units in the Øvre Røssåga power plant were upgraded in 2020. The capacity of each of the three units was increased by 5 MW, mainly by an increase in efficiency. This increased the total capacity from 160 MW to 175 MW and the mean annual generation by around 20 GWh.

A revision of the license provisions and the operating provisions for the two hydropower plants has been in progress for some years and includes three licenses. The revision was claimed by three concerned municipalities in March 2005. In May 2007 NVE adopted revision and requested for a revision document from Statkraft by December 2007. However, Statkraft was by then preparing rehabilitation plans for the Nedre Røssåga power plant. In a meeting with participants from Statkraft, NVE and the three concerned municipalities it was decided to treat the revision in connection with the expansion of the Nedre Røssåga power plant. The time limit for the revision document was postponed pending the application process.

In a letter in December 2011 NVE decided, on the basis of the Water Resources Act (WRA), that the plans for a the new Nedre Røssåga power plant would not infringe public interests to a degree that require a license obligation on the basis of the WRA. Eventual restrictions as to water flows and reservoir water levels would be considered during a total evaluation of the whole system in connection with the revisions of the license provisions. NVE gave permission to start the construction works prior to conclusion of the revision. Then, the construction of the new power plant was only conditional on a construction license for the necessary high voltage was granted on basis of the Energy Act. The conclusion with a license on basis of the Energy Act is only normally discussed in relation to rehabilitation of hydropower plants.

The revision document including the expansion plan was submitted to NVE in November 2013, and the public hearing started. The public hearing was terminated, and NVE submitted their recommendations to the Ministry of Petroleum and Energy in November 2020. Please refer to the Åbjøra hydropower project for a brief introduction to the general background for a revision.

Statkraft SF owns several power plants with high cultural heritage value. Statkraft has in cooperation with the Directorate for Cultural Heritage (Riksantikvaren) (and NVE in the period 2008-2010) prepared a protection plan for its cultural-historical properties in order to take care of these values. The Directorate adopted the conservations of parts of six of Statkraft's power plants. The Nedre Røssåga is one of the six selected power stations. Please refer to the Aura hydropower scheme for more information on conservation.

The construction of the Nedre Røssåga and the Øvre Røssåga hydropower plants in the 1950s and 1960s led to important changes in working conditions. This gives the implementation social and labour historical values. Physically the conservation applies to the portal building (the building in front of the access tunnel) and includes main elements as the general design, the façade composition, use of materials, the wall panels, the doors and the windows. The purpose is to preserve the building with its architectural and sector historical values as an example of a state hydropower development in the early post-war period.

Nedre Røssåga Power Station. The portal building. Photo: Helena Nynäs, NVE.

Project Background

Subsequent to a Parliament decision in 1895 the State bought land properties in the Rana and Korgen districts in Nordland County. The State was then owner of waterfall rights in rivers in the districts, among them most of the rights to Røssåga River. A new Parliament decision in

1900 initiated additional State acquisitions which gave the right to use the entire shoreline of Lake Røssvatnet. During subsequent acquisitions in 1909 and finally in 1948 all fall rights in Røssåga River were owned by the State.

There is a waterfall, Sjøfossen, in the Røssåga River, with its lowest part 30 km downstream of Lake Tustervatnet. There are several falls, but also long sections without falls and rapids. The first investigation for hydropower development was undertaken in 1918. Maps and alternative plans were prepared in the period 1920-1923, but a development was not initiated until the Parliament in 1947 decided on the development of Røssåga River for supply of power to Norsk Jernverk in Mo i Rana, around 40 km north of the nearest of the two power plants. The original plan consisted of two cascade power plants in the Røssåga River and one plant in the tributary Bleikvasselva. The latter plant was never realized, and the runoff is diverted to Røssvatnet for utilization in the two other plants.

Political Aspects

The decision of the development of the Nedre and the Øvre Røssåga power plants are strongly connected with the construction of Norsk Jernverk, which was decided on by the Parliament in July 1946. The justification was to make Norway more self-sufficient in steel and contribute to the economic strengthening of North Norway in general and the Rana region in Nordland County in particular. There were no votes against the establishment of Norsk Jernverk, but the localisation was discussed. After a debate with a duration of 13 hours and 47 speeches, 102 representatives voted for Mo i Rana, 42 voted for Orkdal near Trondheim and 6 representatives abstained.

The construction works went on for nine years and the operation started in April 1955. The access to iron ore was ensured through the purchase of an English iron ore company in Dunderlandsdalen, 30 km north-east of Mo i Rana. In the early 1960s Norsk Koksverk was also commissioned in Mo i Rana, with production of coke and ammonia, based on coal deliveries from Svalbard (Spitzbergen). This strengthened the town's role as an important industrial town. These industrial establishments resulted in increased social and economic impacts. The population in the Rana Municipality increased from around 9,400 in 1946 to around 22,500 by 1964.

However, there were also negative impacts. The industrial production caused pollution. The red smoke is probably most known and was often thick over the town until the 1970s. Serious unintentional omissions caused by leakages have also occurred.

In the 1970s and 1980s Norsk Jernverk was affected by the international steel crisis. The Norwegian steel industry was a national financial and political problem. The Parliament decided in June 1988 to terminate the State ownership of Norsk Jernverk as a part of a comprehensive adjustment of the State-owned industry in Mo i Rana. The production of Norsk Koksverk was also terminated in 1988.

Three licenses were granted for the development of the two power plants.

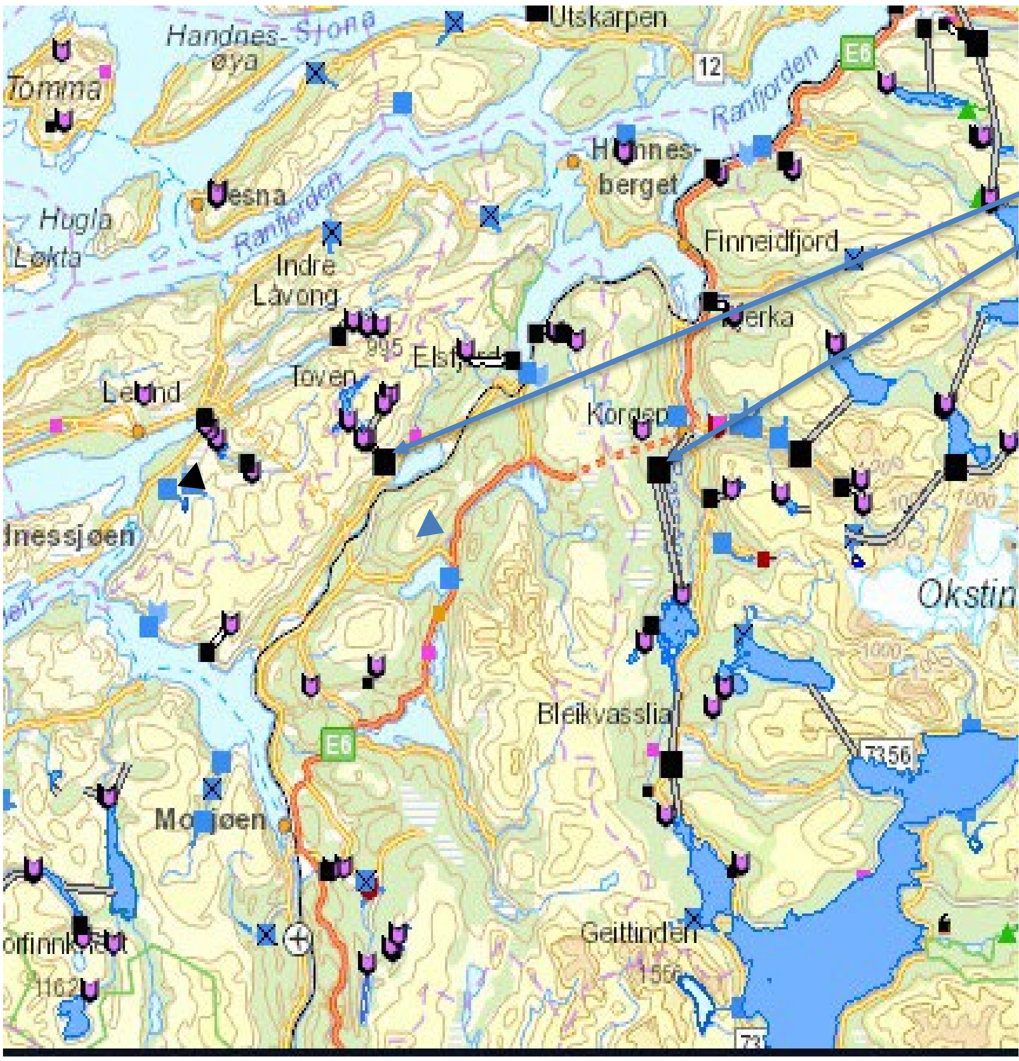
1. The license for regulation of Røssåga was granted by a Royal Decree on 8 July 1954. The license includes the natural catchment area of Røssaga River upstream of the Stormyra pond.
2. The license for regulation of Lake Bleikvatnet and diversion of water to Lake Røssvatnet was granted by a Royal Decree on 13 May 1960.
3. The license for diversion of water from the Vefsna catchment area to Lake Røssvatnet was granted by a Royal Decree on 22 December 1960. The license included originally three local catchment areas south and west of Lake Røssvatnet's natural catchment area.

A revised plan was approved in 1962. The operating provisions were stated on 22 October 1965 and are common for all regulations.

The need for electrification of the country was another task in political priorities together with focus on economic growth and job creation. The Røssåga power scheme had a political value in boosting public electrification in the vicinity combined with other small power plants.

Midt-Helgeland Kraftlag was established in 1951 and took over the existing municipal and private power supply. At that time, a few small hydropower plants, with a total capacity of approximately 5,000 kW, were not enough to meet the power demand. In the supply area there was a population of 50,000 and 50 % still without power supply.

The electrification project was undertaken between 1951 and 1959. The large Røssåga hydropower scheme was part of the solution for capacity needs as well as the Kaldåga scheme with 15 MW/62 GWh hydropower. An associated transmission network and distribution network were also constructed. The rural electrification project was financed with loans (68.7 %), local capital (7.6 %) and government subsidies (23.7 %).



The Kaldåga and the Røssåga hydropower schemes were parts of the electrification program after WW2. For security of local electricity supply several small and medium scale hydropower plants have been developed in the decades after the Kaldåga and Røssåga hydropower plants were constructed.

Project Organisation

The implementation was mainly carried out by the Planning and the Construction departments in the then NVE-Statskraftverkene. During the first years after WW2 the utility had established high qualified staff and skilled workers for this challenging task, and during the implementation the knowledge and experience of hydropower construction were further developed. Both engineers and workers were faced with new challenges. New construction equipment and methods were taken in use, and the works were said to be a new age of hydropower construction in Norway. The utility's leaders highly appreciated the workers for their enthusiasm and learning of effective use of new equipment and construction methods.

Most of the electrical and mechanical equipment were manufactured by Norwegian companies. However, there were also deliveries by foreign companies, for example two turbines delivered by Swiss Escher Wyss and two generators by British Metropolitan Vickers. For several other hydropower projects in Norway during the first decades after WW2 there was a license provision demanding that the licensee should preferably use Norwegian products and services for the construction works and operation (see for example the KØN Hydropower Scheme). A similar provision was not included in the license for the Røssåga hydropower scheme.

Economic and Technical Aspects

The hydropower scheme was commissioned during the period from 1955 to 1962 and included the Øvre Røssaga and the Nedre Røssåga power plants. The flow was well regulated, with reservoirs as shown in the table below.

Reservoir	Natural level (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Capacity (Mm^3)
Røssvatnet	373.6	383.15	372.2	2 309
(Tustervatnet)	372.1	383.15	370.6	
Stormyra	236.0	247.9	241.9	40
Bleikvatnet	400.0	407.5	386.0	250
Sum				2 599

The lakes Tustervatnet and the upstream Røssvatnet were originally two separate lakes at almost the same level, and with 600 m river between them. A dam at the end of Lake Tustervatnet created a merged reservoir, usually called only Lake Røssvatnet. Lake Røssvatnet is the next largest lake in Norway, with an area at HRWL of 218.6 km^2. Only two of Norway's hydropower reservoirs have a larger volume than Røssvatnet.

Stormyra is the intake pond for the Nedre Røssåga power plant and tailwater for the Øvre Røssåga power plant. The intake dam is constructed in the river just downstream of the lower end of Stormyra, which is an approximate level river section at level at around 242-242.5 m a.s.l. Hence the volume of the pond is the Stormyra section of the river. The permitted regulation is seldom utilized, and the variation in the water level is normally a maximum of 0.5 m.

The runoff from Lake Bleikvatnet on the tributary Bleikvasselva River to the Røssåga River is transferred to the Røssvatnet reservoir through a diversion tunnel and is thereby the reservoir for both power plants. The reservoir is regulated between 386.0 and 407.5 m a.s.l. with a capacity of 250 Mm^3. The regulation and the tunnel were operational in 1961/62. A new diversion tunnel from Bleikvatnet to Røssvatnet was constructed in 2008. The gravity concrete dam from the early 1960s was substituted by a rockfill dam with a bitumen core in 1999. The maximum height is 30 m and the length 100 m.

Small pondages are also provided at intakes to tunnels diverting water from the neighbouring Vefsna catchment area south of the Røssvatnet watercourse basin.

The Øvre Røssåga power plant was commissioned with three units in 1961 (2) and 1962 (1). The intake is in the Røssvatnet reservoir (in the Tustervatnet part of the reservoir). From the reservoir there is an open canal of length 550 m to the tunnel intake. The headrace tunnel has a length of 2,715 m and 65 m^2 to the surge chamber. At the surge chamber the tunnel divides into three pressure shafts. The shafts are 180 m long and 3.3 m in diameter and are steel lined. Each shaft supplies one turbine. The turbines are of the Francis type and were manufactured by Kværner (Norwegian). Each turbine had a capacity of around 53 MW by then. The generators were delivered by ASEA.

From the underground power station, a tailrace tunnel was constructed, with a length of 4,600 m and a cross section area of 65 m^2 to the Stormyra pond. The tailwater is usually at 247.9 m a.s.l. but may exceptionally fall lower. With full capacity in the Røssvatnet reservoir the gross head is therefore 135.5 m but may fall to 122.8 m when the reservoir is completely drawn down, which may happen in exceptional circumstances.

The Røssvatn dam was constructed during the period 1955-1957 and raises the level of Tustervatnet Lake so that it merges with Lake Røssvatnet. This is a rockfill dam in two sections with a concrete gravity section in between, which incorporates a spillway and a bottom outlet. The maximum height is 22.5 m, and the length is 300 m (90 m + 120 m + 90 m). The Nedre Røssåga power plant was commissioned with six units during the period 1955-1958. The intake is in the Stormyra pond. The gross head ranged from 246.4 m to 240.4 m to the outlet in the Røssåga river. The intake dam (Dam Fallfors) was constructed just downstream of the end of Stormyra. The dam was constructed in 1957, and is a concrete gravity dam with length of 70 m and maximum height of 20 m.

The headrace tunnel is 7.5 km long with cross section area 65 m^2 from the intake to the surge chamber. Three steel-lined pressure shafts with diameter 3 m and slope 1:1 were constructed from the surge chamber. Each shaft has two branches to feed two turbines, thus the six turbines are supplied from three shafts. The power station is 200 m into rock and is reached by a 1,300 m and 65 m^2 entrance tunnel sloping down at 1:10 to the machine hall. The first four of the vertical Francis turbines were manufactured by Norwegian Kværner, and the two last by Escher Wyss (Swiss). The six turbines were of the same size, around 43 MW. Four of the generators were manufactured by Norwegian NEBB (Norsk Elektrisk & Brown Boveri) and the last two by Metropolitan Vickers (British). From the gate chamber the tailrace tunnel was 2.7 km and 67 m^2 in section area, and from the tunnel portal a 400 m long canal led to the Røssåga River at a normal elevation of 1.5 m a.s.l. around 11 km from the mouth. As described in Project Information the Nedre Røssåga power plant was expanded during the period 2012-2016.

The power from the Røssåga power stations was transmitted by 132 kV lines to factories in the neighbouring towns of Mo i Rana and Mosjøen, and for general supply to the district. A 245 kV line was constructed for power exchange with Sweden and a 300 kV line to Trøndelag in the south was also constructed some years after the commissioning of the Røssåga power plants.

Project Financing

The Røssåga Hydropower Scheme was financed through ordinary State budget allocations, which were approved by the Parliament. In the Parliament debate some representatives put forward a proposal for financing through loans, but the proposal was voted down.

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5 The Nea Hydropower Project (1951-1964)

Highlights

- An example of a foresighted public acquisition of water rights
- A preparation of an overall plan for the Nea-Nidelva watercourse decades before the development took place
- A bilateral cooperation between Norway and Sweden for the establishment of a reservoir in Sweden uppermost in the watercourse
- Swedish financing associated with a power export agreement advanced the implementation of the project
- The power export agreement was of strategic national concern and was managed by NVE and not by the project developer
- The export agreement was flexible as to mitigation of negative aspects of power export in dry years
- The project paved the way for the first large cross-border transmission line and a couple of more hydropower projects partly financed through power export arrangements
- An increased local community electricity tariff improved the self-financing capacity
- The establishment of a large reservoir was important for the watercourse development
- The project made it possible to develop and maintain the critical competency in the power company
- The project was positive for the municipality's economy and the local employment

Project Information

The Nea hydropower plant utilizes runoff from two separate catchment areas in two separate heads. The Nea branch utilizes the head from the reservoir in Lake Vessingsjøen to an outlet in the Nea River. Three units were commissioned in 1960. The Tya branch was completed in 1964 with one unit in the same power station. This branch utilizes the runoff from two tributaries to Nea River. Data for the two branches are shown in table below.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Nea-Nea branch	175	55	375	677	1960
Nea-Tya branch	32	20	200	160	1964
Sum	207			837	

Data from NVE's Hydropower Database, December 2020.

The Nea power plant is in the Nea River in the Tydal Municipality and the present Trøndelag County[1] in mid-Norway, about 100 km east of Trondheim and not far from the Norwegian-Swedish border. The Nea River is the upper section of the Nea-Nidelva watercourse. The power plant was implemented by the 100 % municipality-owned power company, Trondheim Energiverk (Trondheim Electrisitetsverk then)[2].

[1] Trøndelag County is a merging of the earlier Sør-Trøndelag and Nord-Trøndelag counties from 1 January 2018. The Nea hydropower plant was originally in Sør-Trøndelag County.

[2] The company name has been changed during the 20th century. Trondheim Energi or the abbreviation TEV is used here although this was not the name when the Nea power plant was planned and constructed. However, the essential point is that the company was 100 % owned by the Trondheim Municipality from 1901 to 2009, and TEV was a well-known and incorporated term.

The Nea HPP was important for meeting the rapidly increasing electricity demand in Trondheim in particular, but also in small neighbouring municipalities.

Today Trondheim is Norway's third largest town, with approximately 205,000 inhabitants. The population has increased since the 1950s and the 1960s, caused by merging with small nearby municipalities in addition to relocation and the general population growth. In 1960[3] the population was nearly 60,000 and approximately 105,000 when including municipalities which now are incorporated in the Trondheim Municipality. Trondheim Energi was completely incorporated in Statkraft Energi by 1 January 2009. Statkraft Energi is 100 % owned by Statkraft SF.

Project Background

The Nea-Nidelva watercourse originates from the mountainous border area between Norway and Sweden and flows to Trondheim on the Trondheim Fiord. The total length of the main river system from Lake Sylsjøen in Sweden to the sea is approximately 146 km. The river sections are shown below.

Section type	Name	Length (km)	Upper elevation (m a.s.l.)	Lower elevation (m a.s.l.)
River	Nea River	80	830	157
Lake	Lake Selbusjøen	35	157	157
River	Nidelva River	31	157	0

Trondheim Energi had since 1901 planned, constructed, and operated hydropower plants in the Nidelva River south of Trondheim, between Lake Selbusjøen and Trondheim. The exploitation of the resources was essential to meet Trondheim's electricity demand during the first half of the 20th century. Trondheim Energi had developed a relatively large percentage of the hydropower potential in Nidelva River with several run-of-the-river power plants decades before and during the first years after the Second World War (WW2). In the late 1940s the installed capacity was approximately 60 MW, and the mean annual generation was around 450 GWh.

During the first years after WW2, it was obvious that the generation capacity in Trondheim Energi's existing power plants was insufficient to meet the expected future electricity demand. This was clearly pointed out by the power company's director in February 1951. The supply situation was not good neither as regards generation nor transmission capacity. Unintentional power failures and load shedding were not unusual. Additional power plants as well as renewal and upgrading were possible, but the remaining potential capacity was not enough to meet the anticipated demand in the next decades. However, there were other options. Plans for increased electricity generation were in the pipeline, but the time aspect was challenging both to meet the rapidly growing electricity demand and to secure the company's experienced employees for the implementation of new projects.

[3] Statistics Norway: Census in Norway 1960.

Trondheim Energi had for decades been aware of the large power resources in the Nea River upstream of Lake Selbusjøen. The Nea River had a considerable higher potential than the Nidelva River. Comprehensive mapping and evaluation of possibilities had been carried out in the period 1912-1917. A development plan for the entire watercourse was also prepared. The plan was very ambitious and included several reservoirs and power plants and illustrated the optimism at that time. However, the optimistic years just after WW1 were followed by years with poor economy which reduced the financing capacity and brought pessimism, and no development was initiated. The plan was filed, but the potential had been proved.

Trondheim Energi had foresight and had acquired 63 % of the water rights in the Nea-Nidelva watercourse as early as 1914-1917. A private foundation was in possession of the remaining 37 %.

The Nea-Nidelva watercourse from Lake Sylsjøen in Sweden to the sea at Trondheim in northwest, with power plants and reservoirs. Other power plants than those constructed by Trondheim Energi are shown. A more detailed map of the Nea power plant is shown in Economic and Technical Aspects.

The creation of a reservoir in Lake Sylsjøen in Sweden, uppermost in the catchment area, was included in the first plan for regulations in the Nea basin. The Swedish power authorities granted permission for regulation in 1934, with a dam on the Norwegian side of the border. However, the dam construction was not implemented by then. After a granted Norwegian license in 1948 and a Swedish license in 1949, dam construction took place on the Swedish side of the border and was completed in 1952. Lake Sylsjøen is regulated with a volume of 180 Mm^3 between elevation 851 m and 831 m a.s.l. The reservoir was established to supply sufficient water to the power plants in Nidelva River during wintertime.

The reservoir is useful for regulation of the local inflow and is now one of the three main reservoirs in the Nea basin.

Due to the rapidly increasing demand after WW2, the plan to develop projects in the Nea watercourse became highly relevant again. So far there were no power plants of notable size in Nea River. The Nea power plant was a future-oriented project that would meet Trondheim's power demand for several years. Alternative solutions were discussed, both for the Nea power plant and for the entire watercourse. The Nea power plant was finally designed with three units with a total capacity of 175 MW and a mean annual generation on the scale of 600 GWh. Additional plants were of interest later, in line with the anticipated increasing demand and financial ability.

However, it was far beyond the financial capacity of the Trondheim Municipality to develop the project by its own means. In addition, the production would be much larger than the anticipated electricity demand for Trondheim for many years to come. At this time, the central Norwegian energy authorities did not prioritize the project in terms of provision of loans. Trondheim Municipality had therefore negotiated with power authorities in Stockholm (Sweden's capital) in the late summer of 1951. The negotiations resulted in a bilateral understanding of agreement for the construction of the Nea power plant with Swedish capital and repayment through electricity supply to Stockholm. However, the plan was met with restraint, criticism, and also absolute opposition in several interest groups in Norway, both on a county and a national level, as well as in the Parliament. Export of electricity to another country was a principal question which entailed objections. It was also necessary to clarify other conditions until the plan could be general accepted and finally be granted the necessary licenses by the Norwegian energy authorities.

Political Aspects

The Nea project site was planned to be located around 100 km from the Swedish transmission system. Around 1950 Trondheim Energi started discussions regarding power export to Stockholm. It was assumed that an export agreement could be associated with a Swedish loan for financing the Nea power plant.

The Nea power plant and the transmission of electricity to Stockholm were approved by the city councils in Trondheim and Stockholm in 1952. However, it was also mandatory to treat the agreement on a national level in both countries. In Norway, the essential requirements were a hydropower license and an export license. Prior to this it was necessary to discuss, negotiate and clarify different matters at municipal and county levels. One objection among others was that a large Nea project could create a local power surplus and thus compete with NVE's large Aura hydropower project in Møre og Romsdal County south-west of Trondheim. Alternative solutions and changes were even promoted in the process. The licenses by and large were pursuant with the initial plan and target as to project size, location, project developer, available power market, power export, Swedish loan and repayment.

The private foundation still had 37 % share of the water rights. Access to these rights in some wayor another was necessary. An expropriation process was considered, but could be controversial, conflict-creating and time consuming. In order to avoid this and to be able to start the construction works as soon as possible, the counterparts entered into an agreement on an annual fee.

A Royal Decree granted the hydropower license in June 1954. A power export agreement was also necessary and was subject to an approval by the Norwegian Parliament. However, there was a power shortage in Norway after WW2, and a long-term export agreement was therefore controversial. Many stakeholders, including industrials, were worried that the power export would come at the expense of domestic needs. Consequently, the export agreement was subject to internal Norwegian discussions and later new negotiations between the Norwegian and the Swedish counterparts. Among others, the duration of the export agreement was shortened from thirty to fifteen years and focus was on seasonal power and not firm power. In Norway, NVE was involved in the negotiations. Finally, in December 1955 the Parliament approved the export-financing modality (81 votes for, 63 votes against). As a part of the portfolio, the Government had prepared a White Paper on Power Export. The Parliament's decision was based on the understanding that no other realistic financing options were available.

A new 220 kV cross-border transmission line between Norway and Sweden was constructed at the same time as the construction of the hydropower plant took place. On the Norwegian side of the border, the transmission line was constructed and owned by NVE. This was the first major transmission line between Norway and a neighbour country. When the power plant and the transmission line were operational in 1960, this coincided with a power shortage in Norway. In the first year of operation, the cross-border line enabled power imports rather than exports.

The Nea hydropower plant was solemnly commissioned in September 1960, with the Prime Ministers Einar Gerhardsen from Norway and Tage Erlander from Sweden present. The power from the Nea power plant was connected to the Swedish grid system, and the first transmission line between Norway and Sweden was a reality.

The agreement on power export paved the way for a couple of similar agreements within a few years. This included the Hegsetfoss power plant located downstream the Nea power plant and the Linvasselv and Tunnsjødal power plants in then Nord-Trøndelag County. The power export to Sweden occurred mainly in years with higher production than necessary for the Norwegian demand. The debate on power export ceased equally abruptly as it arose.

The settlement of the power trade was done both in the Norwegian and the Swedish currencies. In average, the mean annual export was decided to be 330 GWh, allowing for annual variations due to hydrological variation. Trondheim Energi entered into a power exchange agreement with NVE, which again signed an agreement with its Swedish counterpart. It was important for the Norwegian Government that the Norwegian State was in charge of power export and import.

The Stockholm Contract was terminated in 1975. The Nea power plant had then been repaid through export of approximately 50 % of its generation from 1960 to 1975.
In 1968 Trondheim Energi was given the permission to establish a large reservoir in Nea River upstream Lake Vessingsjøen. The riverbed was submerged and formed a contiguous reservoir together with Lake Essandsjøen. The reservoir is regulated between 729 m a.s.l. and 706 m a.s.l. Lake Essandsjøen's natural water level was 723 m a.s.l. Until the license was granted in 1968 the submersion of the Nedal bogs was a controversial issue for several years. After heated debates in the Parliament a majority voted for the establishment of the Nesjøen reservoir. The reservoir was operational in 1970 and is essential for the hydropower system in the Nea-Nidelva watercourse. See also Economic and Technical Aspects.

The Nea HPP was controversial and hence disputed in the 1950s and the 1960s. The financial solution was undoubtedly unconventional. However, the development was advanced with many years, which in turn opened for an earlier realisation of subsequent power projects. Hence, the development of the Nea hydropower plant and the large Nesjøen reservoir was important for economic growth in Trondheim and the nearby districts.

Project Organization

The power plant was planned, designed, and organized by Trondheim Energi's experienced engineering staff. Similar to many other large power companies at that time, Trondheim Energi had its own construction department. However, the department had insufficient workforce to carry out all construction tasks. The solution was a mix of the in-house workforce and private contractors.

The hydropower license was granted in a Royal Decree in June 1954. A parliamentary approval of export to Sweden was also a premise for project financing. This was granted in December 1955. Then there was no time to waste. TEV had by then already received tenders after prior quotation requests. The requests comprised civil works as well as electrical and mechanical deliveries. Three Norwegian contractors were awarded contracts on dam construction, tunnels and the power station. Trondheim Energi's department for hydropower constructions took care of some small tasks, such as roads, bridges, housing, and water supply facilities. Other in-house undertakings were the construction of a provisional power plant (1.7 MW) for power supply in the construction period, as well as some tunnel excavation.

The deliveries and erection of electrical and mechanical equipment were contracted to Norwegian suppliers. The first three units (the Nea branch) were installed and formally commissioned in September 1960. This stage was completed on schedule and with a minor budget exceedance (7 %). But it should also be mentioned that the power station had been better equipped than originally planned.

Economic and Technical Aspects

The Nea power station consists of two branches, with different heads. The Nea branch has three units of same size, all with vertical Francis turbines. This branch exploits the head from the intake reservoir in Lake Vessingsjøen to an outlet in Nea River. Lake Vessingsjøen is regulated between elevation 674 and 659 m a.s.l., with a volume of 38 Mm^3. The dam from 1960 is constructed as a concrete slab dam, with a length of 380 m, a maximum height of 30 m and a spillway along its entire length. The headrace tunnel was excavated with a length of 2,900 m and a cross section of 26 m^2. A surge chamber was excavated in connection with the tunnel. The pressure shaft with steel lining and declining 33 degrees leads the water to the turbines in the underground power station.

The Tya branch has one unit, which utilizes the runoff from the tributary rivers Tya from south and Lødølja from north with a common intake pond in Lake Sellisjøen. By regulation between 500 m a.s.l. and 493 m a.s.l. the pond provides a storage of 1.0 Mm^3 for daily regulation. A short steel lined pressure shaft leads water from the intake pond down to the Tya unit, also with a Francis turbine. A common tailrace tunnel with a length of 5,900 m leads the water from all four turbines to an outlet in Nea River. A tunnel with a length of 1,100 m provides the access to the power station.

The large Nesjøen reservoir is the intake reservoir for the Vessingfoss power plant (40 MW), which was commissioned in 1971. However, the reservoir has a high importance beyond this. Nesjøen including Lake Essandsjøen is the largest reservoir in the Nea hydropower scheme and is regulated between 729 and 706 m a.s.l., with a volume of 625 Mm^3 and a mean annual runoff of 724 Mm^3. The reservoir covers an area of approximately 66 km^2 and was operational in 1970. The Nesjøen dam is a rockfill dam with a moraine core and a length of 1,000 m. The maximum height is 45 m, and the dam volume is 1.3 Mm^3. The Nesjøen dam is in an open mountain landscape and is an attractive structure, and the dam is a popular destination for many tourists in the summertime.

The Nea hydropower plant with the two branches Nea (from east) and Tya (from north and south) and the common tailrace tunnel.

The Sylsjøen dam is of the concrete slab type and is located in Sweden, 1.5 km from the Norwegian border. The dam length is 330 m, and the maximum height is 26 m. The dam was completed in 1952 and the reservoir is regulated between 851 m and 831 m a.s.l., with a volume of 180 Mm^3.

There was an intensive hydropower development in Norway through the first decades after WW2. The Nea HHP is one of many power plants from these years and is performed with the technology and the planning philosophy from the 1950s and the 1960s. Other power plants from the same time and later are larger and in some cases also more remarkable from a technical point of view. However, the Nea HPP with discussions on power export is a fascinating narrative. The same are the stories about the construction works and the workers. Trondheim Energi, the contractor, and supplier of electro - mechanical equipment, developed an experienced workforce which later followed the implementation of power plants in the watercourse. This was typical, lasted for decades and resulted in state-of-the-art construction methodologies and well operating power plants in a gradually more comprehensive and effective hydropower system.

Except for some micro power plants, the Nea power plant was the first hydropower plant in the Nea catchment area and is also the largest. Five other plants were commissioned in the period from 1966 to 1989. Total installed capacity was then approximately 400 MW, with a mean annual production of 1,550 GWh. The total reservoir capacity of the three essential upstream reservoirs in the main river course is 840 Mm^3 which is of the same size as the mean annual inflow. This enables stable production of firm power during winter.

The power development in the Nidelva section also continued after the early 1950s. This river section has less potential than Nea River, but there was still beneficial to carry out renewal and upgrading as well as constructing new power plants. The present seven power plants are both serial and in parallel. The largest of them (Bratsberg power plant) was commissioned in 1977 and utilizes a head of 145 meters from Lake Selbusjøen to an outlet in Nidelva downstream the other power plants in the river. Bratsberg HPP contributes with approximately 60 % of the mean annual production of the power plants in Niedelva River. Lake Selbusjøen is regulated between 161.3 m and 155.0 m a.s.l., with a reservoir volume of 348 Mm^3. Lake Selbusjøen and the reservoirs in the Nea basin provide together a good regulation of the flow.

An approximate increase of the total capacity and the mean annual generation in the Nea-Nidelva watercourse from the early 1950s to 2020 are shown in the table below, with data from NVE's Database per December 2020.

Section	Early 1950s		2020	
	Capacity, MW	Generation, GWh	Capacity, MW	Generation, GWh
Nidelva	60	440	230	990
Nea	0	0	400	1 550
Sum	60	440	630	2 540

The power generation in the Nea-Nidelva watercourse has increased by 480 % from the early 1950s to 2020. However, almost 100 % of the power plants in Nea River were commissioned before 1990. A large share of the increase in Nidelva River took also place before 1990. In addition, an upgrading of old power plants in Nidelva River has been implemented during the last three decades and allows for more efficient and environmentally friendly operations in this river section.

Even though the presented data are not completely comparable, the importance of the Nea HPP in a greater context is documented. The development was also essential for the further downstream development in the Nea River, and hence for the electricity support to Trondheim and the nearby municipalities. The percentage increase of generation is in line with the consumption increase and many times the percentage population growth.

The power development was also economically beneficial for the Tydal Municipality, where the power plants in the Nea River are located. The increased employment during the construction period was an advantage for a rural municipality with a limited job market other than farming and forestry. The construction period led to improved economy for many individuals and increased income to the municipality. The municipal profits in the operation period have been taxes from the power company and license power.[4]

On the other side, there were also negative impacts. Tydal was sparsely populated, with approximately 1,000 inhabitants and an area of some 1,200 km^2. For better or worse, the intensive construction period over 30 years influenced individuals, society and the environment. The population has decreased since the 1960s. This is not restricted to the Tydal Municipality. Some other nearby rural municipalities have a percentage population decrease of roughly the same size, while the population has increased in Trondheim and other urban municipalities.

[4] An owner of a hydropower plant larger than a given size is obliged to deliver a given share of the produced power to the host municipality. The license power shall be delivered to a price which is decided by the Ministry or negotiated by the parties.

The increasing power exchange with Sweden created a need to increase the transmission capacity. The 220 kV line was upgraded to 300 kV in 1976. Due to a robust design, it was not necessary to reinforce pylons and insulators. However, the need for a cross-border exchange capacity continued to grow. On the one hand, this catchment area was vulnerable to dry years. On the other hand, there was an increasing need for Norwegian hydropower for peaking and balancing purposes in neighbouring countries. Thus, a new 400 kV line was constructed in parallel with the old line and was operational in 2010. At the same time, the old transmission line was dismantled.

As mentioned, the Nea hydropower plant were coupled with developments in the Nea-Nidelva watercourse. However, there was a need for more power generation. In the 1970s and 1980s TEV was one of three parties in a Joint Venture which constructed five power plants in the Orkla watercourse south of Trondheim. See the chapter on the Orkla watercourse.

Closer to the present hydropower situation, the introduction of a new electricity market applied by the Energy Act from 1991 initiated a new energy regime with changed legal provisions for power generation, sale and distribution.

Project Financing

All power company assets were mortgaged in order to provide security for the loans. The financing of the Nea power plant included three main sources:

Financial source	Approximate share
Loan in Sweden	71 %
Norwegian capital market	12 %
Equity	17 %

The Trondheim Municipality (and not the power company) took up loans in a Swedish bank, which again issued bonds in the Swedish capital market. The loan had an amortization period of fifteen years at a 5 % interest rate. The Swedish loan was repaid through power export to the electricity company in Stockholm at a negotiated price. The annual export should in average be 330 GWh, allowing for seasonal variations due to hydrological conditions. The main volume of electricity export was in the high flow season. The debt was repaid in 1975.

Trondheim Energi entered into a power exchange agreement with NVE, which again signed an agreement with its Swedish counterpart. The power was traded in accordance with the contractual prices. The prices were partly in Norwegian currency and partly in Swedish currency.

NVE's profit from the cross-border trade, which originated from differences in the power prices in Norway and Sweden, was transferred to a fund, which, among others, was used to finance rural electrification, including district transmission (sub-transmission) lines. In a formal Recommendation to the Parliament in 1955 it was indicated that the State authorities would assist in obtaining a loan in a Norwegian bank. The loan was suggested with an amortization period of 25 years and with an initial non-interest period of five years.

Finally, 17 % of the required capital was raised through Trondheim Energi's operating surplus. In 1954, one year before the project was approved, the Trondheim Municipality's Council decided to increase the electricity tariff with 20 %. The transmission line from the Nea power plant to the Norwegian-Swedish border also entailed a Norwegian investment. This investment was financed through allocations by NVE over the State budget.

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6 The Røldal-Suldal Hydropower Scheme (1952-1967)

Highlights

- A Public-Private Partnership
- Fifteen years lead time for the implementation of the first five large hydropower plants with two thirds of the time for the planning and license procedure
- The scheme facilitated industrialization and was mainly developed for supplying industry
- The power plants were designed for supply to energy intensive industry with focus on firm power production
- Most likely the power plants would be designed with considerably higher capacities for flexibility if implemented today
- The project had strong local backing as a means to secure regional employment
- The project was granted a time-limited licence owing to a private company as developer, but this was solved in 2020
- Significant foreign financing
- Challenging weather and transport conditions during construction
- A highly disputed reservoir and dam complex

Project Information

The Røldal- Suldal Hydropower Scheme is in the Ullensvang Municipality [1] and the present Vestland County[2] and the Suldal Municipality in Rogaland County in Southwestern Norway. The scheme consists today of 9 hydropower plants and 17 reservoirs. The driving force for development was the supply to planned high energy intensive industry. The power plants are connected to the 300 kV grid.

The Røldal-Suldal watercourse has its upper sources in Langfjella Mountains on the west side of the large mountain plateau Hardangervidda. There are two river courses, each of them with outlet into Lake Suldalsvatnet. The courses are called the western and eastern course or the Røldal and Suldal rivers, respectively. There are many tributaries with small lakes and tarns to each main river.

The scheme exploits hydropower resources in each of the two watercourses in cascade power plants. The two series meet in a common power station and tailwater in Lake Suldalsvatnet. In the tables below the plants in each cascade are listed from the upper one to lowest. All data are from NVE's Hydropower Database in December 2020.

The main parts of the power plants were constructed in the intensive period, 1965-1967. Two power plants in the original plan were commissioned in 1977 and 1981. The Vasstøl power plant from 2012 and the Midtlæger power plant from 2016 exploit the head between reservoirs that were established in the 1960s.

[1] The Ullensvang Municipality is a merging of the earlier municipalities Ullensvang, Odda and Jondal from 1 January 2020.

[2] Vestland County is a merging of the earlier counties Hordaland and Sogn og (i.e.and) Fjordane from 1 January 2020. Some of RSK planned power plants were in the then Røldal Municipality in Hordaland during the licensing process.The Røldal Municipality was incorporated into the Odda Municipality in 1964.

The Røldal cascade:

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Middyr	1.3	2.4	66	5.3	1981
Svandalsflona	20	11	200	42	1977
Midtlæger	3.5	2.6	154	14	2016
Novle	40	16	275	240	1967
Vasstøl	4.9	4	149	24	2012
Røldal	166	56	365	904	1966
Suldal I	180	70	306	1 105	1965
Sum	416			2 334	

The Suldal cascade:

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Kvanndal	40	15	314	187	1967
Suldal II	150	31.5	559	772	1967
Sum	190			959	

Total Sum	606			3 293	

Suldal I and Suldal II have a common power station.

There are many reservoirs, the total capacity is plentiful, and there is a satisfactory interaction between reservoirs and power plants.

Until October 2020 the power plants were owned by Røldal-Suldal Kraft (RSK), which had been especially established for the implementation and operation of the power scheme. RSK was organized as a private limited shareholding company. RSK was again owned by Norsk Hydro (91.3 %) and Statkraft (8.7 %). Norsk Hydro is a private limited company 41.4 % controlled by the Norwegian State[3]. Statkraft is 100 % State owned. As seen, this was a mix of owners, but most of the ownership was in private hands.

One characteristic of the Norwegian hydropower sector has been the right of reversion to the State for power plants with licenses granted to private developers after 1917. The right of reversion means that the State assumes ownership of waterfalls and any hydropower installations free of charge when a license expires. As the date of reversion stated in the license approaches, private power plants will either be sold to public companies or ownership will revert to the State on the specified date. This provision has been a legal obligation for more than a hundred years. The purpose was to ensure public control over large-scale renewable and everlasting hydropower resources.

[3] By the end of 2019, the largest investor was the Norwegian Government represented by the Ministry of Trade, Industry and Fisheries. Norsk Hydro has also foreign shareholders.

Røldal-Suldal Kraft was granted license for the development in December 1962. Since the majority of the ownership was private and the license was time-limited to 60 years, the stated reversion of the power plants should take place in 2022 if the ownership had not been changed before.

A new ownership constellation was created in the late autumn of 2020. Norsk Hydro and the public owned concern Lyse AS (Ltd.) founded an ownership company with Lyse as main owner and Hydro as minority owner. The shares are 74.4 % and 25.6 % for Lyse AS (Ltd) and Røldal-Suldal Kraft, respectively. Other hydropower plants fully owned by Lyse AS were also included in the constellation. This meets the rule that large hydropower plants shall at least be two thirds publicly owned, and then there will be no reversion. Norsk Hydro will still be allowed to use certain quanta of the power for industrial purposes.

The Lyse concern has their main office in the Stavanger Municipality and Rogaland County, not far from the power plants in Røldal-Suldal. The name of the new company is Lyse Kraft DA. Lyse has developed hydropower plants in Rogaland since 1947.

Norsk Hydro (in everyday speech often known as Hydro) was founded in December 1905. The company has established and operated large factories for power-intensive industry in Norway and abroad since then. Important products have been fertilizers, aluminium and aluminium products. The factories need large amounts of electricity and Hydro has therefore constructed large hydropower plants in Norway to be self-sufficient. Hydro is therefore a power producer, a power user as well as a notable industrial actor.

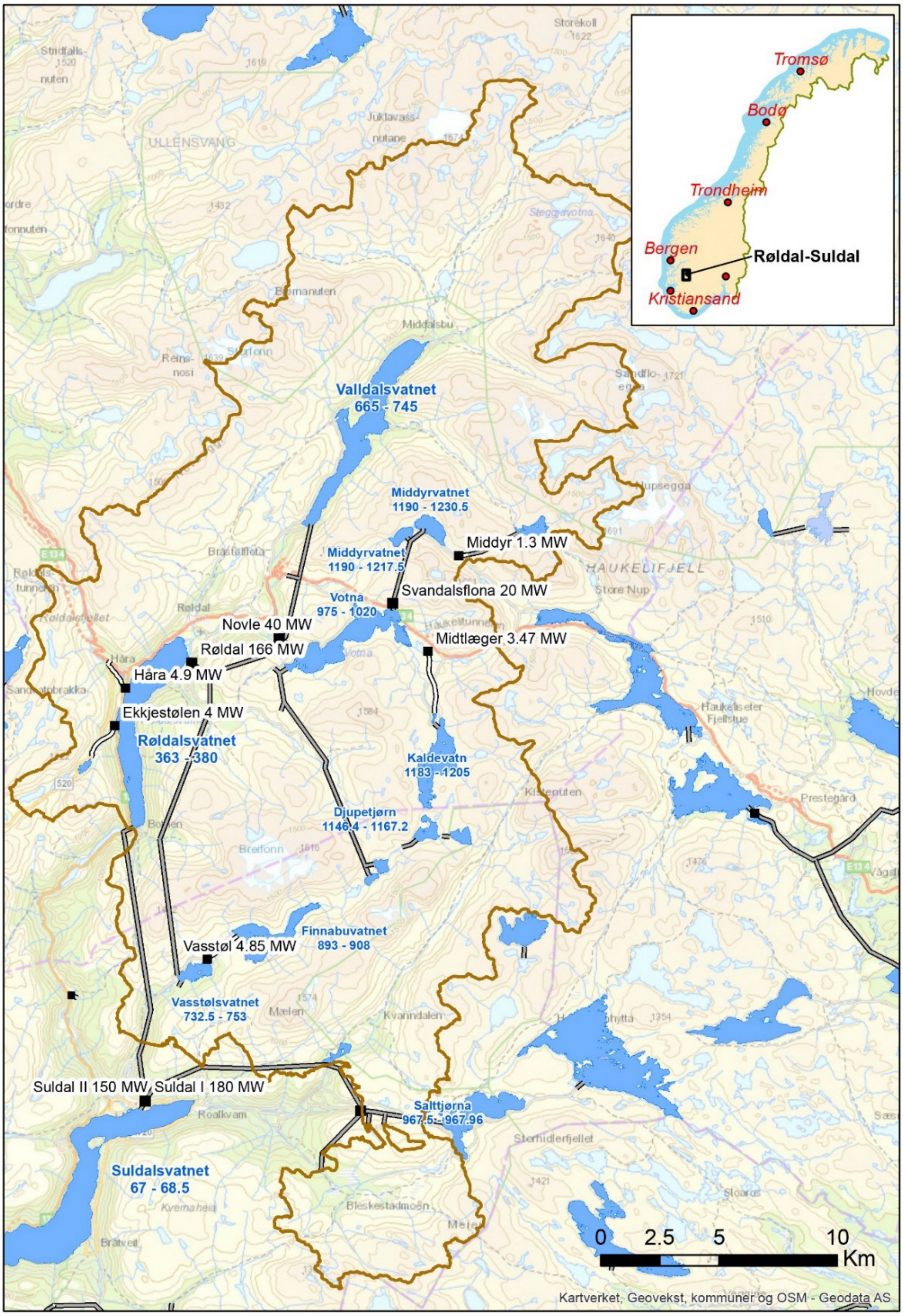
Project Background

The scheme was developed by the large industrial company Norsk Hydro (Hydro), which planned to expand their business to aluminium production. NVE came in as a shareholder, particularly because of obligations for power supply to a new aluminium smelter at Husnes in the Kvinnherad Municipality and Hordaland County. The location is in a coastal area west of Røldal and Suldal.

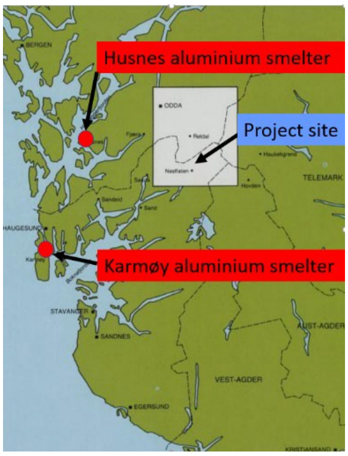
The smelter was owned by Sør-Norge Aluminium, SØRAL (South Norway Aluminium). The company was founded in June 1962 and the investment decision was made late in 1962. Shortly after the government issued the license for the Røldal-Suldal hydropower project. Husnes aluminium smelter was commissioned in November 1965. The aluminium company later became a part of Hydro Aluminium. Norsk Hydro also made an investment decision to construct an aluminium smelter at Karmøy south of Husnes, which was commissioned in 1967.

The background for the establishment at Husnes was economic challenging times for the regional business life at the end of the 1950s. The herring fisheries failed, and fishermen, the canned food industry and the ship building industry were hit. This situation was difficult, and local authorities and other enterprising people wanted to invest in industrial development. Hydropower in large amounts was available and there were appropriate sites for the factories and work forces. The first Secretary-General (1945-1953) of the United Nations, Mr. Trygve Lie was engaged in providing international capital for industrial establishments in Norway. He succeeded in early 1962. Plans were carried out and a license was granted in December 1962. The license opened up for an annual power supply of 950 GWh. The power was delivered from the Røldal-Suldal hydropower plants and the Tokke power plant further east. Mr. Lie was also Industry Minister for a few months from August 1963.

Through their subsidiary company A/S Rjukanfoss Norsk Hydro acquired the main part of the waterfall rights in the Røldal-Suldal watercourses in 1954. However, the planning of the development in Røldal and Suldal started before the acquisition in 1954. Norsk Hydro considered the possibilities after a technical inspection in 1952.



The Røldal-Suldal Hydropower Scheme.



The lead period for the first five hydropower plants was approximately 15 years. The first ten years was a planning and licensing period. In the same period the industry company Norsk Hydro developed large aluminium smelters in theregion. This is a very impressive example of industrial and power plant coordination.

Political aspects

The Røldal-Suldal hydropower scheme was on the one hand championed by the region and local municipalities in need of employment opportunities and on the other hand by the industry company Norsk Hydro in need of more power for industrial supply. Hydro started to acquire water rights in the early 1950s. A license application was submitted in early 1961.

The proposal was to exploit the western and the eastern watercourses separately. The license was granted in a meeting in the Parliament in December 1962. During the winter of 1963, the State represented by NVE, and Norsk Hydro represented by Rjukanfoss A/S (Ltd.) founded the company Røldal-Suldal A/S to carry out the acquisition and development of the Røldal and Suldal watercourses. The field works started at once, and five power stations were commissioned in the period 1965-1967. The power was delivered to the 300 kV-interconnected system of West and East Norway.

In the meeting in December 1962, the Parliament discussed and approved three recommendations concerning the Røldal-Suldal hydropower development and the aluminium factory at Husnes:

- Permission for a joint stock company with A/S Rjukanfoss and the State as participants for acquisition and regulation of the Røldal-Suldal watercourse
- A contract on power supply to Sør-Norge Aluminium
- Cooperation between the State and Norsk Hydro for the development of the Røldal-Suldal power scheme

The Røldal-Suldal hydropower development was approved in the Parliament. However, some representatives expressed concern for the environmental impacts. This focused on the large reservoir in the valley Valldalen. The spokesperson for the recommendation stated that the reservoir with a regulation amplitude of 80 m would create a 10 km long lake in the valley.

Alternative solutions to avoid the impoundment of the valley had been evaluated but had not shown to be economically viable. A construction of the Røldal power plant would hardly be feasible without the Valldalen reservoir. After all, the regulations were comprehensive and would lead to large changes and challenges for many inhabitants in the influenced municipalities. However, district authorities, among them the municipalities of Røldal and Suldal, had given their consent to the plans. The advantages were expected to be significantly larger than the anticipated damages and inconveniences. The development provided both municipal income and employment. Røldal and Suldal were small societies reckoned in population, with approximately 600 and 1,200 inhabitants, respectively.

In the autumn of 1969, RSK applied for some additional regulations. The background was the will to utilise the remaining potential within the catchment area and included several reservoirs and transfer tunnels with river and creek intakes. The license was given in July 1972. The consequences of the additional regulations were an increased reservoir capacity that secured winter generation and reduced loss of water in flood periods, resulting in higher energy production.

Like many other licenses in Norway at that time there was a clause demanding that the licensee preferably should use Norwegian products and services for construction works and operation. A precondition was that the Norwegian deliveries should be with of quality as good as foreign deliveries, in due time, and with prices which did not exceed foreign prices by more than 10 %. A premise was also that no conflicting interests were present. This clause was a national policy to raise Norwegian competence and was also a support to the supplier industry. Many large projects were in the pipeline, and hence there was a promising market for suppliers. Norwegian suppliers were competitive in the Norwegian market and were gradually awarded a considerable share of the orders. When the intensive development period decreased in the 1980s some suppliers tested the international market, and in particular the turbine manufacturer Kværner was awarded challenging delivery contracts.

Project Organisation

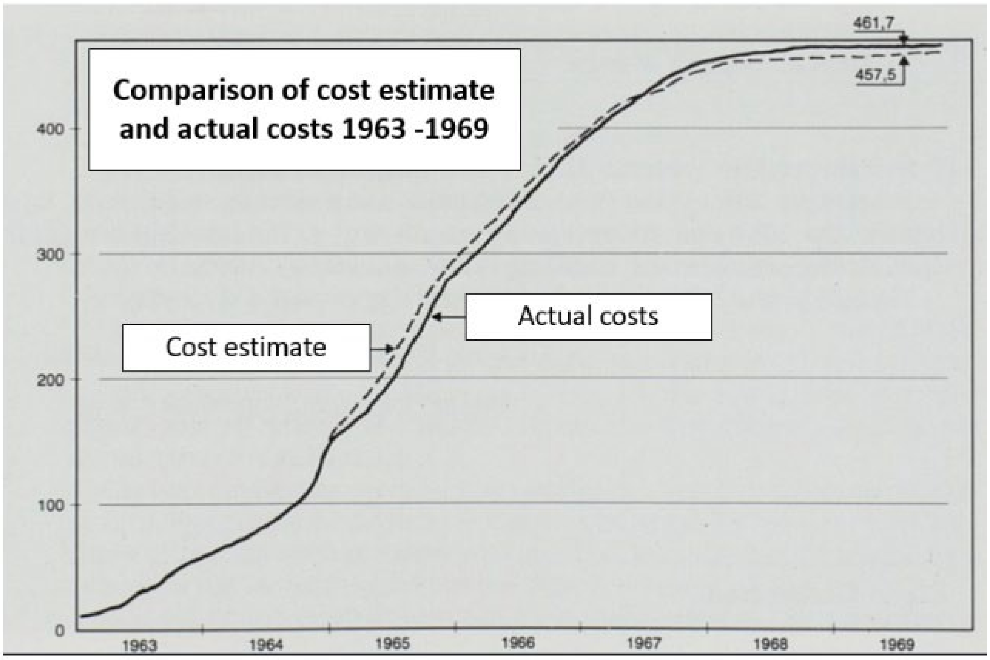
The Røldal- Suldal Hydropower Scheme is one of few examples of hydropower development in Norway which was implemented by a Public Private Partnership (PPP). Norsk Hydro, one of the world's major producers of aluminium, was the major shareholder while the Norwegian State represented by NVE was a minority shareholder.

Norsk Hydro was responsible for the implementation. The engineering tasks were mainly carried out by Hydro's department for power plant construction. This department had since 1946 almost continuously been employed in design and management of hydropower related tasks. The staff was rather small, but with high competency and experience. Most of the construction works were carried out by five large contractors that had together 1,000 workers in action, in addition to RSK's own staff.

The construction works were technically challenging and a fight against nature forces. Wintertime was often extremely snowy with metres of snow. Mild weather and rain could give rapidly melting and floods in the narrow valleys. Then the snow also became heavy with the risk of avalanches on the steep mountainsides and thus blocking rivers and roads. The steep and narrow valleys also made road construction works and transport difficult. Transport is a crucial part of any power plant construction, and not only within a limited work site but also when driving between the sites. In addition, the most challenging, the transport of large and heavy equipment to the power plants. The route was far from simple, with narrow, steep and winding roads and included boat transport over Lake Suldalsvatnet in some cases. The roads that were constructed for access to the construction sites had similar challenges. It was, therefore, difficult, and expensive to construct roads in this terrain.

According to the license conditions the mechanical and electrical equipment were manufactured and installed by Norwegian producers. The eight Francis turbines were delivered by Kværner while the contracts for electrical equipment were awarded several suppliers, but a majority, the generators, went to NEBB.

The power plants, which were clarified for operation in stage 1, were Novle, Røldal, Suldal I, Kvanndal and Suldal II. The five power plants with a total generation capacity of some 2,200 GWh were commissioned in the period 1965-1967, one year earlier than planned. The essential construction works – power stations, waterways and reservoirs were then nearly 100 % operative. One unit in Suldal II was erected later in the late 1960s and the finalisation of the essential reservoirs was carried out by then. The five power plants in stage 1 followed the budgets for 1961-1969. See figure below. Later, several mainly small reservoirs and transfer tunnels were established in the upper parts of the catchment area during the years after1972. The present capacity and mean annual generation for the power plants in stage 1 are 576 MW and 3,208 GWh which are 96 % and 98 % of figures for the power plants today.



Economic and Technical Aspects

The final implementation was based on an overall common development plan for the two watercourses (Watercourse Master Plan). The Suldal hydropower station has generation capacity from two different watercourses, which is illustrated in the names Suldal I and Suldal II. The hydropower project also paved the way for rural electrification and road building.

The hydropower stations and the reservoirs allowed for flexible and secured energy generation capacity. The scheme should deliver energy for large-scale industry throughout the 8,760 hours in a year. If the project had been designed and developed as a green-field project today, it is reasonable to assume that more focus would have been given to peaking and flexible power operation (re. integration of Variable Renewable Energy technologies), resulting in a higher installed capacity.

The construction of large dams for reservoirs and transfer of water from neighbouring valleys by long diversion tunnels called for the use of state-of-the art construction equipment. In this period, each of the large schemes in Norway also included research and development to improve equipment and tools. In the same period, several large hydropower developments were going on and the information from one construction site were distributed to other developers. In total these schemes allowed for building of expertise, training, and education. This know-how capital is a spinoff that is as valuable as the sustainable kWh production.

There are many reservoirs, with a total capacity of more than 800 Mm^3. The table below shows data for the reservoirs which are directly linked to a power station from the period 1965-1967.

Reservoir	Natural level (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Capacity (Mm^3)
Valldalen	665	745	665	290
Votna	975	1 020	975	119
Røldalsvatnet	380	380	363	115
Sandvatnet	929	950	924	46
Sum				570

The power plants have mainly traditional Norwegian design, with reservoir, headrace tunnel, pressure shaft, underground power station and a tailrace tunnel. All power stations are equipped with vertical Francis turbines.

Some power plant data by then illustrate the intensive period 1965-1967:

Plant	Tunnel (km)	Tunnel (m^2)	Gross head (m)	Capacity (MW)	No. of units	Headwater	Tailwater
Røldal	8.7	20-30	365	160	2	Valldalen	Røldalsvatnet
Novle	0.5	15	275	40	1	Votna	Røldalsvatnet
Suldal I	11.0	40	306	160	2	Røldalsvatnet	Suldalsvatnet
Kvanndal	6.5	12	314	40	1	Sandvatnet	Kvanndal R.
Suldal II	7.8	22	559	70	1	Kvanndal R.	Suldalsvatnet
Sum	34.5			470	7		

Space was reserved for a second unit in Suldal II and this was installed later.

An unusual solution is the relationship between the Røldal and the Novle power plants. The Novle power station discharges to the supply tunnel from the Valldalen reservoir to the Røldal power station. Hence, the tailrace water level is determined by the water level in Valldalen.

Suldal II exploits the head from a small intake pond (1 Mm^3) just downstream of the outlet from the Kvanndal power station down to the same power station as for the Suldal I power station. The Suldal I and the Suldal II power stations have a common tailrace tunnel to Lake Suldalsvatnet. This lake is regulated between 68.5 m a.s.l. and 67.0 m a.s.l.

In addition to the natural inflow to the reservoirs, tributaries were also led directly into the supply tunnels, some of them by means of comprehensive intake works.

When planning the power stations great attention was paid to the standardization and the rationalization in order to make erection works as low-cost as possible and to simplify the operation and maintenance of the power plants. This influenced the width of the machine halls, which is the same at the Suldal, Røldal and Novle power stations. Hence it was possible to use the same auxiliary crane and to move it in turn from one station to another, and thus it could be used as a crane no. 2 during the erection.

The reservoir in Valldalen was important for the project but were also environmentally controversial. The complex is therefore worthy of a relatively comprehensive description. The Valldalen dam is the largest of the various dams in the development. The dam is a 200 m long rockfill dam with a central impervious moraine core. The maximum height is 93 m, and the volume of the dam masses is 1.8 Mm^3. The dam was the largest rockfill dam in Norway at that time. On account of the large water regulation height (80 m) the intake for the Røldal power station was constructed in two superimposed sections equipped with upper and lower trash racks.

The dam is constructed in a narrow gorge far down in the valley. Several summer farms in the valley, famous for their goat milk cheese "Røldalsosten", were submerged. The maximum water level reached above the natural Lake Valldalsvatnet in the upper part of the valley. A great part of the storage was obtained by impounding the valley. The area of the reservoir at maximum level is 7.3 km^2 while the original area of Lake Valldalsvatnet was around 1.0 km^2.

The proposal to use Valldalen for a large reservoir was met with many objections from the local and tourist interests. However, the reservoir was regarded as the key to the entire regulation of the western watercourse. More than 50 % of the capacity in the main reservoirs in this part of the river system is in the Valldalen reservoir. Even with a lower maximum level, the valley would have been submerged, but with a lower maximum water level. Once it was decided to obtain regulation capacity in the valley the arguments for providing a large storage to make the project economic more feasible became overwhelming.

The construction of the rockfill dam started in 1964 and was carried out in a high tempo despite a challenging transportation task. The transport lengths in Valldalen were short, but the volume of masses was large, and the construction time was short, to a large degree restricted to the summer and autumn season. The time schedule was tough, anda considerable number of vehicles were needed, with many ordinary trucks and not least large special trucks.

The dam gates in Valldalen were closed in May 1966 and the storage of water began. The water level rose during the summer and nothing unexpected was observed before the middle of August when a questionable leakage was observed. It was then deemed necessary to start injection of the core and partly open the gates to reduce the reservoir filling. Some weeks later the injection seemed to be effective. The leakage decreased and the filling was carefully completed. The injection continued in spring and summer the following year, and the reservoir was operational that year. Since then, leakages have been normal. Dam safety is important in Norway. Any watercourse facility within defined consequence classes shall be monitored by a person (watercourse responsible, VTA) who is authorized by NVE. The VTA is a qualified person with the responsibility to ensure that the security aspects in a watercourse are in accordance with given standards. NVE has the overall national responsibility and regularly undertakes dam inspections and reviews of the owner's dam security system. NVE has the authority to require more thorough investigations based on an inspection and can also require mitigating measures if necessary.

Norway's regulations for embankment dams have changed since the dam in Valldalen was constructed in the 1960s. Thus, a comprehensive rehabilitation of the dam was carried out in

2007 and 2008. The background was new requirements, inspections and investigations which meant that NVE required reconstruction.

The Votna reservoir serves as the intake reservoir for the Novle power plant. There are four dams on the reservoir. The Votna I dam is an unusual construction. The dam is a combined concrete structure, with the main section comprising a double curved arch dam curved in two planes and with a concrete slab abutment on one of the valley sides. The arch dam is 55 m high and accounts for 136 m of the 182 m long crest. The whole structure is topped by a vehicle road which continues to a second dam. Dam II is a concrete slab dam with 40 sections. The total length is 250 m, and the maximum height is 24 m. The reservoir was operational in 1967.

The Røldal-Suldal hydropower development brought about negative environmental impacts. These impacts were treated through steps in the Master Plan and detailed design of the field works that followed all the proposed regulations laid out by the licensing authorities.

Project Financing

The first stage of the project was financed with 4.4 % equity, 17.6 % through loans from shareholders and 78 % through external loans. The interest rate of the domestic loan was 5.5 %. 60.5 % of the external financing was raised in two foreign loans (USD) with same amount. The interest rate was 0.25 % and 0.75 % higher than the domestic loans. Some of the foreign loans were given for 25 years. The first five years was an interest-only period and the next twenty years was the repayment period.

Due to the extension works in 1973-1974 and 1975-1976, additional foreign loans were secured in 1972 and 1974. The total amount was 25 % of the loan for stage 1.

As of 31 December 1985, all foreign loans were repaid. The devaluation of the USD in 1971 eased the debt burden.

Norsk Hydro took approximately 20 years to repay the investment and had during the next 35 years firm electricity renewable generation at low operational and maintenance costs until the present agreement with Lyse Kraft AS (Ltd.) as a result of the expiry of the license.

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7 The Skogfoss Hydropower Plant (1956-1964)

Highlights

- Resource-sharing with the Soviet Union (USSR) despite political tensions
- A private-public partnership through cooperation between a large industrial company and a municipal power company
- Considerable share of grant support and concessional loans
- Steady cooperation between three countries regarding important reservoir operation
- A cascade development in two countries and a main reservoir in a third country
- Important growth of electricity support to a district with notable electricity deficit
- Successful construction works despite project site in arctic climate with long, dark and cold winters

Project Information

The Skogfoss Hydropower Plant was commissioned in 1964. The power plant is located on the Pasvik River in the Sør-Varanger Municipality in the present Troms and Finnmark County[1]. The river is the border between Norway and Russia. Both countries have built two hydropower plants along this river stretch.

Skogfoss was the first of two Norwegian HPPs in the Pasvik River. The downstream Melkefoss HPP came later (1978) and is smaller.

Name of power plants	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Commissioned year
Skogfoss	48	258	19.7	289	1964
Melkefoss	22	255	10.0	141	1978
Sum	70			430	

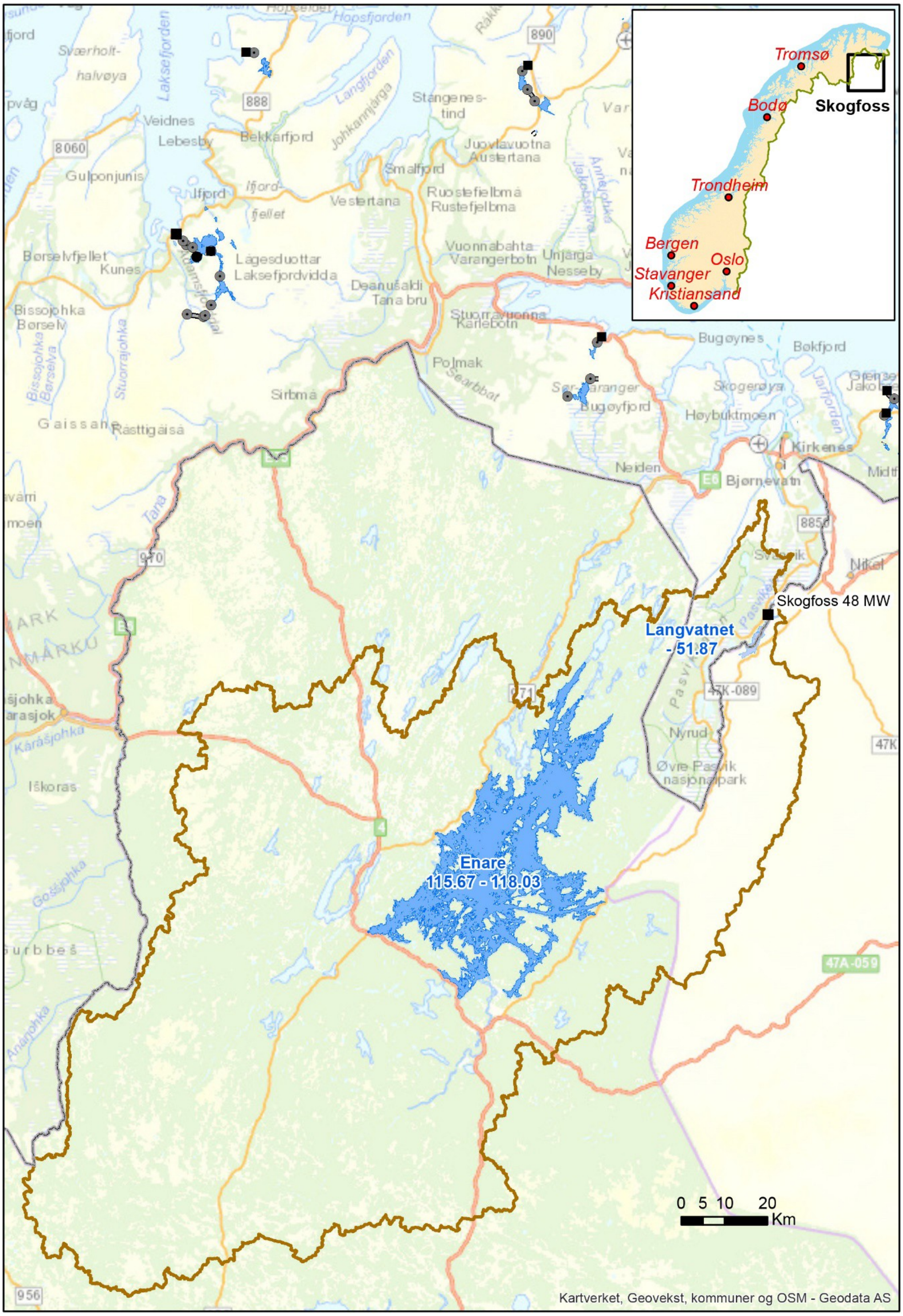
Data from NVE's Hydropower Data Base, September 2020.

The present owner and operator of Skogfoss and Melkefoss HPPs is Pasvik Kraft AS, which is 100% owned by today's Varanger Kraft (Varanger Power). Pasvik Kraft in its present corporate form (stock-based) was established in 2000, while Varanger Kraft was founded in 1938. Varanger Kraft is owned by seven municipalities in East Finnmark and has been a stock-based company since 01.01.1994.

Project Background

The Skogfoss project was planned to supply electricity to the eastern part of Finnmark County. The development enhanced electricity distribution both for public consumption and the iron mining industry in this area. This was also part of a continuing process for the rebuilding of Finnmark after the Second World War (WW2). There were, and still are, limited hydropower resources in Finnmark. Utilization of the resources in the Pasvik River would therefore be an important contribution.

[1] Troms and Finnmark County is a merging of the earlier Troms and Finnmark counties from 1 January 2020. Skogfoss hydropower plant was originally located in Finnmark County.



The Skogfoss Hydropower Plant with catchment area. The Melkefoss hydropower plant is north of (downstream) Skogfoss. See also map under Economic and Technical Aspects.

Finnmark is the northernmost part of Norway, and East Finnmark borders to Russia (previously the Soviet Union) to the east. The Pasvik River constitutes the border for about 106 km. The river falls about 70 meters along this stretch. The Pasvik River has a length of 143 km from the large lake, Inari, in northern Finland, via Finland, Russia and Finnmark to the sea near Kirkenes.

The hydropower resources in the Pasvik River were considered by the mining (iron ore) company, A/S Sydvaranger, already around 1910, with a desire to develop one of the falls in the river for hydropower. This was difficult then since Norway and Russia each owned one side of the river. Just before WW2 the question was topical again, although the Finnish - Russian War (the Winter War) of 1939-1940 made the plans of no interest. In 1944-1945, the Nazi forces destroyed most of the energy infrastructure in Finnmark when they capitulated and retreated from east to west through Finnmark. The energy production facilities in East Finnmark were defect after the war, and for many years to follow. The transmission system was also in bad condition. A development in Pasvik River was therefore highly desirable for public support (households) as well as supporting A/S Sydvaranger and other industry.

In 1947, Finland and Russia (the USSR by then) entered into an agreement as to the regulation of the lake, Inari (in Norwegian Enare). This was a smooth start to the exploitation of the energy potential of the Pasvik River.

Political Aspects

The planning and construction of power plants on the border section of the Pasvik River is a policy phenomenon. Despite the Cold War which prevailed from the 1950s to the late 1980s, power plants were built along the river in a spirit of great harmony between Norway and the Soviet Union (USSR). The planning, construction, and operation of the Skogfoss HPP (and subsequently the Melkefoss HPP) is therefore of particular interest as a good example of international cooperation.

Successful political negotiations between Norway and the USSR in the 1950s made possible the exchange of equal shares in the border stretch of the Pasvik River. The positive result of the negotiations was an essential prerequisite for the construction of the Skogfoss HPP and the later Melkefoss HPP.

In December 1957, USSR and Norway entered into an agreement on hydropower development of the waterfalls along the common border. Norway was granted the right to develop Skogfoss and Melkefoss, while USSR obtained the right to develop the water falls at Boris Gleb (commissioned in 1963, 56 MW, gross head 19.3 m) and Hestefoss (Hevoskoski) (commissioned in 1970, 47 MW, gross head 16.9 m).

[2] A/S Sydvaranger was founded in 1906 and was originally a private limited company. After WW2, the Norwegian State became a large shareholder. Due to non-profitable operation the iron or mining was terminated in the late 1990s and Sydvaranger was sold. The present owners are Varanger Kraft (63 %) and Sør-Varanger Municipality (37 %).

While the agreement did not affect sovereignty issues, it gave the other country access to construct and operate the assets located on the other side of the border, given that the dams crossed the border and the corresponding flood gates may be located on the other side of the border. The Norwegian licence to construct and operate Skogfoss HPP was granted in a Royal Decree in December 1958.

In 1959, Finland, USSR and Norway entered into an agreement regarding operation of the 2,600 Mm^3 Inari reservoir. Since then, representatives from the three counties have met regularly to discuss the regulation and discharge from Lake Inari.

Project Organization

The Skogfoss hydroelectric project was developed as a joint venture between the mining company A/S Sydvaranger[2] and the municipal power company Varanger Kraft, with the name Sameiet Skogfoss Kraftverk (JV Skogfoss Hydropower). The State was licensee of the waterfall rights on the Norwegian side of the Pasvik River. A Royal Decree in May 1961 granted the leasing of the rights to A/S Sydvaranger for a common hydropower development by A/S Sydvaranger and Varanger Kraft, and with financial participation from the State.

The leasing agreement was renewed in March 2003, with Pasvik Kraft as leaser. Pasvik Kraft has been a stock-based production company since 2000. Until this time A/S Sydvaranger was in possession of 50 % ownership of the power production. In addition to the new corporate form, Pasvik Kraft AS took over A/S Sydvaranger's share of the ownership.

Economic and Technical Aspects

The commissioning of Skogfoss HPP in 1964 was important for the electrical coverage in East Finnmark. Before 1964 the capacity was approximately 10 MW in three rather small hydropower plants. Hence, Skogfoss with capacity 48 MW gave a considerable increase (480 %). Based on today's mean annual production, Skogfoss has given an increase from c. 55 GWh to c. 345 GWh (525 %). Production is higher today than in 1964 (higher flow, improved operation), but anyway, the relative increase was considerable even in 1964. Without a doubt, the Skogfoss hydropower plant was highly welcome.

The hydropower plant has a catchment area of some 17,000 km^2, and a mean annual runoff of approximately 6,600 million m^3. A concrete Ambursen (buttress) dam with length 380 meter crosses the river and creates an artificial intake pond, with a small regulation (1.0 m). However, the main purpose of the dam is to increase the head. The maximum dam height is 15 m. The dam is partly in Norway and partly in Russia. In addition, an earth embarkment dam Menika, located 2 kilometres inside Russia, also belongs to the Skogfoss facility. This dam closes a side branch of the river. The dam length is 200 m and the maximum height is 15 m.

A channel leads water from the intake pond to the power station, which includes two vertical units with Kaplan turbines. The power station is partly placed in hollowed out rock. Another channel leads the water back to the river. The power station and the channels are located on the Norwegian side of the border.

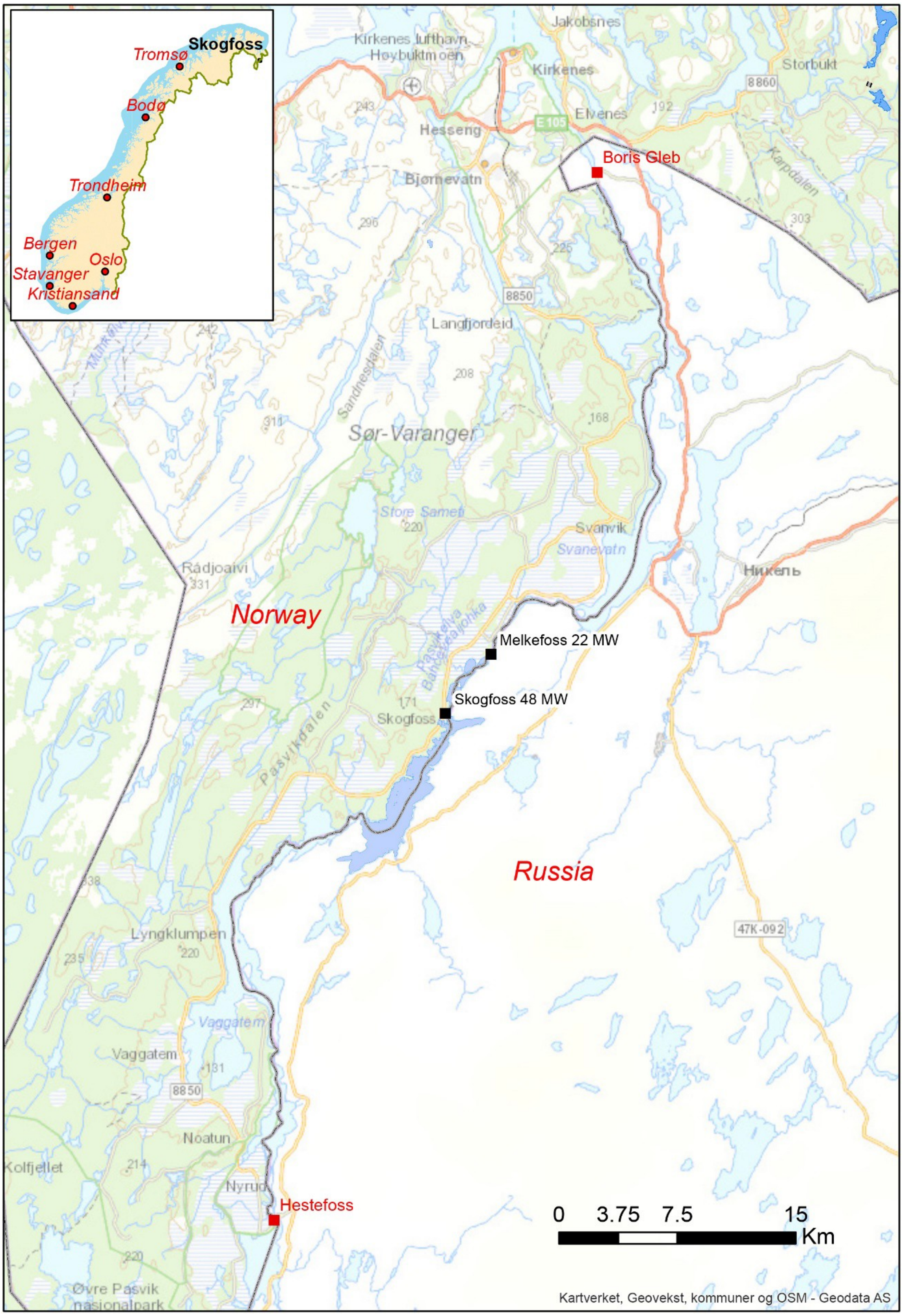
Skogfoss hydropower plant (HPP) is one of seven HPPs in the Pasvik River. The river originates from the large lake, Inari, in Finland. After a short stretch in Finland, the next stretch is in Russia, near the border to Finland. The lower river stretch includes 106 kilometres of the border between Norway and Russia. The seven schemes were planned and constructed between 1951 and 1978. This was during the Cold War period between the Soviet Union (Warsaw Pact) and NATO (USA and West European Countries, Norway included). In spite this, the three involved countries established a good atmosphere for development of the resources.

Pasvik Kraft owns two of the seven hydroelectric plants in Pasvik River, namely Skogfoss and Melkefoss HPPs. Both are low head plants. Russia owns the other five, also low head plants. Four of the Russian HPPs are situated between Skogfoss and Lake Inari. The lowermost Russian (Boris Gleb HPP) is downstream of Melkefoss. The reservoir capacity and the catchment area downstream Inari is small, and hence the power plants can be operated based on the reservoir capacity in Lake Inari. The capacity of Inari is approximately 40 % of mean annual runoff.

A simple transmission line was established from Norway to Boris Gleb in Russia for the supply of electricity during the construction period from 1960. In 1962 Boris Gleb HPP was linked to the transmission system belonging to Varanger Kraftlag for import of 1 MW capacity. The agreement was terminated after 2.5 years.

The seven hydropower plants in Pasvik River have a total installed capacity of approximately 255 MW, and a mean annual production of, 1.3-1.4 TWh. The total installed capacity in the four plants along the border section is approximately 170 MW, which generates about 0.9 TWh in mean annual production.

The uppermost Russian HPP, Kaitakoski, has its intake in Lake Inari. The lake is regulated between HRWL 119.5 and LRWL 117.14 m a.s.l. With the large surface area of a little more than 1,000 km^2, the reservoir volume is almost 2,600 Mm^3. Before the regulation, the natural variation of water level in Inari was 1.25 m. An important positive result is that the mean water level is 0.5 m higher in the ice-free period and is constant during summer. In the natural state the level had been decreasing. The regulation has enabled a consistent discharge, but there are also negative ecological consequences because the natural flow variations have disappeared, together with the rapids in the river.



The Norwegian Skogfoss and Melkefoss HPPs and the Russian Hestefoss and Boris Gleb HPPs in the border section of the Pasvik River. There are three Russian HPPs upstream the border section of the river (Kaitakoski, Jäniskoski and Rajakoski).

Lake Inari in Finland is the main reservoir for the seven downstream hydropower plants, and cooperation between the three involved countries is therefore essential for optimal operation of the cascade power plants. This also includes ecological and other environmental aspects.

There are regular meetings with authorized representatives from all three countries to follow up the provisions and to ensure fair treatment of each country's points of view. Mutual understanding and respect are important factors, and these were in place from the very beginning, and the cooperation has been trustful and consistent.

Project Financing

The Skogfoss project was financed entirely by domestic resources. The financing also included transmission lines. Shareholders were the mining company A/S Sydvaranger (energy consumer) and the power company Varanger Kraftlag (energy producer). Each of the shareholders financed 50 % of the power plant, while Varanger Kraftlag financed the transmission lines.

Kommunalbanken; KBN (The Norwegian Agency for Local Government) is a public bank and was one of the lenders. KBN is an important lender to municipalities and other public governance institutions. The bank was founded in the mid-1920s as a governmental establishment. Since November 1999 the bank has been a stock-based business. Another source of financing was grants from a governmental rural electrification support fund. The financial plan is shown in the table below.

Financial plan for Skogfoss hydropower plant and transmission lines.
Figures are calculated on basis of listed financing amounts in NVE's Annual Report 1963.

Investor	% of total budget	Component	Source of financing
A/S Sydvaranger	45	Power Plant	Own funds
Varanger Kraftlag	32	Power Plant	Loan from KBN
Varanger Kraftlag	3	Power Plant	Loan from A/S Sydvaranger
Varanger Kraftlag	21	Power Plant and transmission lines	Grant - rural electrification support fund

75 % of A/S Sydvaranger's contribution was amortised immediately, while the remaining 25 % was amortised over a period of 35 years, after a grace period of five years. The loans taken up by Varanger Kraftlag had a tenure of 30 years at an interest rate of 4.5 %. The grants from the rural electrification fund were given in order to bring down the end-user price of electricity. The grants were immediately depreciated.

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8 The Tokke Hydropower Scheme (1957-1965)

Highlights

- The Central Government had an innovative/opportunistic approach to project financing through the subscription arrangement
- World Bank co-financing
- Local and governmental co-financing
- Strong local political involvement for development
- Priority to using the power for municipality and county development
- Cascade hydropower development
- Construction works through more stages, based on the first Norwegian example of a total implementation plan for a cascade development.
- Development of a Norwegian skilled workforce in planning, construction, and manufacturing of electro-mechanical equipment
- Large underground power stations, tunnels and shafts improved the state-of-the-art for technical construction knowledge and was used in subsequent projects
- The project is an example of daily peaking capacity
- Transmission development, associated with cross-border connections

Project Information

The development of two large watercourses in the municipalities of Tokke and Vinje in the present Vestfold and Telemark County includes Tokkeåi (Tokke River) with its tributaries and neighbouring rivers. The project area is in the central part of southern of Norway, 200-250 km southwest of the capital city of Oslo.

The first phase of the development included 4 power stations and 13 reservoirs commissioned between 1957 and 1965. The 4 plants are Tokke (430 MW), Vinje (300 MW), Songa (120 MW) and Haukeli (5 MW). Haukeli power plant was the first plant. It was built to deliver the required electrical energy for construction of the three larger plants and to contribute to local electrification.

The Tokke development is among the first examples of total cascade planning to develop power stations and reservoirs to meet the growing need for electricity in the southern Norwegian public sector including small industry. The location was not far from the central populated areas in southeast Norway, giving the cascade system added value for the government's endeavour to rebuild Norway after the Second World War.

There are today 8 hydropower plants and 16 reservoirs in operation in the Tokke and Vinje watercourses. The current installed generation capacity and annual mean energy generation is 997 MW and 4,832 GWh, respectively. The total catchment area is approximately 3,000 km^2.

The initial plan for water resources included plants in two cascades. The main cascade included four large plants. These are from upstream: Kjela (891 m a.s.l.), Songa (974 m a.s.l.), Vinje (687 m a.s.l.) and Tokke (466 m a.s.l.). The altitudes refer to the maximum level of the intake reservoir.

The plants in the Tokke Hydropower Scheme are listed in the table below. The first construction stage (until 1964) included the three largest plants Tokke, Vinje and Songa.

Name of power plant	Capacity MW	Max. Discharge m^3/s	Gross Head m	Mean annual generation capacity GWh	Year commissioned
Tokke	430	128	393.5	2 328	1961
Vinje	300	165	222	1 052	1964
Songa	120	52	287	589	1964
Kjela	62	41	174	282	1979
Lio	43	14	346	306	1969
Byrte	20	8	285	135	1969
Haukeli	5	2	268	38	1957
Hogga	17	169	12	102	1987
Sum	997			4 832	

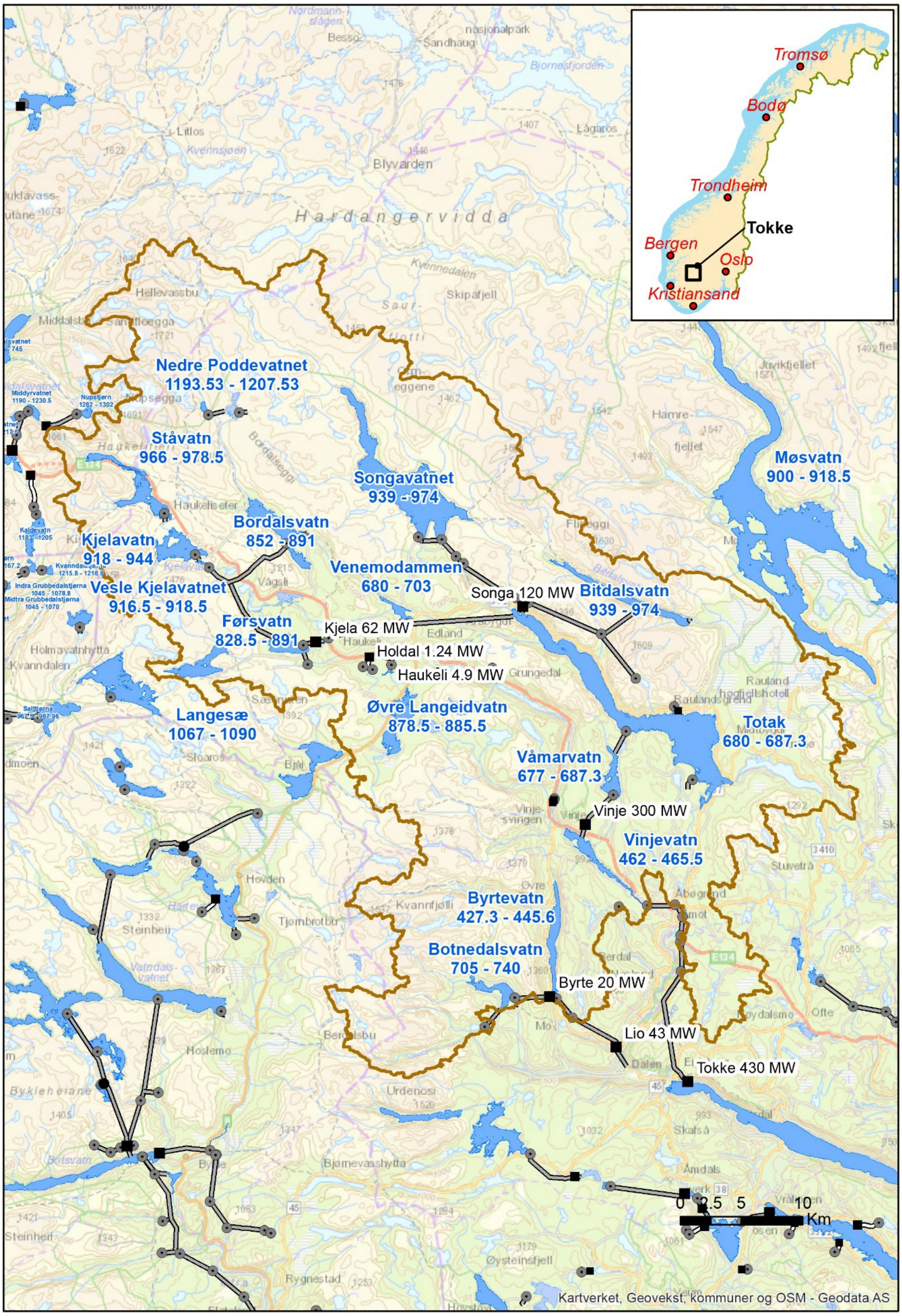
Data are in accordance with NVE´s Hydropower Database per December 2020.

In 2003 Norway developed a strategy for implementation of small hydropower plants. Six small hydropower plants in the Tokke catchment area have been built during the last two decades for the supply of electricity to the local grid.

Project Background

In the early 1950s, shortage of electricity threatened economic growth, particularly in southeast Norway. No transmission backbone system connected this region with other regions, and the Tokke hydropower scheme was the last remaining large project in this region. The project was lobbied by representatives from the population centres (central politicians, trade and industry and the power industry) as well as by local politicians in the project area.

Already in 1917 the State acquired some of the water rights in the Tokke and Vinje watercourses, but discussions on purchasing water rights started some years earlier with involvement of private sector, municipalities and the State. However, when the planning started in the early 1950s, the State still controlled less than 60 % of the necessary water rights. A local municipality owned power company, Skiensfjordens Kommunale Kraftselskap (SKK) (Skiensfjordens Municipal Power Company) wanted to participate in the development. They referred to the success in project sharing with Vestfold Kraftselskap, VK (Vestfold Power Company) in the previous Åbjøra project (commissioned in 1951). The State refused the proposal because they wanted a hydropower cascade development to meet the electricity needs of the whole region, including south-eastern parts of Norway. The State then decided to expropriate the remaining water rights.



The Tokke hydropower scheme as planned and developed originally. The Hogga power plant was planned and constructed later. See the next map.

The Tokke hydropower scheme included the Hogga hydropower plant.

Political Aspects

Already in 1946, representatives for local municipalities requested the Norwegian Parliament to start planning of Tokke and Vinje watercourses for hydropower development. They faced pressure to develop the local economy and considered large scale hydropower development as a means for electrification since large areas of the district still lacked electricity access and economic development.

The Central Government faced economic dilemmas regarding project development. Due to other urgent priorities, the Central Government did not consider it a realistic option to fully finance the project over the State Budget. As already referred to, the Central Government wanted to develop the project as a solely State Power Utility project. To finance the project over the State budget would also mean that "unreasonably" large public resources would be spent on a project that would benefit the most developed part of the country. On the other hand, a significant part of the export-oriented industries was located here.

Discussions on the Tokke development also included the question if Norway could assist Denmark in their endeavour to secure electrical power supply for the development of Denmark. This discussion was parallel to discussions on exporting electric energy in the flood season from power plants on the river Glomma in eastern Norway south of the capital Oslo. However, development of technology for thermal energy resulted in Denmark using coal because of lower kWh cost and reliable firm power generation.

At that time Norway had many hydropower schemes under development but lacked skilled manpower and money. The World Bank ("Marshall help") favoured hydropower for large scale energy supply, energy intensive industry, and export of electrical energy to neighbouring countries. This was part of hard political discussions between parties that favoured export and parties that argued that Norway needed the power for its own industrial development and expansion of public access to electricity. It was opened for export of seasonal power and a small amount of firm power.

The Parliament formally approved the Tokke project in 1955, followed up by budgetary allocations in 1956.

Contrary to other large hydropower schemes after WW2, the Tokke scheme did not have a crucial link to energy intensive industry. It was a mix of public energy, small and large industry demand in south-east Norway that put pressure on a rapid development of the Tokke project.

For the Central Government, it was important to cover the needs of the entire region. By allowing the State power company to be responsible for the whole scheme, several small and medium hydropower projects planned by companies from local and nearby municipalities could not be developed. These plans did not give the large-scale solution to rural and urban electrification that was governmental policy. With the commissioning of the Tokke project, rationing of electricity by and large ended in south-east Norway.

Project Organisation

The project was implemented by NVE which was the State Power Utility. To a large extent NVE applied its own workforces for planning and construction. However, unlike the Aura hydropower project some years earlier (commissioned in 1953), more of the enterprise contracts were awarded after competitive bidding processes. Then the Utility had to compete with external contractors.

Due to World Bank financing, the Utility set up separate project accounts. A consumer-based financing was established whereby municipalities and counties participated for the right to purchase power. However, they had no influence on the development itself. This form of financing proved efficiency and many politicians argued that this was a model for the future, but the model was not commonly used in the years to come.

Economic and Technical Aspects

The Tokke scheme provided an opportunity to boost technical development of Norway and develop skilled workers both in hydropower design, electro and mechanical manufacturing and civil construction. More than 1,200 people received their income from this development over two decades. The challenges with underground power stations, long tunnels, dams and large, high pressure Francis turbines, large generators and high voltage transmission lines were solved by parallel activities in Research and Development. This resulted in technical knowhow that put Norway in the forefront regarding cascade development, high pressure underground hydropower, and Francis turbines for high heads.

The Tokke scheme gave, to some degree, opportunity for hydropeaking. The so-called capacity factor indicates the possibility for peaking. The capacity factor is the relationship between mean annual power output and "maximum output". Maximum output is the amount of energy (electricity) that a generator could produce when it is running at full load all year (8,760 hours). A low capacity factor indicates the possibility for peaking and vice versa for a high capacity factor.

Hydropower plants designed to serve energy intensive industry, like the Aura project (1953) had a high capacity factor. The two main power plants in the Tokke hydropower scheme, i.e., the 430 MW Tokke hydropower plant and the 300 MW Vinje hydropower plant had a low capacity factor. By using the flexibility in the reservoirs this opened for seasonal generation capacity (winter) and to some extent daily peaking capacity to meet peaking demand. In retrospect, this has proved to be a future-oriented solution.

However, the Vinje hydropower plant, located upstream the Tokke hydropower plant, has a much lower capacity factor than the Tokke hydropower plant. In other words, the Tokke plant is today a bottleneck for efficient operation of the cascade system. It should also be noted that the head between the intake reservoir for the Vinje hydropower plant and the tailrace water for the Tokke hydropower plant could be developed into a single hydropower plant. However, turbine technology in the late 1950s was not developed for such high head Francis turbines, between 650 m and 700 m.

The planning of the Tokke hydropower scheme comprised originally six power plants, and with three main plants in stage 1 (Tokke, Vinje and Songa). However, the region had load shedding which put challenges on large scale construction works with demands for electricity. The Haukeli power station (5 MW) with its reservoir was therefore put into operation in 1957 to secure electricity supply to the construction works for the development of the Tokke and Vinje watercourses.

Haukeli power plant was meant to be a temporary station, for the first construction stage only. The turbine and generator came from another recently inaugurated large hydropower project, the Aura scheme, and was also there used for power production in the construction period. In other words, this is an example of reuse. Nevertheless, Haukeli was beneficial for local supply also after the construction period. The equipment was solid and in operation for decades, due to frequent and proper maintenance. The old power station was replaced by a new one in 2013, with approximately the same installed capacity.

Tokke, Vinje and Songa HHPs are all constructed with underground power station technologies. Underground power stations in combination with tunnels and shafts became more and more usual in Norwegian hydropower after WW2. This was first justified mainly for security reasons, but gradually it shown up to be better than surface power stations regarding technology, economy and the environment.

Stage 2 with three additional power stations was implemented later (1969-1979). The Hogga hydroelectric power plant (1988) downstream the Tokke HPP is a run-of-river HPP benefiting the upstream reservoirs and was not included in the original development plan.

The development of the Tokke project was positive for the region. Employment is already mentioned, and there were positive effects on social life and municipal economy. However, there were also losses. There were tough conditions, both natural and artificial. Accidents occurred during construction works, and some of them with severe consequences such as serious injuries and death. 15 workers perished in the period 1956-1963, and additional 8 up until 1972.

Transmission costs amounted to 26 % of total budget costs. This is a high share and illustrates this large scheme's aim to electrify both local municipalities and municipalities in other counties.

As for most other large generation projects, the transmission lines associated with the Tokkeproject were building blocks in the national backbone transmission system. The project included development of more 300 kV transmission lines into the capital area. Tokke also contributed to connecting the western and eastern parts of southern Norway. The project also paved the way for the first large interconnection between Norway and Sweden in southern Norway. This was Norway's first 420 kV transmission line.

The required grid capacity also influenced the technology. When southern Norway's grid system was connected to Sweden in the early sixties, power oscillations (dynamic stability) were experienced in high export situations. These situations were associated with high power generation in Tokke and Vinje power plants. A technical committee was established, and the problem was mitigated by improved turbine regulators.

In order to maintain safe operation during outages of critical transmission components in high export situations, system protection schemes with trip generators were installed in the Tokke power station. This measure, which is still in use, allows safe operation according to the N-1 criterion in high power export situations, even in cases of outages of critical transmission components.

Project Financing

The first stage of the project was financed through three sources, namely loans raised from a customer subscription arrangement (49 %), a World Bank (WB) loan (36 %) and allocations over the State Budget (15 %). The second stage was financed by a second WB loan and over the State Budget, while subsequent stages were financed solely over the State Budget.

The WB loan was given to the Norwegian government, which allocated the funding to the State Power Utility through the ordinary annual allocations approved by the Parliament (The Tokke project was not a separate legal entity). The interest rate and loan tenure were 4 % and 25 years, respectively. In addition, the government negotiated five years free of instalment payments.

A premise was that the subscription arrangement was a starting point. Project loans should be as favourable as project shares for the lenders. The lenders provided an interest-only loan until 1975 at 4 % interest rate by subscribing to a certain capacity at a capacity factor of 0.7. This implied that the plant could produce at maximum capacity for 6,000 hours annually. This gave them the right to purchase power at a lower price than the ordinary State utility price. Besides, in the case of a power shortage, power supply to the lenders was prioritized, i.e., that they were less likely to face rationing.

The subscription arrangement succeeded in raising the expected capital. The lenders, i.e., municipalities through distribution and power companies and small industrial enterprises that purchased power from the State Power Utility, raised capital through equity and loans from their electricity customers, banks and pension funds. However, large industrials did not subscribe as much as been expected, although the expected subscription amount was raised. Some power companies also raised the electricity price in order to raise capital. Later, Vestfold Kraftselskap, VK (Vestfold Power Company), one of the partners in the Åbjøra project used the same financing modality for the Hjartdøla hydropower project.

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9 The Tussa Hydropower Project (1957-1965)

Highlights

- Long lead time caused by differences in strategy by cooperating local communities as well as technical and financial constraints
- Example of blasting under water for tapping a large lake for reservoir purposes
- Local electrification schemes for isolated networks in rural areas
- Public supply mixed with small scale industrial development
- Development of a powerful local scheme with peak power ability to stabilize the frequency in the local network powered by many mini and small hydropower plants
- Combining supply of small workshops and rural electricity in isolated network
- Electrifying small industry that utilized local natural resources
- Illustrates the value of electrification
- The project shows how municipal cooperation can help in achieving common goals

Project Information

The Tussa Hydropower Plant is in the village Bjørke at the end of Hjørungfjord in the Volda Municipality, Møre and Romsdal County. Hjørungfjord is one of many fiords in the Møre og Romsdal County on the west coast of Norway. The area is characterised by islands, fiords, and high mountains. The nearest town is Ålesund, which is a two hours' car drive and a ferry stretch from the Tussa hydropower plant.

The Tussa hydropower plant is owned by the publicly owned power company Tussa Energi that owns and operates 1 mini hydropower plant with output less than 1 MW, 19 small hydropower plants (1-10 MW) and 2 larger power plants, which are Åmela (34 MW, 1977) and Tussa (64 MW, 1961). Their total capacity is 176.9 MW and annual generation capacity is 714.2 GWh. Tussa Energi distributes electricity to several municipalities in the vicinity and owns and operates the distribution transmission lines. In addition, many small and mini hydropower plants owned by farmers and small industry companies feed their surplus electrical energy into the grid. Tussa Energi has power plants with reservoirs, and the Tussa and Åmela power plants are important for stabilizing the frequency in the grid system. Most of the small private plants have none or limited storage facilities.

Tussa Energi is owned by 13 local municipalities and the Møre and Romsdal County. The construction of the Tussa power plant was estimated to cost 25.3 mill NOK (1956) and included necessary transmission lines to customers. The final regulation license was given in 1957 and the construction works started the same year.

The Tussa hydropower plant utilizes the head between the intake reservoir in Lake Tyssevatn (656-610 m a.s.l.) and the outlet in the sea. The power plant consists of reservoirs, dams, diversion tunnels, waterways (tunnels and pressure shaft), an underground power station with two units with Pelton turbines, and an access tunnel. The Tussa power plant was constructed in two stages, stage 1 (1957-1961) and stage 2 (1961- 1964). The total catchment area to the intake reservoir in Lake Tyssevatn is 55.5 km^2 and the mean annual natural inflow is 190 mill m^3. The total reservoir capacity is approximately 125 mill m^3 which gives a regulation capacity of 65 %, of which around 85 % (107 mill m^3) is in the intake reservoir.

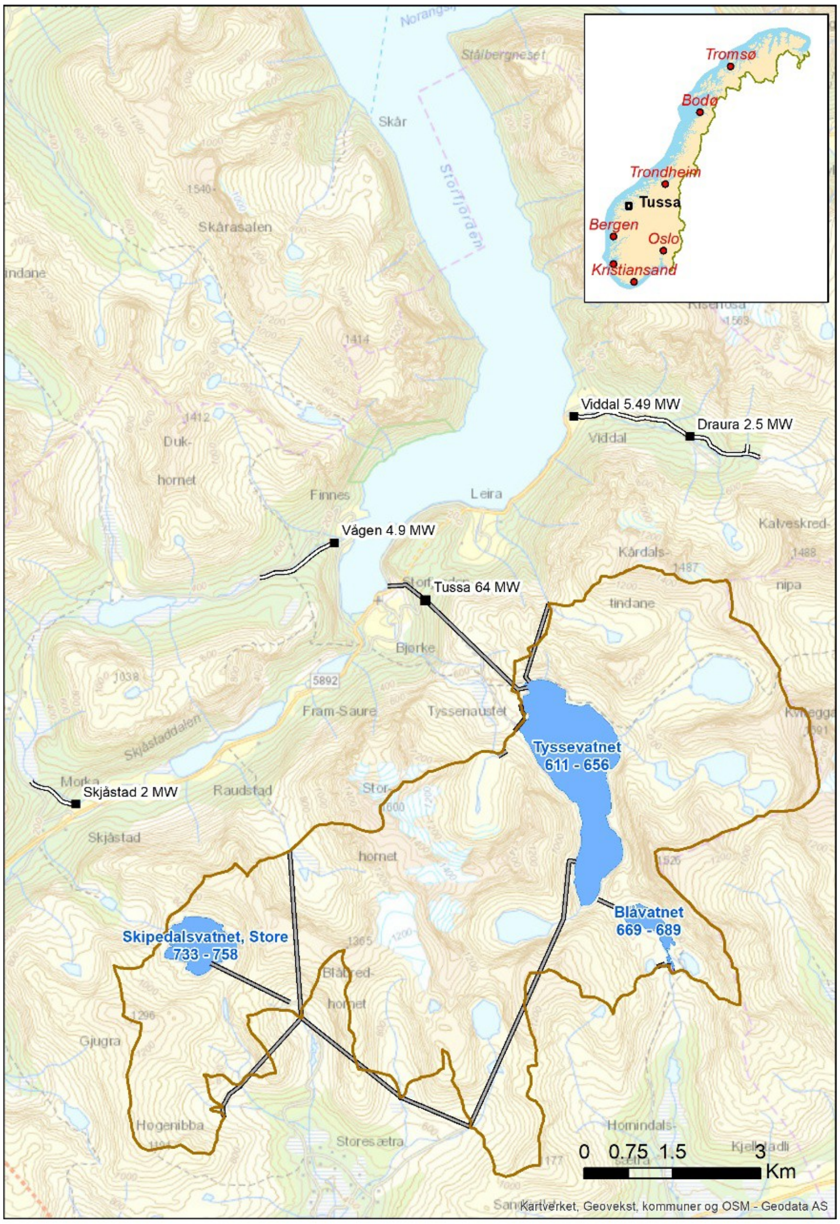
The large reservoir capacity and direct outlet to the sea give the power plant an extremely flexible operation with option to meet changes in weather conditions and electricity demand.

The plant data are listed in the table below.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Tussa	64	11	646	272	1961

Data from NVE's Hydropower Data Base, December 2020

The power plant is now connected to the central grid, but the connection to a transmission system was a challenging process when the power plant was planned and commissioned in the 1960s.



The Tussa Hydropower Scheme.

Tussa Energi was granted a regulation license for the Tussa hydropower plant in 1957. Because Tussa Energi was organized as a share holding company, the municipal owners could risk a limited license period. Therefore Tussa Energi was rearranged to meet the demand from the energy authorities (NVE) to secure a never-ending license for exploitation of the Tysse River.

Project Background

The Møre and Romsdal County is characterised by high and steep mountains and long and deep fiords. On the low-lying areas between the fiords and the mountains, centuries ago people started to cultivate the land. Their daily income was earned by combining agriculture and fishing.

The first electricity generation from small streams started 130 years ago and was trigged by small industries that utilized local natural resources like timber from forests, wool from sheep, milk from goats and waste from the fishing industry. Many micro HPP were constructed to serve private small enterprises making clothes, barrels, shoes, furniture etc. The internationally well-known Devold company has its origin from this period and is still in forefront in making woollen underwear for artic use. Another internationally recognised company is Ekornes that is still a leading company in furniture, especially relaxing chairs. The small hydropower plants powered local isolated grids and load shedding and power failure occurred frequently.

Harnessing of power in river waterfalls in the 19th century.

The main town in the district is Ålesund, a town based on the rich marine fish resources. South of the town there were 15 municipalities on islands and along the numerous fiords.
Between the First World War (WW1) and the Second World War (WW2), there was a trend that municipalities took a leading role in electricity generation development in close cooperation with local industry. The municipalities and the main town Ålesund early on focused on the high waterfall in the Tysse River, called the Tussa Project. However, numerous discussions in the municipalities resulted in a decision that the development of some of the small rivers were better tailored to meet forecasted electricity demand growth, available technology, competence, and available capital.

In 1946 there were 291 hydropower plants in the Møre and Romsdal County with a total capacity of 52,071 kW electric and 2,692 kW non-electric. Most of these plants were for general electricity supply and miscellaneous industry. A majority of the plants were micro hydro with less than 10 kW installed. The electrical capacity in some of the then municipalities which became future owners of the Tussa plant is listed in the table below. Many of the plants were private, but there were also a few municipal plants. In general, most of the largest plants generated AC while plants with a few kW generated DC. Number of plants and electric capacity in the municipalities in the district are listed in the table below.

Municipality	Number of plants	Electric capacity (kW)
Hareid	4	373
Ulstein	2	562
Ørsta	7	3 409
Hjørungfjord	10	97
Herøy	6	173
Sykkylven	2	1 266
Volda	16	2 221
Vartdal	10	443
Sande	5	228
Vanylven	3	40
Syvde	5	22
Sum	70	8 834

The rationale behind the Tussa Project can be found in the local history through three decades before construction of the Tussa plant started. The following three examples from municipalities in the region illustrate the situation.

Sykkylven

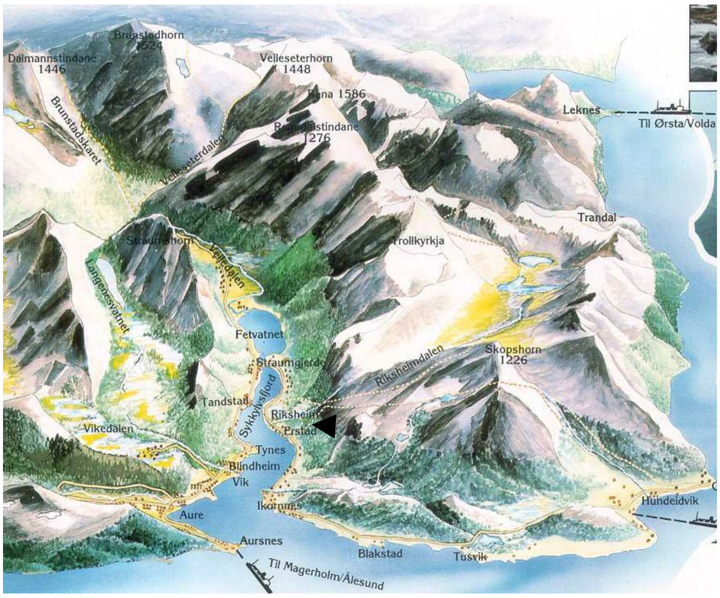
One example is the Sykkylven Municipality that developed the small Riksheim hydropower plant (1.2 MW, 1916-1920) in one of the fiords. In the 19th century the community in Sykkylven derived export revenue from the exploitation of the local timber resources. These resources were rapidly depleted, but the community accumulated both mercantile knowledge as well as experience in the exploitation of hydro resources during this period. Many sawmills powered by hydro were in use. At the beginning of 20th century, the growing population made it necessary to find other sources of income if the people were to continue living and working there. In 1915 there were a total of 2,800 inhabitants in Sykkylven of which 20 were employed in industrial businesses.

The experience gained in the timber industry, in the sawmills and in the various small workshops, led to the idea of utilising the rich hydro resources to produce electricity in their endeavour to develop local industry. These were brick production, textile mills, mechanical and electrical products like transformers, as well as furniture factories. In 1910, a few workshops located near river rapids were already supplied with electricity from micro (less than 100 kW) hydropower plants. The new technology was brought to the community and high voltage transmission lines had become possible. The Sykkylven Municipality organised a committee to be responsible for planning, financing, and construction. This committee had to find the answer to three major questions:

* The current electricity demand and in the next 10 years
* Output and investment costs of alternatives with one small and one larger river
* The income possibilities

Investigations of public electricity demand and discussions with representatives of the small but growing industry, especially the furniture industry, concluded that the demand 10 years ahead would be 600 kW. The current demand was found to be 120 kW.

To find the possible income the committee had a yearly fixed price per watt on lamps and a fixed price per horsepower (hp) for engines and heating. A slogan urged everybody to join, and the committee worked hard to persuade people to order electricity. From the local tradesmen they got the yearly consumption of oil and spare parts for oil lamps, and this was compared to the calculated price of electricity.



Map of Sykkylven and the Riksheim watercourses.

The construction of the Riksheim powerhouse, the 1,100 m long pipe-line with diameter 400 mm and the intake pond lasted for two years. During the time of construction, the local interest was high and there was never any problem to find willing hands when the heavy equipment arrived. One hundred men pulled the turbine and generator on snow from the harbour to the power station on the hillside, and the pipes were rolled up the steep hill by means of ropes.

They also had to find local solutions for the transmission lines. Due to the First World War price of copper increased by 500 % and they were forced to use mostly iron wires purchased for agricultural purposes.

The investment cost had increased by 350 %, and although the consumption of electricity increased rapidly, the income could not cover repayment of the loans. The deficit had to be paid by the community. After three years of operation, increased consumption made it necessary to replace the iron wires by copper to reduce the energy losses. Three years after a second turbine of 750 kW had to be ordered. The tariff was increased, and a lot of people had problems with paying for the power they used. The municipality also wanted to develop industrially, and this new growing industry could not survive without access to sufficient power at reasonable prices. Finally, the problems were solved by cheap loans from the national bank.

Some highlights from Sykkylven:

1) Triggers for the construction were increasing electricity demand from small workshops and the need to create more jobs. The registered demand from industry in 1915 was 120 kW. The demand from industry and domestic use in 1925 was estimated to be 600 kW.
2) The Sykkylven Municipality organised a committee to plan, finance and construct the hydropower plant. For planning and technical advice during construction a hydropower consultant from Ålesund was chosen. The municipality decided to construct a plant with 450 kW capacity. Local companies and workforces were strongly involved in the construction works, which was hampered by limitations in available technology and the budget. The intake and penstock were designed for a 2 MW plant, and already in 1920, an additional turbine of 750 kW was installed.
3) The plant was financed by the municipality after they received strategic loan from the Norwegian Government. Introduction of a programme for use of electricity and to earn money on the surplus power. An aim was to convince customers to substitute kerosene oil by electrical lighting. To meet operation cost, budget constraints and need for new capital for upgrading the plant, tariffs were gradually increased. The increases were not an easy task because many costumers had problems in paying the bills.

During the first 30 years of electricity generation the Riksheim power plant was looked upon as the "heart of the community", providing light for people and electricity for industrial growth and job creation. Because of the need for more and predictable power generation the Sykkylven Municipality decided to join other municipalities in developing the Tussa Project.

Ulstein

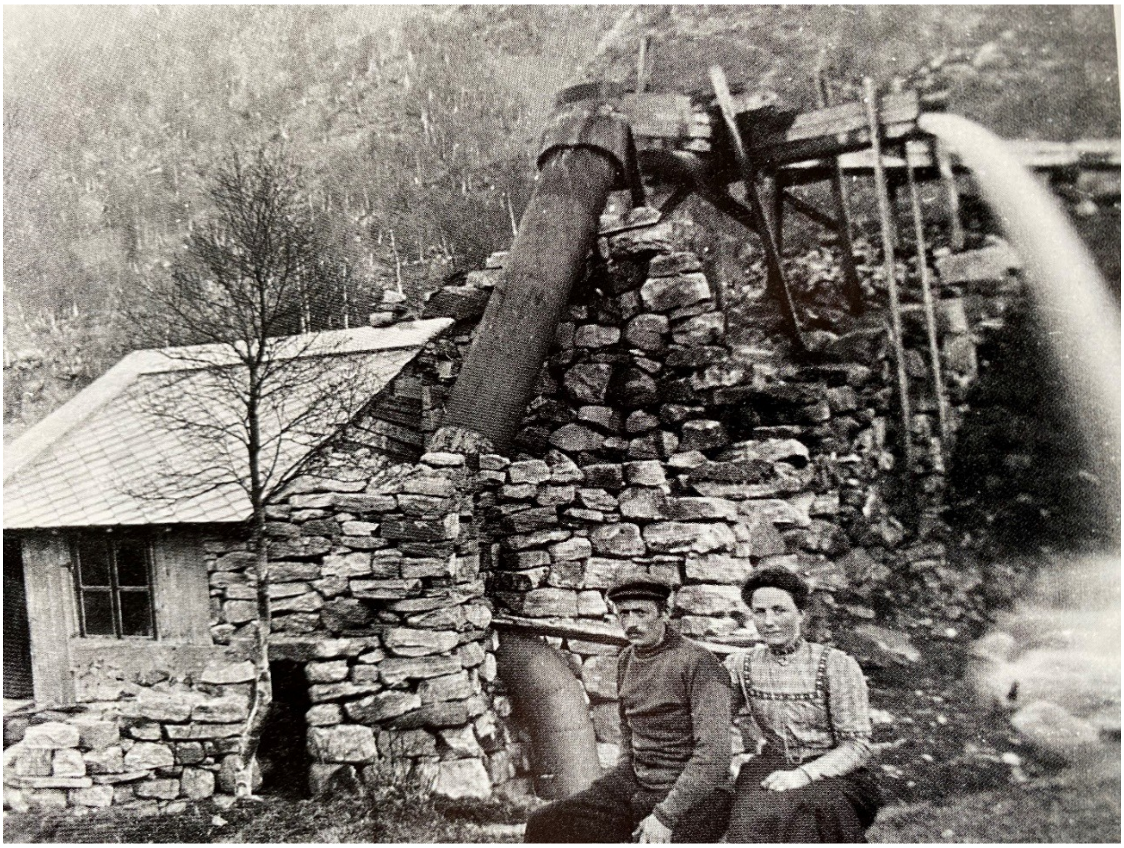
In the middle of a dark winter evening in December 1917 the adventure of electricity reached Ulstein Municipality with brightening light in several homes. The new development had its origin from 1912 after very good years for local workshops, industry, fishing, and agriculture. Agriculture had new and modern machinery that dramatically reduced the workload for women that normally harvested and processed the grain. Engines had been put into numerous fishing boats and replaced rowing and use of sails. This called for local mechanical workshops that could perform repair and maintenance work. The damming of small lakes and water in small streams powered waterwheels attached to belts that secured operation of different machinery. Many solutions were very sophisticated, but had low efficiency compared to use of electricity. However, the use of electricity was only rumours and talk in 1912.

One remarkable example from this period was the courage of the farmer Ole Erdal and his wife Berte. He had no waterfall, but a small stream and land to divert water by a channel and developed a head of a few metres (9.5 m). He generated DC electricity by means of a self-constructed turbine and a dynamo around 1910. The capacity was 37 kW. They gave light in the main house and in the barn. In the dark winter nights, the whole farm looked like a fairy-tale castle with its electrical lights. They also had electricity for heating the house and for cooking. This made life much easier both for the husband and his wife. The need for cutting trees for firewood was reduced, and it was much easier to cook food without unhealthy smoke and the less efficient wood stove.

Their example encouraged other to start thinking, and the idea of cooperation in new projects started because they realized the benefit of electricity. This could reduce the need for employing farm workers, and these workers would anyway go to the industry that could pay more. Electricity would benefit both the growing industry and the traditional farmer. It was also argued that electricity could be the alternative to oil in the fishing boats. Today, 100 years later, this is still a discussion in Norway!

The use of local produced electricity also reduced the need for purchasing oil for kerosene lamps. This money could be used for other local purposes. The electricity also reduced pollution in houses. It was like the sun entered into the house after the sun had lifted water from the ocean to the mountains and created rivers where waterfalls could be harnessed for electricity generation.

Compared to the situation in the rich fisheries, new technology was soon used by most of the fishing fleet, and everyone wanted the benefit of electricity. The question was how to organize this. Both private and municipal solutions were discussed: many standalone small power plants or fewer larger power plants; local isolated grids or a more expensive transmission system between the valleys. The local opinion in Ulstein was that the municipal alternative would give benefit for all and reduce trouble with speculative investors. But the reality was a mix. In 1915 there were 28 power plants in the Møre and Romsdal County, 26 with waterpower and two steam plants powered by coal. Four years later the number was 185 power plants and most of these operated on isolated grids.



The farmer Ole Erdal and his wife Berte had both the means, competence, and the courage to develop their own micro hydropower plant and were the first to enjoy the benefit of electricity in the Ulstein Municipality. Photograph from the collection of Jostein Mo, Ørsta.

Ulstein kommunale elektrisitetsverk (Ulstein Municipal Electricity Company) suggested the Ulstein River as the source for the first hydropower plant for the electricity company in December 1915, and in December 1917 the plant with 750 kW was inaugurated. Some farms had the pleasure of electric lighting from the beginning, while others had not because the wiring failed. The consumption by farmers, factories and workshops soon proved that the plant was too small and planning for expansion by an additional 600 kW started. Already from the beginning it was known that the reservoirs and the inflow in the catchment area could cater for approximately 1250 kW that could be run throughout the year, with some constraints in cold winters and dry summers.

Ulstein Municipality quickly realised that the demand for electricity would overrun the capacity of the Ulstein River and together with neighbouring municipalities eyes were on the Tysse waterfall in Bjørke in Hjørungfjord Municipality. Another 1,400 kW would be Ulstein Municipality's share of that project. However, the Tussa power plant was a large project and several municipalities in cooperation were necessary for finance. Ulstein Municipality had economic constraints because of the new plant in the Ulstein River. The decision was therefore to develop smaller streams to meet the growing demand until a more powerful cooperation could agree on the large Tussa scheme.

The challenges in construction of high voltage transmission lines in steep mountains and large fjords also contributed heavily to the negative arguments. Ulstein Municipality therefore sold its shares in the Tussa scheme to a local bank and focused on developing other small streams for electricity generation and expansion of power lines to neighbouring islands for electrification of local farms and small fish industries. However, together with other municipalities, Ulstein returned to the Tussa Project after the Second World War.

Hareid
Life in Hareid Municipality had many similarities to Ulstein Municipality. People had long working days and gradually new technologies were used when economic and practically available. Food, house, clothes, and energy (mostly from wood) were obtained locally and gave rise to grain mills, spinning and weaving in the evenings when kerosene lamps gave working light.

In the Hareid Municipality the income from the rich fisheries also promoted the use of new technology and most farmers had a share in a fishing boat. Some of them invested in larger boats for seal hunting in the Artic. They made good money and income from the pelt, the blubber, and the oil from animals. From the far north of Norway, they had seen what electricity could do because Hammerfest town had electrified already in the 1890s. In Hareid the Ytredal River had been used for saw and grain mills and could be transformed to produce electricity. Six farmers with shares in seal hunting boats jointed forces and purchased water rights in the river and used a local engineer to plan a micro hydropower plant. The plant was constructed in 1918 with two units of 37 kW and 47 kW. The total cost of NOK 14,289 was equally shared between the investors. One of the investor's wives was responsible for operation because the men continued to work on the fishing boats. The power plant was closed and dismantled in 1939.

Because they had 24 hours with generation capacity the owners of the Ytredal River micro hydropower plant installed electric water heaters and used the electricity during night-time. There was light and electric heating in all houses, even in the hen coop. The electricity introduced a new way of life. For example, they prepared a coffee kettle in the evening for the morning so they could just push the button to get it heated. Then they had coffee and breakfast in the morning while in bed with their wife!

More people wanted to take part in this life and 26 persons established Storelvens electricity company in 1917 to build the Storelv hydropower plant in Brandal and low voltage distribution lines. In June 1918 they entered into an agreement with the landowners and a license was granted from the electricity authority (NVE) to produce and sell electricity and establish the necessary grid. The 88 kW plant was in operation already in January 1919 and the rush probably resulted in low quality equipment since the turbine collapsed after a few months. A new Pelton turbine was put into operation in 1920. The cost for this unit alone was more than double of the total cost for the entire plant in 1918 and was a warning of the hard times to come after the First World War. The repayment of loans was hard and the frequent load shedding and power failures due to low technology in power production and grid distribution, cold winters and dry summers reduced the benefit. Soon most of the electrical heaters were turned off. One reason for the generation trouble was that the intake pond could only store water for a few hours' operations.

The growing loan expenditure forced the owners to ask the municipality to take over the responsibility for the loans. Six years after the accident with the turbine there were hard internal discussions in the municipal authorities on the question whether the municipality could afford to take over responsibility for the loans. The discussions lasted until 1927 when a decision was made for the Hareid Municipality to be responsible for the loans and maintenance of the power plant in Storelva in Brandal, although this process was not terminated before 1934.

In the Hareid Municipality a large fertilizer factory from the early 20th century was based on waste from the rich fisheries and was one of the largest in Norway. The energy for the factory was a steam unit with direct driven machinery based on waterpower. The growing price for coal during First World War and the years after made the steam engine uneconomic.

The mini hydropower plant in Storelva gave the owners an unreliable electricity supply and economic troubles. There were hard discussions with the municipality on taking on responsibility.

Quarrelling of private or public ownership of Storelva hydropower plant.

A water turbine that powered a dynamo of 18 kW was therefore installed. Combined with direct belt driven machinery the electricity met the factory`s energy needs and the need for electrical lighting and heating in houses for the family that owned the factory and some neighbours.

The factory used water from the Hareid River where the municipality in 1917 had acquired water fall rights and the right to regulate lakes. There were options for two power stations in a cascade and one in the centre of Hareid and close to the fertilizer factory. The difficult discussions in Hareid Municipality concerned whether to build upstream in the river (Nesset River) or close to the sea (Hareid River). Due to reduced grid expenditures the site close to the sea was chosen. The hydropower plant was financed by a local bank and inaugurated in 1919 with an expected capacity of 185 kW, but they reached only 150 kW due to low efficiency. An accident subsequently reduced the practicable capacity to 120 kW. Two lakes in the catchment area were regulated as reservoirs (6.3 mill. m^3) to ensure power generation in low flow periods. The fertilizer factory was an important customer and took 90 kW for their expansion. They would also benefit from the regulations upstream of their intake in the river, but their own 18 kW hydropower station lost water and operated only in high flow periods. The electricity deliveries by the municipality did not meet the quantum and quality required by the factory and discussions lasted for several years after the First World War. The discussions continued in the courts. The factory claimed compensation for low voltage and reduced production. For example, they had a customer in Germany that had ordered 2,000 sacks of fertilizer but received only 300 because of load shedding. Part of the story was that the municipality had promised more electrical capacity than they could expect to produce. The case was closed in 1932, 15 years after it started. In 1928 Hareid kommunale elektrisitetsverk (Hareid Municipal Electricity Company) owned two power plants and produced 120 kW and 29 kW in the Hareid and Brandal power plants, respectively.

There were two main customers, with 20 kW in Brandal and 118 kW in Hareid (the fertilizer factory) and 494 small customers. The demand for electricity showed that they could sell 200 kW. During the hard years after the First World War the municipal electricity company hardly had income to cover loans, operation, and maintenance costs. Unforeseen expenses in the grid system were especially difficult. They sold all they could produce but had no capacity to supply new customers. In 1930 a new 260 kW turbine was put into operation in Hareid River.

During the depression people had difficulties in paying the tariffs and many reduced their consumption and used other sources like wood and paraffin for heating and cooking. The electricity company were pushed by the bank to increase their tariffs, but the company feared that this would lead to less sales. It was discussed whether to reduce tariffs for household consumption and increase tariffs for industry. Finally, after four year of discussion the tariffs for household were reduced by 25 % in 1932. More customers could then afford to use electricity. The negative side was that the available generation capacity could not now meet the demand. The focus was again on the upperpart of the Hareid River which is called the Nesset River. An application for the construction of a plant with 500 kW was submitted and was presupposed to be financed by loan in Kommunalbanken (The Norwegian Agency for local Governments - a public bank). The license was given on the condition that Hareid Municipality cooperated with two neighbouring municipalities regarding costs and energy sharing. The cooperation failed and Hareid's difficult economic situation prevented further investments in capacity for some years.

In 1938 Hareid Municipality joined forces with five neighbouring municipalities and created a common public electricity company, Vestre Sunnmøre Kraftlag (VSK) with aim to develop a small hydropower plant in the Gjerdsvik River. However, WW2 stopped many of these plans. This cooperation was expanded to Søndre Sunnmøre Kraftlag (SSK) with focus on developing the Sørbrandal hydropower plant on another island and with a capacity of 7 MW.

The Nesset power plant was planned, financed, and built after WW2 and was in operation with 530 kW in late 1947. After this investment, the local isolated grids were connected, leading to enhanced electrification of new houses. The power plant Sørbrandal was completed in 1951.

Construction of the Gjerdsvika hydropower plant followed and was commissioned with 4 MW in 1954. The planning and construction by SSK and four local municipalities including Hareid. The financing was a mix of local public money and local industry that needed the power and loan in the Kommunalbanken and a subsidy from the State. Extremely good years for the fisheries after WW2 gave a boost to industrial development and development of new technology based on available electricity. The surplus electricity was soon taken.

The distribution of hydropower plants with capacity higher than 1 MW which are supported by the Tussa Power Plant with its large reservoir capacity is shown in the figure below. In addition, many mini- and micro hydropower plants (not shown) are in operation. Today they all feed the electric energy into a 22 kV distribution network. Most of the small schemes not owned by the electricity company have limited storage capacity and rely on the instant runoff for their generation capacity. They produce variable power; hence the customers are heavily dependent on flexible hydropower plants like the Tussa power plant to keep the frequency at desired standard. The Tussa hydropower plant is nicknamed the "argaste" power plant in the region, meaning that it is the most valuable (awesome, incredible) asset in the electricity system.

Existing hydropower plants with capacity 1 MW or more in the region.

Growing industry and growing public demand for electricity gave the Hareid Municipality headaches regarding the frequency and stability of power supply. This fed the arguments to join five other neighbouring municipalities in the early planning to harness electric energy from the Tussa waterfall in Hjørundfjord. They all participated in establishing Tussa Energi in November

1917. The preparatory work took three years. When sharing of expenditures was discussed the economic difficult decades between the First and the Second World War began, and this stopped further development of the Tussa waterfall.

Political Aspects

During WW2, NVE had the same objective to grant licenses as earlier. The organisation also had the power to set out conditions for State support, and through studies they saw the benefit of several municipalities putting their resources together for cooperation both for developing hydropower resources and building transmission and distribution lines. One prerequisite for license to develop the Sørbrandal and Gjersvik power plants was therefore that the municipalities in the region cooperated. Shortly after 1945 the L/L Søre Sunnmøre Kraftlag was created, owned by eight municipalities.

When Tussa Energi applied for development of the Tussa Project after WW2 they found it necessary to invite other local electricity companies to obtain a positive response on the application for development and the application for a State loan. However, the merging of all the different local electricity companies went on for 20 years.

Project Organisation

The public power company Tussa Energi (called Tussa Kraft then) was established in 1919 to develop the Tysse waterfall in Hjørungfjord. The company was owned by municipalities in the region, but due to hard economic times after the First World War some of them sold their share of the water rights to a local bank. In the last decade before WW2 the municipalities had their water rights on paper but had neither the competence nor the money to start construction of the large Tysse fall.

Ørsta and Ulstein Municipalities had sufficient power supply from their own small plants. Hareid Municipality had plans for developing more small plants locally. Herøy and Hjørungfjord Municipalities had limited electric supply, but no resources to develop the Tussa scheme alone. Other neighbour municipalities as Sykkylven, Vartdal and Volda had their own small plans. Sande, Syvde and Vanylven Municipalities had purchased the right to develop hydropower in the South Brandal River but lacked economic resources.

On the other hand, the politicians knew that without electricity they could not develop modern workshops and factories and would have to face that after education people would move to municipalities with potential for growth.

The power company L/L Søre Sunnmøre Kraftlag was established in 1946 and originates from the experience of many municipalities and their endeavour to electrify villages, farms, and industry to increase living standards. The company was founded to develop the energy resources in the Brandal River in South Brandal, the Gjerdsvika River and connect local low voltage distribution lines on isolated grid to a more powerful transmission line based on the 9.5 MW Sørbrandal and the 4 MW Gjerdsvika power plants. Prior to these two plants many mini and micro hydropower plants were in operation in small and large rivers. In addition, small diesel units in the valleys and on islands also generated electricity to small workshops and public supply.

The economic growth in the region pushed by rich fisheries soon consumed all the new power and in 1956 there was no more surplus power and no more local water falls with appropriate size that could be developed for electricity generation.

Four municipalities (Hjørundfjord, Vartdal, Ørsta and Volda) re-established Tussa Energi in 1946 and in 1956 L/L Søre Sunnmøre Kraftlag, the Sykkylven Municipality and Møre and Romsdal County were invited to join. Eight municipalities owned L/L Søre Sunnmøre Kraftlag and now 13 municipalities and the Møre and Romsdal County would own Tussa Energi. The target for Tussa Energi was to develop hydropower resources and upgrade and extend distribution and transmission lines to meet all electricity needs in the 13 cooperating municipalities. Parallel to plan the development of the Tysse River in 1961 they also planned the development of the Åmela River. The application for license was submitted in 1969. The permission was given in 1973 and the 34 MW Åmela hydropower plant with reservoirs was inaugurated in 1977.

Economic and Technical Aspects

The first construction stage of the Tussa hydropower plant was planned, constructed, and commissioned in the period 1957-1961. This stage included the underground power station with two Pelton units. The waterway with tailrace tunnel (750 m) from the power station, pressure shaft with lining (860 m), headrace pressure tunnel (1,740 m) and reservoir in Lake Tyssevatn. The reservoir was obtained by underground blasting and lake tapping. This was one of the first in Norway and the tunnel intake was 50 m under original water level. The catchment area is 22.5 km^2 and the mean annual runoff is 75.5 mill m^3.

The two Swiss made Pelton turbines, brought to Norway during the war for use in a high head scheme south in Norway were purchased from the State. The plan was to put one in operation and wait with the second. This would be enough with the available water from the first development stage. A turbine needs a generator for electricity generation and the Norwegian manufacturer National Industri offered a very favourable price for the generators but had never built a generator of this size. In the conditions for the license, NVE had written that Norwegian industry should be preferred if they could compete by not more that 10 % extra compared to other bids. Tussa Energi wanted to support the building of competence in Norwegian industry and the result was to purchase two generators, and one of them from National Industri.

This prompted the decision on a second stage that followed shortly after (1961-1964). This included diversion tunnels to neighbour rivers and streams to expand the catchment area. The diversion tunnel to Lake Blåvatn was carried out during the construction of the Tussa power plant, and the diversion tunnels to the nine other intakes were implemented during the construction of the dam on Lake Tyssevatn. These tunnels totalled 14.77 km.

To cater for the increased inflow a dam was built on Lake Tyssevatn, which increased the reservoir capacity and made the operation of the power plant more flexible. The work was completed in 1964 after delays with the rock filled dam du to constraints finding enough good moraine for the core. After the second stage the catchment area was 55.5 km^2 and mean annual runoff was 189.5 mill m^3. The total reservoir capacity is around 125 mill m^3, and 85 % is in the LakeTyssevatn. The direct intake in the main reservoir and outlet in the sea, makes the Tussa power plant extremely flexible.

Later upgrading of the electro and mechanical equipment was done around 1995 and in 2016 an innovative upgrading started with new Pelton runners with state-of-the-art technology that increased the capacity and resulted in upgrading of the generators. The power station is fully digitalised to enhance maximum flexible operation with best efficiency to be a powerful player in the electricity market.

The power plant has a relatively large reservoir capacity. See data in the table below.

Reservoir	Natural level (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Capacity (Mm^3)
Tyssevatn	636	656	610	107
Blåvatn	689	689	669	4
Store Skipedalsvatn	753	758	733	13.6
Sum				124.6

NVE's Database gives no figures for Blåvatn, but it is regulated by lake tapping. The capacity is estimated. Although this is not precise, it is assumed that the table gives a reasonable idea of the respective reservoir capacities.

The reservoirs were established by construction of a rockfill dam with a moraine core and one part with massive concrete. Lake tapping then enables utilization of a volume below the natural water level.

Project Financing

In 1919, after WW1 the five municipalities, Hjørundfjord, Hareid, Herøy, Ulstein and Ørsta established Tussa Energi to harness the rich energy resources in the Tysse River. Land and the water rights for the scheme were purchased with funds from their own resources, a loan in a local bank. An agreement with the six landowners stated that part of the sum should be paid when the development started. In the meantime, the agreed interest for the remaining sum should be paid monthly.

A decade after the establishment of the power company nothing had been done, but interest on the loan was difficult to pay because of general hard economic constraints. Both the bank and the six landowners feared for their money. The five municipalities had paid differently and this mix of unforeseen economic development, which seriously affected the five municipalities' ability to pay and the demand from the bank and landowners resulted in solution in the Court. It all ended with enforced sale and the local bank, Hjørundfjord Sparebank, took over the ownership of the river rights and necessary land in 1938. The bank applied to NVE for a license for development, but the application was refused.

The first 20 years ended with nothing, and the next decade passed before a new municipal controlled Tussa Energi was founded. An additional 20 years passed before the Tussa hydropower plant could produce electricity. This was a lead time of approximately 50 years. These 50 years included the Second World War, the hard economic period in the 1920s and the 1930s. However, it was also 50 years with many small hydropower developments that to a large extent catered for the electricity needs and secured economic prosperity in some of the municipalities.

In 1948 the four municipalities Vartdal, Ørsta, Hjørungfjord and Volda created Tussa Energi as a shareholder company where the owners were responsible for invested capital only. This was based on the experiences on the previous cooperation model after WW1 that dramatically failed. To purchase the water rights and the necessary land from the local bank and landowners and finance the development costs, Tussa Energi needed both bank loans and State support. NVE set a condition for State support that the municipalities should cooperate so that that development was beneficial for the entire region.

Before Tussa Energi could commence development there was a need for more customers for marketing of the large electric energy potential. This meant construction of transmission lines to supply the new customers.

The construction of the first stage of the scheme was estimated at 25.3 mill NOK (1956) and included necessary transmission lines to customers. 10 mill NOK was from own means and 15 mill NOK was a loan. The construction of the second stage was planned during the first stage and included diversion tunnels to eight intakes in small streams and two reservoirs by lake tapping. Tussa Energi took up an additional loan of 20.5 mill NOK to achieve this.

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10 The KØN Hydropower Scheme (1958-1965)

Highlights

- Cooperation for sharing reservoirs between two countries
- Cooperation between a State power utility and a local public power company
- Hydropower operation to enhance local farmers ability to earn money from tourist salmon fishing
- Small power plants and single transmission lines for rural electrification were replaced by larger hydropower plants and an improved public grid
- Reservoir development serving downstream run-of-the-river hydropower plants
- An example of compensation for impounded land and resettlement
- License obligations supported Norwegian manufacturing companies
- Financing provided by Norwegian, Swedish and World Bank lenders

Project Information

The hydropower scheme Øvre (Upper) Namsen (KØN) is in the Namsen and Linvasselva watercourses in Lierne, Røyrvik and Namsskogan municipalities, Trøndelag County[1]. The hydropower scheme is about 200 km north of Trondheim, Norway's third largest city. The Namsen River originates from mountains areas in mid-Norway and runs southwards and westwards to its mouth at Namsenfjorden (Namsen Fiord) near Namsos in Trøndelag. The catchment area borders on Sweden in the east and on Nordland County in the north. The adjacent Linvasselva watercourse borders on Sweden in the east and the Namsen catchment area in the north. The Linvasselva River flows into Lake Kvarnbergsvattnet in Sweden, which is close to the Norwegian border. From there the Ångermannselv River crosses Sweden eastwards to its outlet into the Baltic Sea.

Hydropower development in the upper part of the Namsen watercourse area followed the development of Nedre (Lower) Fiskumfoss hydropower plant in the lower part of the Namsen River (1946-1957).

<u>K</u>raftverkene i <u>Ø</u>vre <u>N</u>amsen, KØN ("The Power Plants in Upper Namsen") was established as c<u>o</u>-ownership on a 50-50 basis between NVE and Nord-Trøndelag Elektrisitesverk (NTE) in 1959. NVE represented the Norwegian State while NTE operated on behalf of Nord-Trøndelag County. The purpose was planning, implementation and operation of hydropower plants in the Upper Namsen.

The KØN hydropower scheme consisted originally of three cascade power plants and five reservoirs in Norway (Røyrvikfoss, Tunnsjø and Tunnsjødal). The development included in addition one power plant (Linvasselv) with its intake reservoir in Norway and power station and tailwater in Lake Kvarnbergsvattnet in Sweden. All four power plants were commissioned in the period 1962-1965. KØN owned 100 % of the three plants in Norway and had a partial ownership of the power plant in Sweden.

The Tunnsjøfoss hydropower plant was commissioned more than twenty years later and exploits the head between two existing reservoirs.

[1] Trøndelag County is a merging of the earlier Sør-Trøndelag and Nord-Trøndelag counties from 1 January 2018. KØN was in then Nord-Trøndelag County.

NTE was founded in 1919 and was 100 % owned by Nord-Trøndelag County until 2018. Since 2018 NTE is owned by the municipalities in the earlier Nord-Trøndelag County. NTE's "home supply area" was Nord-Trøndelag County, which borders on Nordland County in north. NTE's hydropower development has traditionally and almost 100 % taken place within the county.

Statkraft[2] was separated from NVE in 1986 after political debate for many years. NVE's share was then transferred to Statkraft. NTE bought Statkraft's share of KØN in 2004, and the power production was incorporated into NTE's operations.

The total present installed capacity in the four KØN power plants in Norway is 231.5 MW, with mean annual generation capacity of approximately 1,078 GWh. The four plants are 100 % owned by NTE Energi, which is a subsidiary company in NTE. The Linvasselv power plant in Sweden is owned by NTE Energi and Swedish interests. The power plants and data are listed in the table below. The power plants are in series, and the number (no.) shows the order from the uppermost to the lowest location.

No.	Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
1	Røyrvikfoss	16.6	69	28.5	89	1965
2	Tunnsjø	30.4	61	60	146	1963
4	Tunnsjøfoss	8.5	124.3	8	30	1986
5	Tunnsjødal	176	90	238	813	1963
	Total in Norway	231.5			1 078	

Data from NVE's Hydropower Database, December 2020.

The four units in the Tunnsjødal HPP were rehabilitated 1987-1990 with an increased capacity of 7 MW for each of them.

The Linvasselv power plant has these data:

No.	Name	Capacity	Discharge	Head	Generation	Commissioned
3	Linvasselv	73	77	107	200	1962

There is one Norwegian owned unit and one Swedish owned unit in the Linvasselv power plant. The units are 25 MW and 48 MW respectively, with mean annual generation of 42 GWh and 158 GWh.

There are also power plants in the lower section of the Namsen River. These plants are the run-of-the-river type, with only small intake ponds. Two of them were already constructed when KØN was developed and two have been constructed later. The KØN scheme influenced these plants positively due to the reservoirs and changed flow contribution over the year. All four are owned by NTE and are listed in the table below.

[2] The Norwegian name when included in NVE was NVE-Statskraftverkene (NVE-the State power utility).

No.	Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
6	Åsmulfoss	12	133	10	85	1971
7	Aunfoss	29.5	130	29	214	1959
8	Øvre Fiskumfoss	7.6	141	6.7	56	1976
9	Nedre Fiskumfoss	41.5	141	34.5	302	1946-1957
	Sum	90.6		80	657	

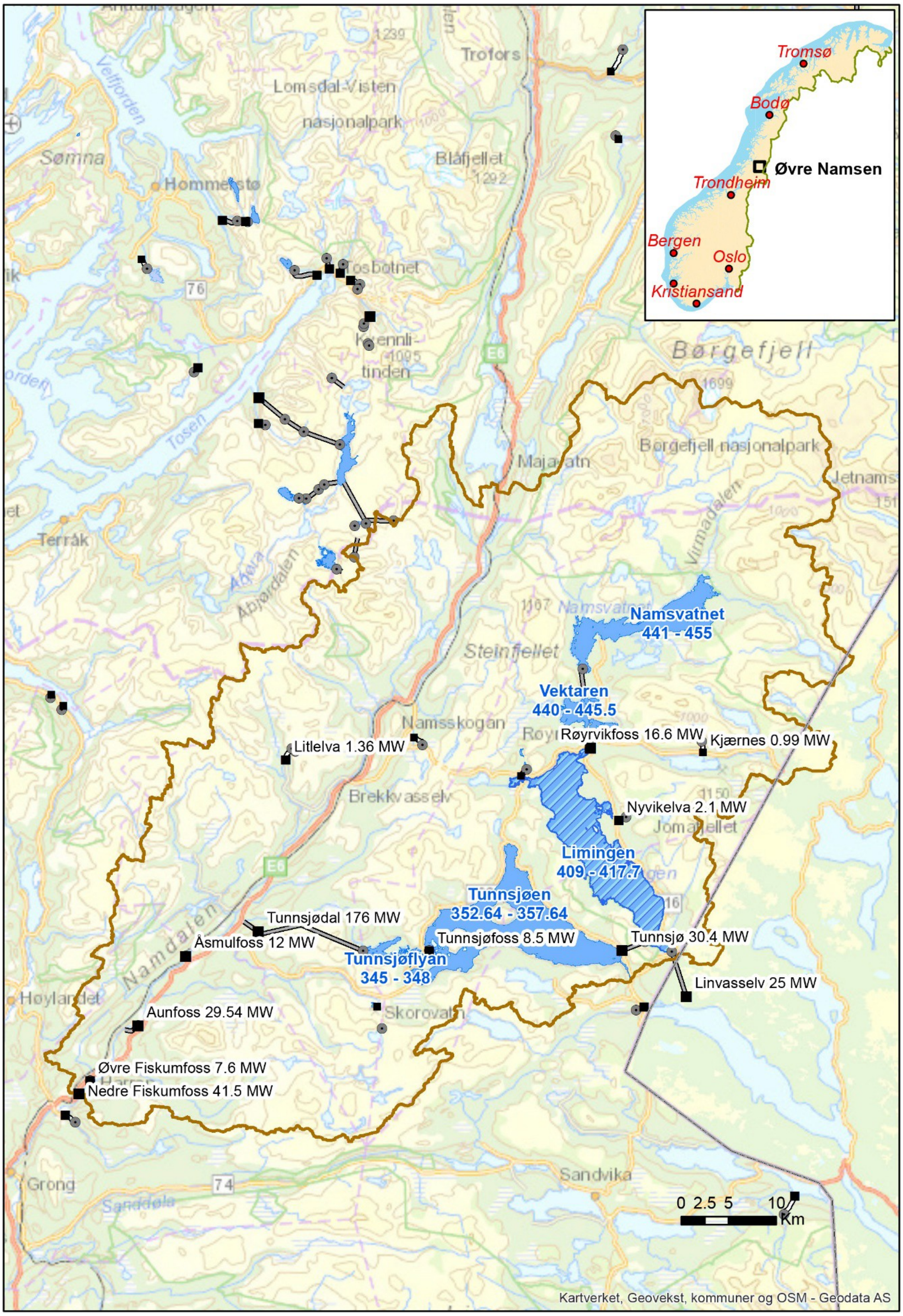
Data from NVE's Hydropower Database, December 2020.

This means that the present total capacity in the KØN scheme and the Lower Namsen is about 320 MW with a mean annual generation of more than 1,700 GWh.

The lower section of the Namsen River is important for salmon spawning and salmon fishing. The large reservoirs in Upper Namsen allow for flexible operation to serve electricity generation and to secure waterflow in the river to enhance the discharge during salmon fishing periods in the Lower Namsen River during the summer.

The KØN hydropower scheme includes five reservoirs. The series of reservoirs are, in order, the lakes Namsvatnet, Vektaren, Lyjmede (Limingen), Tunnsjø and Tunnsjøflyen. Namsvatnet, Tunnsjø and Tunnsjøflyen are in the Namsen watercourse while Vektaren and Limingen are in the Linvasselv watercourse. Water from the Upper Namsen is diverted by a dam at Lake Namsvatnet and led by tunnel to Lake Vektaren and further to Lake Limingen. Hence the KØN hydropower scheme "borrows" Lake Vektaren and Lake Limingen in the Linvasselv watercourse. Lake Limingen is intake reservoir for the Tunnsjø HPP in Norway (the Namsen watercourse) and the Linvasselv HPP in Sweden (the Linvasselv watercourse) and is important for the scheme. An overview of the connections between the reservoirs and the power plants is given in Economic and Technical Aspects.

A revision of the licensing provisions for the four granted regulations licenses has been in process since 2017, with an ongoing public hearing. The licenses were granted during the period 1942 to 1962. Notice of the revision was given by the three concerned municipalities in June 2013 and a decision to open the process was made by NVE in April 2017. NTE prepared a revision document as a basis for the public hearing. After the hearing NVE will evaluate the comments and submit their recommendations to the Ministry of Petroleum and Energy. Please refer to the Åbjøra hydropower project for a brief general introduction on the background for a revision.



The KØN hydropower scheme.

Project Background

The area of Nord-Trøndelag County was 22,400 km^2. The population in 1960 was approximately 116,000, spread over 48 municipalities, most of them predominantly rural.

NTE was responsible for hydropower supply in Nord-Trøndelag County, and it was essential to increase power production to meet the increasing demand. KØN was established in 1959 with this objective, with NVE and NTE as partners on behalf of the State and Nord-Trøndelag County.

In 1960 NTE owned four power plants with total capacity of about 105 MW. Two of them were in the lower part of the Namsen River. Beyond this there were several small private power plants in the county, and among them a few of the largest with a capacity of 2-3 MW. Shortly after the Second World War (WW2) there were many private small hydropower plants with a capacity from a few tens of kW and up to some hundred kW (micro and mini plants).The plants supplied farms, small craft enterprises, households, and schools in small societies via single transmission lines. The transmission system was strengthened during the 1950s, and more and more consumers were linked to the public supply. The micro and mini hydropower plants were closed by turns. This was a result of a national policy for rural electrification and took place all over the country.

NTE had implemented the Nedre Fiskumfoss and the Aunfoss hydropower plants in the lower section of the Namsen River during the period 1946-1959. Additional plants were considered, and one of them was commissioned in 1971. However, these power plants were run-of-the-river plants, even though reservoirs had been established in the Upper Namsen in the 1950s. There was a need for more production and higher reservoir capacity, and it was decided to exploit the resources in Upper Namsen.

In 1960 there were two reservoirs in Upper Namsen, the lakes Tunnsjøen and Namsvatnet. The regulation of Lake Tunnsjøen was established in the late 1940s and Lake Namsvatnet was regulated in the early 1950s. Both were authorized through licenses. The regulations were carried out to even out the water flow in Namsen River, and thus reduce the flood losses in the downstream power plants. The reservoir capacities are 458 Mm^3 and 440 Mm^3, respectively. Until the KØN development the water release from both reservoirs was based on the needs of the Nedre Fiskumfoss HPP and subsequently the Aunfoss HPP. The development of Upper Namsen was then advantageous for the plants in Lower Namsen because of reduced flood losses.

Political Aspects

There were two main political aspects, one national and one international. In a national context the implementation of the KØN hydropower scheme was a cooperation between the State represented by NVE and Nord-Trøndelag County, represented by the public power company NTE. The project was originally promoted by Nord-Trøndelag County. During the processing it was realised that the development was comprehensive and complicated and would most likely exceed the county's technical and economic ability. It was therefore concluded that it was better to leave the development to the State and the county in a cooperative venture. The Ministry, the NVE Board, other government agencies and the county were involved in the subsequent process.

Lake Namsvatnet is regulated 14 m and is the highest located reservoir in the scheme. The dam construction at Lake Namsvatnet started in 1948 and was completed in 1952. This impoundment was the first part of the thirty years of hydropower development in the Upper Namsen. Six farms were submerged, and the farmers were forced to find somewhere else to live. They were all offered farmland other places, with full compensation for clearing of new land. The authorities in

Upper Namdal secured acceptance for compensation standards and methods for the negotiations. This solution to the regulation of Lake Namsvatnet was achieved by the local council making determined efforts to secure the interests of the community. This approach set a possible solution for local authorities facing similar issues anywhere in the country.

For Namsvatnet is seems that there was a simple solution as regards compensation. It may be more difficult if the developer wants to acquire more comprehensive rights, which have been the case for many extensive hydropower developments. In such situations, an expropriation process and a judicial decision is a possible legal approach. This is a separate court which applies especially for decisions in matters which are a predominantly discretionary, for example the determination of compensation. The legal provisions for an expropriation process are set forth in detail in Norwegian legislation. However, expropriation is often a challenging and time-consuming process.

In an international context the KØN hydropower scheme includes a flexible cooperation between Norwegian and Swedish interests. The Namsen River is a major river with few lakes in its upper course. Only Lake Namsvatnet in the main watercourse and Lake Tunnsjøen in the tributary Tunnsjøelv are of any size. Lake Limingen in the adjacent Linvasselv watercourse would offer plentiful storage, but the lake drains to Sweden. Thus, the runoff could not just be diverted to the Namsen watercourse. The idea then came up, that using Lake Limingen for transferring water from Upper Namsen to Lake Tunnsjøen and even regulating Lake Limingen for storage would not infringe on Swedish interests. Sweden could even benefit by being allowed to use a part of the storage in Lake Limingen for regulating the runoff flowing to Sweden. The scheme was planned and agreed upon on this basis by both countries. The Linvasselv power plant in Sweden utilizes the natural runoff from Lake Limingen's catchment area, which is entirely in Norway. Another hydropower station, Tunnsjø hydropower station, exploits the head between Lake Limingen and Lake Tunnsjøen with a capacity equal to the runoff from Lake Namsvatnet and with the flexibility of the regulation of Lake Limingen. The bilateral agreement between Norway and Sweden includes terms and conditions both for operation of the reservoir in Lake Limingen and the sharing of the production in the jointly developed Linvasselv power plant. The export agreement was associated with the foreign loan and is a practical example of cooperation between two countries that gives a win-win situation.

Like many other hydropower licenses in Norway at that time and later on, there was a provision demanding that the licensee should preferably use Norwegian products and services for the construction works and operation. A precondition was that the Norwegian deliveries should be with a quality as good as foreign deliveries, on time and with prices which not exceeded foreign prices by more than 10 %. A premise was also that there were no conflicting interests. This clause was a national policy to raise Norwegian competence and was also supporting Norwegian supplier industry. Many large projects were in the pipeline, and hence there was a promising market for suppliers. Norwegian suppliers were competitive in the Norwegian market and were gradually awarded a considerable share of the contracts in the next decades. The provision was also stated in the license for the Orkla hydropower scheme around 1980. When the intensive development period decreased in the 1980s some suppliers tested the international market, and in particular the turbine supplier Kværner was awarded challenging contracts in other countries. The conclusion is that the clause was of great importance and the impression is that the provisions as far as possible were followed.

Project Organisation

NTE and NVE established a co-ownership, with each owner having 50 % of the shares for the generation component. NTE had the right, but not the duty, to utilize 50 % of the power. Each of the companies raised 50 % of the capital. The transmission component was entirely owned and financed by NVE.

The construction works were carried out by contractors and with supervision by NTE. NVE's Electrical Department were consultants for NTE concerning the electrical equipment.

According to the license conditions a significant part of the mechanical and electrical equipment was manufactured and installed by Norwegian suppliers. An exception was one Kaplan turbine from Sweden in the Røyrvikfoss power plant. There were deliveries of five units in the Tunnsjø HHP (1 unit, 30 MW) and the Tunnsjødal HPP (4 units, 37 MW each), all of them of the Francis type. These turbines and the generators were designed, constructed, and installed by the Norwegian suppliers Kværner and NEBB (Norsk Elektrisk & Brown Boveri), respectively. NEBB was incorporated in the multinational Swiss industry concern ABB (earlier Asea Brown Boveri) in 1988.

The Norwegian turbine suppliers had high competence with Pelton and Francis turbines, while Sweden had higher competence and experience on Kaplan turbines.

Economic and Technical Aspects

The power production in KØN's power plants in Upper Namsen was an important contribution in due time as to power supply in Nord-Trøndelag County and outside Nord-Trøndelag through the grid in mid-Norway. The present mean annual production is approximately 1,080 GWh, without the Linvasselv power plant.

The scheme was also advantageous for the already constructed Nedre Fiskumfoss and the Aunfoss hydropower plants in the lower sections of the Namsen River. It was estimated that the increased average annual production in the two power plants due to the development in the Upper Namsen was of the magnitude of 100 GWh. Then, KØN had a capacity of around 1,180 GWh.

There are also two plants which were constructed later, with a total mean annual production today of 140 GWh. It is not unlikely that KØN made these projects economically feasible. If so, additional 140 GWh can be credited to the development in Upper Namsen, which ends up with 1,320 GWh in direct and indirect production. If the two last power plants had been feasible without KØN, the gain would have been less. With a 25 % increase due to KØN, the increased production is about 30 GWh and KØN's contribution to the hydropower system is almost 1,200 GWh.

A crucial and remarkable part of the scheme was the diversion of water from Namsvatnet in the Namsen catchment area to Lake Vektaren in the Linfosselv watercourse. The Røyrvikfoss hydropower plant releases water from Lake Vektaren to Lake Limingen. Although water from Lake Limingen naturally flows to Lake Kvarnbergsvattnet in Sweden, a part of the reservoir is also utilized in the cascade of the KØN power plants on the Norwegian side. The Swedish part is the reservoir for the Linvasselv power plant with outlet at Kvarnbergsvattnet.

The main dam at Lake Namsvatnet consists of sections of different types of concrete dams, an arch dam, a slab dam and a gravity dam with a spillway. The dam length is 200 m and the maximum hight is 20 m and was operational in 1952.

The hydraulic connections between reservoirs and power plants are shown below.

Upper Reservoir	Lower reservoir	Connection	Watercourse
Namsvatnet	Vektaren	Transfer tunnel	From Namsen to Linvasselv
Vektaren	Limingen	Røyrvikfoss HPP	Linvasselv
Limingen	Kvarnbergsvattnet	Linvasselv HPP	Linvasselv
Limingen	Tunnsjøen	Tunnsjø HPP	From Linvasselv to Namsen
Tunnsjø	Tunnsjøflyen	Tunnsjøfoss HPP	Namsen
Tunnsjøflyen	Namsen River	Tunnsjødal HPP	Namsen

The reservoirs are shown in table below.

Reservoir	Natural level (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Capacity (Mm^3)
Namsvatnet	440	454	440	458
Vektaren	440	445.5	440	39
Limingen	417.7	417.7	409	790
Tunnsjøen	355.8	357.6	352.6	440
Tunnsjøflyen	345	348	345	13
Sum				1 740

Lake Kvarnbergsvattnet in Sweden is regulated between 313 m a.s.l. and 303 m a.s.l., with a regulation volume of 625 Mm^3. The regulation has been permanent since 1950.

A Swedish water regulation utility was awarded a license for a 6 m lowering (below natural water level) in Lake Limingen in 1952. NTE was granted a license for 2.7 m increased lowering in 1959. The same resolution licensed the right to transfer the runoff from Lake Namsvatnet to Lake Vektaren and further to Lake Limingen.

Hence there are two licenses for the reservoir in Lake Limingen. One is for Sweden for the release of water to the Linfosselv power plant. The other one is Norwegian license for release of water to the Tunnsjø power plant and Lake Tunnsjøen and finally to the Namsen River. This release is equal to the release of water from Lake Namsvatnet to Lake Vektaren. Hence, Lake Limingen is the reservoir for two power plants. The production in the Linvasselv power plant is distributed in accordance with runoff in the respective catchment areas.

The KØN scheme includes four power plants in Norway. A short description of each of them is given below. All of them are planned and constructed with traditional Norwegian solutions at that time. As to more specific technical solutions for the three plants from the 1960s one is referred to the book, Norwegian Hydropower Plants (see Sources). The indicative generation is lower than the present generation. This may for example be due to increased runoff, changed conditions, increased operation experience and different basis for the calculation of the generation.

The Røyrvikfoss power plant utilizes a 28.5 m head between Lake Vektaren and Lake Limingen and was commissioned in 1965. The plant consists of an intake, 800 m tunnel, a surge chamber, a short pressure shaft, a surface power station with one Kaplan turbine and a short tailrace to Lake Limingen.

The reservoir in Lake Limingen is divided between Sweden and Norway as follows:

Reservoir	Natural level (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Capacity (Mm^3)
In Norway	417.7	411.7	409.0	230
In Sweden	417.7	417.7	411.7	560
Sum				790

The Tunnsjø power plant with operation from 1963 harnesses a 60 m head between Lake Limingen and Lake Tunnsjøen. The plant consists of an intake and a 2,740 m supply tunnel to a surge chamber. From the surge chamber a short concrete lined pressure shaft leads the water down to the underground power station. From the power station the water passes through a short tunnel into Lake Tunnsjøen. There is one unit with a Francis turbine in the power station. The Tunnsjøfoss power plant was commissioned in 1986, with an 8 m head between the intake Tunnsjøen and the tailwater of the small Lake Tunnsjøflyen. The power station is constructed above ground.

The Tunnsjødal power plant is the largest and the lowest located power plant in the KØN hydropower scheme. The power plant utilizes the 238 m head between the small reservoir in Tunnsjøflyen and the outlet of the Namsen River. The Grøndal dam at the Tunnsjøflyen reservoir is a rockfill dam with a moraine core. Dam length: 200 m and maximum height: 17 m. The facilities were operational in 1963. The intake reservoir is small, but the power plant takes advantage of the large reservoir in Lake Tunnsjøen just upstream of the intake reservoir. From the intake a 10.9 km headrace tunnel leads to the surge chamber. Two pressure shafts with a 35° declination lead the water down to the underground power station. Each shaft supplies two Francis turbines, and the four turbines have the same capacity. The discharge is led to the Namsen River through a 2,100 m tailrace tunnel. The length of the access tunnel to the power station is 350 m.

When commissioned the Tunnsjødal power plant with upstream reservoirs delivered a large share of its annual production during the winter period. Then an increased winter production in the Nedre Fiskumfoss and Aunfoss power plants was achieved. The combined operation of the reservoirs enabled reduced flood loss, which gave an increased output in an average year of about 100 GWh in the then power plants in the Lower Namsen River. To distribute the power, the 300 kV transmission network was expanded more than 200 km to the regional load centre to the south. It also meant that the power could be utilized in a larger area and facilitated power exchange, i.e., exports. Compared to the Nea project the power export was less controversial. The budgeted generation and transmission components of the project costs amounted to 51 %3 and 49 % respectively.

Project Financing

The county raised 16 % of the capital as equity, while the remaining 84 % was provided by Kommunalbanken, KBN (Public bank for municipalities). The loan tenure was 30 years. The Ministry of Finance decided to increase the total allocation to KBN. On the other hand, the Norwegian State issued bonds in Sweden to raise capital.

KBN was established in 1927 with the objective to provide loans to municipalities with difficult economy. KBN is the main lender to municipalities, county municipalities, municipal associations, and inter-municipal companies and to other companies involved in municipal tasks. The bank is today 100 % owned by the State.

For NVE, about 59 % of the total financing was raised through the World Bank. However, the loan was not a direct project loan, but a loan to the Norwegian Government, which was relayed to NVE through the ordinary allocations.

An electricity fee on consumption was introduced in 1951 and was earmarked for the electricity sector. The fee applies to all electricity consumption either produced in Norway or imported and is paid to the Treasury. After most households had been electrified around 1960, about 50 % of the tax revenues were used for transmission lines for several years. This fee was used for financing the transmission infrastructure associated with the KØN project, but exact data are not available.

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[3] Including the 60 kV sub-transmission network between the power plants.

11 The Sira-Kvina Hydropower Scheme (1960-1988)

Highlights

- Almost 100 % debt financed, and more than 60 % of the debt was raised abroad
- Foreign exchange losses considerably increased financing costs
- Joint utilization of the hydropower potential in two neighbouring river basins
- Complicated connection of the two river basins
- Developed hydropower technology and competence through R&D project initiated by challenges in construction of tunnels and power station equipment
- Paved the way for industrial development
- Strengthened the national transmission backbone system and paved the way for cross-border power exchange
- Option for strong support of variable renewable energy technologies (VRE)
- Today, an example of digital operation of cascade systems

Project Information

The Sira-Kvina Hydropower Scheme utilizes the hydropower resources in the adjacent and parallel southbound Sira and Kvina watercourses. Both watercourses were early on considered promising for hydropower development.

The two river basins are in Agder County[1] in the south-western part of Norway, between Kristiansand in Agder County and Stavanger in Rogaland County. The Sira River has its sources in the Sirdal mountain range on the border area between Agder and Rogaland counties. The river flows through the Sirdal Valley and the long lakes, Sirdalsvatn and Lundevatn, to the mouth in the sea at Åna-Sira. The length of the river is 152 km.

The Kvina River with length 151 km originates from small sources north of Lake Roskreppfjorden and flows through mountainous areas and the Kvinesdal Valley to the mouth in the sea at Feda, near Flekkefjord.

The hydropower scheme consists of 7 hydropower plants with an installed capacity of 1,760 MW and a mean annual generation of 7,115 GWh. Natural lakes and the impounding possibilities have given considerable total reservoir capacity. The power plants are in the Sirdal, Kvinesdal and Flekkefjord municipalities and Agder County with exception for the Duge power plant, which is in the Sandnes Municipality, Rogaland County. The power plants are listed in the table below.

[1] Agder County is a merging of the earlier Aust-Agder and Vest-Agder counties from 1 January 2020. The watercourses in question were nearly 100% in Vest-Agder County.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Roskrepp	50	67	88	136	1979
Kvinen	80	77	120	259	1981
Solhom	200	110	215	810	1974
Duge	200	100	220	303	1979
Tjørhom	120	90	158	583	1973
Tonstad	960	253	442	4 357	1968
Åna- Sira	150	375	47	667	1971
Sum	1 760			7 115	

Data from NVE's Hydropower Database, December 2020.

The Duge and the Tjørhom power plants are in the upper part of the Sira watercourse, while the power plants Roskrepp, Kvinen and Solhom are in the Kvina watercourse. Duge is a pump storage power plant. The Tonstad and the Åna-Sira power plants are the two lowest located of the plants and utilize water from both rivers and are in the Sira watercourse. The total reservoir capacity is around 3,000 Mm^3 with an energy content of some 5,600 GWh. The Tonstad power plant is Norway's largest when ranked in mean annual generation.

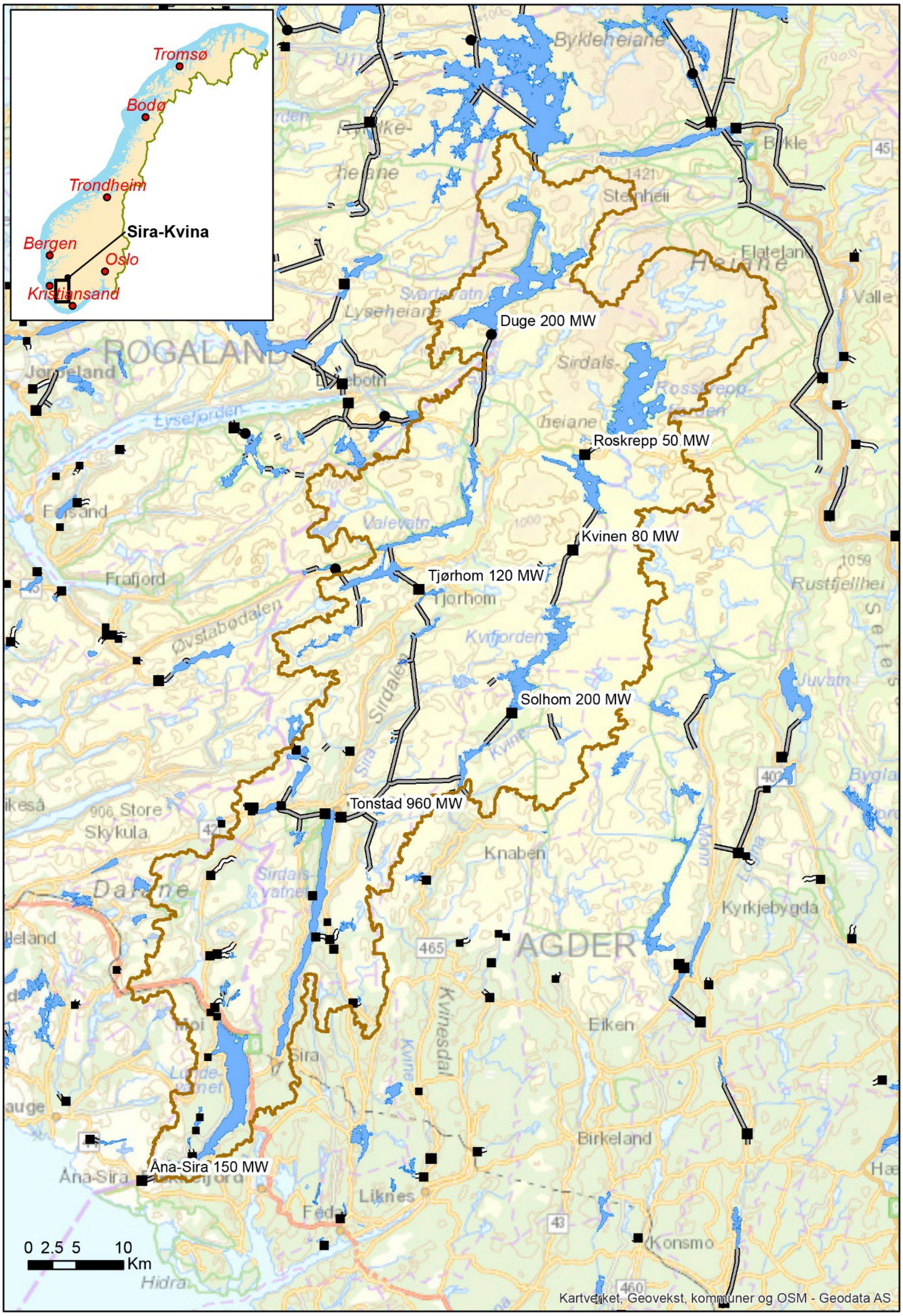
The first license was granted in July 1963 after three years with licensing procedures, and the construction started in the summer of 1963. Two additional licenses were granted in 1977 and 1978. The Tonstad power plant was the first and is also the largest of the plants and was inaugurated with two units of its totally five units in 1968. The Duge pumped storage plant with intake in the large Svartevatn reservoir was commissioned in 1976.

The owner is Sira-Kvina Kraftselskap (SKK), a Joint Venture (JV) of Lyse Produksjon AS (41.1 %), Skagerak Energi AS (14.6 %), Agder Energi Vannkraft (12.2 %) and Statkraft Energi AS (32.1 %). SKK was founded in 1963, and is organized as a DA. This means that each shareholder is responsible for SKK's liabilities corresponding to their respective equity shares.

The four original shareholders of the JV have subsequently been reorganized, merged, or unbundled. The Sira-Kvina Kraftselskap is still a JV of the original four participants, but the share distribution of the equity has changed due to transactions between the State Power Utility (NVE by then and now Statkraft Energi) which originally had 43.6 % of the shares, and two of the other shareholders. The transactions relate to other hydropower projects.

The original shareholders Vest-Agder Kraftselskap (VKA) and Skienfjordens Kommunale Kraftselskap (SKK) have been incorporated in the power companies Agder Energi Vannkraft and Skagerak Energi, respectively. The power company Lyse Produksjon has replaced the Stavanger Municipality as shareholder. Lyse's main office is in Stavanger in Rogaland County, not far from the power plants in Sira-Kvina. Lyse Produksjon has developed hydropower plants in Rogaland County since 1947.

A revision of the license provisions has been in progress for some years.



The Sira-Kvina Hydropower Scheme.

Project Background

The planning for a hydropower development of the Sira and Kvina watercourses originates at the beginning of the 20th century. In 1913 the Stavanger Municipality acquired the rights to harness most of the waterfalls in the Sira watercourse. Development plans were prepared during and after the end of the first World War. However, the plans were not followed up because it was decided to construct hydropower plants in the Lysefjorden (the Lyse fiord) area which is closer to Stavanger. In the inter-war period NVE prepared plans for the Kvina watercourse, but the Second World War (WW2) stopped further development.

After WW2 the State purchased a part of the water rights in the Kvina watercourse. Skienfjordens kommunale kraftselskap (SKK) bought also rights in the Kvina watercourse and Vest-Agder Kraftselskap (VAK) purchased most of the remaining water rights in the Sira watercourse. SKK and VAK were public owned power companies, and it was appropriate to cooperate on the preparation of a common development comprising both watercourses. The development of the Kvina and Sira watercourses would be a large hydropower scheme with several large hydropower plants in cascades and with options for large reservoirs. The water rights were held by two public power companies and a municipality in the southern part of Norway in addition to the State. The State focused on supplying large aluminium industry in the area while the three other parties focused on securing electricity supply of the public sector and local small-scale industry.

In the early 1950s the semi-official "Association for the Study on Norway´s Waterpower" presented a masterplan for the two watercourses as a separate or a combined development. The association was active for around twenty years and identified many of the large hydropower options in Norway. The archives and the staff were incorporated in NVE around 1970. At that time NVE included NVE-Statskraftverkene (the later Statkraft, from 1986) and a part of the staff started there with feasibility studies. Another part started in a new department in NVE which was responsible for annual reporting to the Ministry of Petroleum and Energy on Norway's hydropower resources. In 1981-1992 NVE was responsible for hydropower resource planning which was used in the large Masterplan for Watercourses in Norway organised by the Ministry of Environment. The work with annual reporting on hydropower resources is still going on, with focus on upgrading existing plants and identifying options for new plants.

The report from 1953 on the Sira-Kvina options concluded that the alternatives were equal as to hydropower potential, but that a common development would reduce the investment costs by 13 %. A joint development meant that 60 % of the water in the Kvina River basin would be transferred to the Sira River basin. In both cases several owners would be involved. An arbitration panel was appointed to assess each participant´s share in a future joint ownership. Based on these assessments a joint association between the four parties was established in 1957 with the purpose of preparing a plan and a license application, as well as implementing and operating the entire power complex. The ground had then been prepared for a rational planning and implementation process.

A series of studies resulted in two alternatives which were proposed to the owners, one for separate developments along the two rivers and one for combining them in one by transferring water from the Kvina River to the Sira watercourse. The choice between the two would be neutral with respect to ownership. A challenge, however, was the local community interests, since the locations of the power stations would be decisive for who would get the future tax income. Diplomacy solved the problem by an agreement among the communities on their respective share of the total taxes, independent of the alternative chosen. The owners then concluded on the combined solution.

Hydropower development of complex schemes has a long lead time and an adequate planning at an early stage on a scheme´s own merits cannot go deep into details. A plan at this stage far into the future may be futile, and likely to be overtaken, by technology changes as well as by changing external circumstances, long before it can be implemented. Among early watercourse plans prepared in Norway, only a few have been implemented something like that initially conceived.

However, with increased experience a stage will sooner or later be reached when expected demand growth does warrant a coordinated development within a reasonable time horizon. The planning process may then realistically focus on optimizing an entire power complex. Many possible combinations within the framework of the complex must be compared to come up with an optimal overall plan and an optimal staging of the elements over time. This stage was reached in Norway in the first decades after WW2. The Sira-Kvina hydropower scheme belongs to this category. The Tokke hydropower scheme is another example. A master plan is then the basis for the license application, which was the case for the Sira-Kvina hydropower scheme.

Political Aspects

When the license application was submitted in 1960 both alternatives were described, but it was applied only for the combined alternative. This implied that 60 % of the water flow in the Kvina River was transferred to the Sira watercourse for utilization in the Tonstad power station with a head of around 440 m and further through a head of near 50 m in the Åna-Sira power plant.

The license was awarded in accordance with the applied alternative in July 1963, and the Joint Venture Sira-Kvina Kraftselskap (SKK) with four parties was founded in October 1963. The parties were the State represented by NVE 43.6 %, a so-called Rogaland group (Stavanger Municipality, Lyse Kraftverk and another power company) with 32.9 %, Vest-Agder Kraftselskap with 12.2 % and finally Skiensfjorden Kommunale Kraftselskap with 11.3 %.

The three regional participants' motivations to develop the two river basins was mainly associated with meeting the demand in their respective supply areas. On the other hand, the State Power Utility also wanted to facilitate industrial development. In 1971, an aluminium smelter was commissioned at Lista far south in Norway, currently with a production capacity on extrusion billet and foundry alloys of 94,000 million tons per year (mtpy). In 1974, a manganese smelting plant was established, currently with an annual output of 18,000 tonnes of silicomanganese produced in three 30 MW smelting furnaces. Both smelting plants are in the region.

The Sira-Kvina development secured electric supply to both regional public and industrial needs. The large hydropower plants and the large reservoirs provides an option for further development of weekly peaking capacity to serve the power system when large quantities of variable renewable electric energy are fed into the grid system in the coming years. The scheme is also located strategically close to sea cables connecting Norway to Europe. Redesigning of the Tonstad power plant is considered with capacities many times higher than the capacity in the present plant. This kind of development, however, has both political, financial, technical, and environmental issues.

The development also adds income to earmarked business funds in the concerned municipalities. The funds have enabled grants and loans for the establishment of industry, agriculture, and infrastructure. In the Sirdal Municipality the incomes also have been invested, among other purposes, in schools and health institutions, beyond what otherwise would have been possible.

Project Organisation

The location of the JV's main office was discussed. Until the planning phase the work had been led from offices in the capital Oslo and this location was also suggested for the new main office. Kristiansand and Stavanger were also proposed. It was looked upon as a compromise when it was decided to establish the main office in Tonstad in Sirdal, in 1966. However, the decision has later shown to be a good solution. During both the construction period and the later operation period it has been favourable that the entire organisation was gathered near the operation sites. This proximity provided the organisation with better local knowledge and increased local competence. This competence created a breeding ground for establishment of local workshops also serving offshore industry. An example is the development of Norhard rock drilling company specialized in drilling pressure tunnels and shafts for small hydropower plants.

With exception for the largest dams, all main planning and designs were carried out at Tonstad. The use of landscape architects and the cooperation with NVE's Nature and Landscape Department has contributed to good environmental solutions. During the construction period around 5 Mm^3 rock in tunnels, shafts and power stations was excavated. A large share of this was used in the dam and road construction, and the remaining masses were deposited in the terrain with a best possible design.

The project design was undertaken by a separate project implementation unit, which was managed by NVE. Most of the equipment, such as turbines, generators, and transformers, was manufactured in Norway and the construction works were undertaken by Norwegian contractors.

The implementation was carried out in six stages between 1963 and 1989. The approach in stages reduced the financial stress on the power company (and the owners), balanced increased supply with demand growth and enabled optimal use of the work force. The cost per kWh was low. All stages with exception for some minor exceedances in stage 4 were implemented in accordance with the budgets.

Economic and Technical Aspects

In order to transmit the power, 300 kV transmission lines were constructed. These lines contributed to expansion and strengthening of the national transmission backbone system. Indirectly, the project paved the way for the Skagerak HVDC link between Norway and Denmark in 1974.

A comprehensive complex of power plants and reservoirs were developed. The table below shows the connections between the power stations and the reservoirs.

Power station	Upstream reservoir	Downstream reservoir
Roskrepp	Roskreppfjorden	Øyarvatn
Kvinen	Øyarvatn	Kvifjorden-Nesjen
Solhom	Kvifjorden-Nesjen	Homstølvatn
Duge	Svartevatn	Gravatn
Tjørhom	Gravatn	Tjørhomvatn
Tonstad	Homstølvatn and Ousdalsvatn	Sirdalsvatn/Lundevatn
Åna- Sira	Sirdalsvatn/Lundevatn	Åna (sea level)

The reservoirs are listed in the table below. The data are from SKK's web-side.

Reservoir	Natural level (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Capacity (Mm^3)
Roskreppfjorden	894	929	890	684
Øyarvatn	820	837	820	104
Kvifjorden-Nesjen	677	715	677	274
Svartevatn	780	899	780	1 398
Gravatn	628	660	625	351
Tjørhomvatn	492	497.6	492	3
Ousdalsvatn	482	497.6	482	12
Homstølvatn	482	497.6	471	55
Sirdalsvatn/Lundevatn	46.2	48.5	44	161
Sum				3 042

As seen, most of the reservoir capacity is created through dam construction and thereby impounding. The total capacity is large, 3,042 Mm^3. This gives an option for energy storage of approximately 5,600 GWh.

The management of the works over almost three decades is an impressive achievement. Like other large hydropower projects, also the Sira-Kvina hydropower scheme contributed to confirm the Norwegian competency in hydropower development regarding planning, construction, manufacturing of equipment and operation of power plants. The hydropower scheme is remarkable, with its power stations, the headrace and tailrace tunnels, reservoirs, diversion tunnels and shafts, dams, and its organisational aspects. It would be too much to describe all elements of the scheme. Thus, attention is given to a rough outline of the scheme and a few constructions. These constructions are the Tonstad power plant and the Duge pumped storage power plant with the large dam and reservoir at Svartevatn. The numerous rockfill dams of various heights, lengths and infilled dam masses and the many kilometres of tunnels are also remarkable.

All seven power stations are located underground, with units from one and up to five. In total there are sixteen units, all of them with Francis turbines, including the two reversible turbines in the Duge pumped storage power plant. The excavation of headrace and tailrace tunnels comprises many tens of kilometres. Some of the waterways were objects for research and development involving the Norwegian University of Science and Technology (NTNU) in Trondheim for design of surge chambers and solving complicated oscillations through thorough analysis.

The two watercourses are developed separately in their upper sections and are joined in the Tonstad power plant with outlet at the north end of the Sirdalsvatn/Lundevatn reservoir. There are limited reservoir possibilities in the optimal location of the interconnection. Therefore, two communicating intake reservoirs, Homstølvatn in the Kvina branch and Ousdalsvatn in the Sira branch were planned. In fact, finally there were three communicating reservoirs since Tjørholmvatn is located a relatively short distance upstream of Ousdalsvatn, and with the same HWRL. These reservoirs are rather small, with volumes of 55 Mm^3 in the Kvina side and 15 Mm^3 together in the Sira side.

The two tunnels with length 18 km from Ousdalsvatn and 7.6 km from Homstølvatn meet in a headrace tunnel. This tunnel is 5.8 km from the confluence to the surge chamber above the Tonstad power station. Since the minimum water levels in the Homstølvatn and Ousdalsvatn reservoirs differ by 11 m, the design implies a complex operating procedure as well as complicated oscillations. These circumstances required thorough analyses in the design phase.

The construction of the Tonstad power plant was the most pressing task in stage 1, with water from the Kvina branch. In this stage two inclined shafts with length 660 m and diameter 3.6 m down to the power station were excavated. Both shafts are steel lined. The power plant was commissioned in 1968 with two units, each of them with a capacity of 160 MW. In the next stage the tunnel system from Sira were completed which resulted in more inflow to Tonstad. Then two additional units of the same size as those in 1968 were ready for operation in 1971.
The first vertical Francis turbines in Tonstad were the largest manufactured and installed in Norway at that time. The 195 MVA generators were the first in Norway with water cooling in hollow windings for the rotor as well as the stator.

In stage 6, in 1985, the erection of a unit number five with a capacity of 320 MW was initiated, and with completion in 1988. A new cavern was excavated for the new unit and an additional pressure shaft with diameter 4.8 m was also established. The new unit was the largest in Norway at that time. Although the total capacity in the power station was increased by 50 % the generation was not significantly increased. The argument was that the higher capacity enabled more generation in periods with high energy prices. This was also the argument when the capacity in the downstream Åna-Sira power plant was enlarged correspondingly, from two to three units in 1989, which will say from 100 MW to 150 MW. Near twenty years later S-KK prepared plans for an even larger capacity in Tonstad. In 2007 a doubling of the capacity, with two 480 MW units with reversible Francis turbines, was applied for. Tonstad was then suggested as a part pump storage power plant. However, in 2011 SKK cancelled the license application.

The Duge pumped storage plant was commissioned in 1979 and utilizes a mean head of 220 m between the Svartevatn and the Gravatn reservoirs. Duge was the first pump storage power plant in Norway, with two vertical Francis turbines designed as reversible pump turbines. Each turbine is 100 MW in the generation modus. The Duge power plant is the only plant with reversible turbines in the Sira-Kvina hydropower scheme. The turbines are installed for the purpose of generating power, but also for the filling of the Svartevatn reservoir. The mean annual natural inflow is only 600 Mm^3 while the reservoir capacity is close to 1,400 Mm^3. There are intakes at two levels in the reservoir. This is due to the large regulation height of 119 m and the use of the reversible turbines. The power station is located underground with a 1,400 m long access tunnel. A 12 km tunnel leads the water to the outlet at the Gravatn reservoir.

The Duge power plant is a good example of typical use of pump storage in the Norwegian energy system ; to enhance storage by transferring water from a lower catchment area to a particularly large reservoir at a higher elevation. In periods with low electricity prices and unfilled volume in the upstream reservoir, water is pumped through the long tailrace tunnel and up to the Svartevatn reservoir. The pumping occurs mainly in spring and autumn and at weekends in summer. There are often large price differences from year to year, and the reservoir situation also varies. Hence, the use of pumping is not regular.

The Svartevatn dam is a rockfill dam with moraine core. The dam length is 420 m, and the maximum height is 130 m, creating the Svartevatn reservoir with a regulation between 899 and 780 m a.s.l. A mass volume of 4.7 Mm^3 was needed for the dam construction. The dam was ranked as the largest in northern Europe when completed in 1976. Preparatory works started in 1972, and the construction works were carried out over the next four summers with an effective construction season less than 20 weeks a year due to rough weather conditions. The dam is constructed in a narrow U-shaped gorge with gneiss bedrock. Although an arch dam would have a considerably lower cost, the dam was constructed as a rockfill dam due to security reasons in case of sabotage or acts of war. A warning system was installed in case of dam failure. The Norwegian Geotechnical Institute (NGI) was consulting engineer and specified a comprehensive system of monitoring instruments for use during both construction and operation. This has been valuable for research and later dam projects. Because of new dam regulation, the dam was rehabilitated in 2012-2015. Svartevatn Dam is shown on the report's front page.

The reservoir capacity is more than twice the mean annual runoff from the local catchment area. Hence, without pumping it will take more than two years to fill up an empty reservoir. This means that the reservoir makes up a multi-year regulation and that a filled reservoir can cover several years of low flow. The reservoir content can be utilized through four power stations with a summarized head of around 870 m. The energy content of the filled reservoir is approximately 2,900 GWh.

Roskreppfjorden is the next largest reservoir in the scheme. This reservoir is the uppermost in the Kvina branch and is regulated between 929 and 890 m a.s.l. which creates a volume of 684 Mm^3. The energy content of the filled reservoir is approximately 1,500 GWh. A rough estimate implies that the reservoir capacity is of the same size as the mean annual inflow. The reservoir content can be utilized through five power stations with a summarized head of around 900 m. There are three rockfill dams with moraine core at Roskreppfjorden, one main dam and two relatively small secondary dams. The main dam with a length of 360 m and a maximum height of 48 m has an infilled volume of 560,000 m^3. All three dams were constructed in the period 1966-1968 and were rehabilitated from 2004 to 2006.

The dams at Svartevatn and Roskreppfjorden are not the only ones in the SKK's hydropower scheme. In fact, there are several dams, mainly rockfill dams. Together there are fifteen rockfill dams (main dams and secondary dams) and two concrete dams. The total length of the rockfill dams is around 4,300 m, with a mass volume of about 9 Mm^3. The concrete dams are the Kilen arch dam at Gravatn and a gravity dam at Øyarvatn. The Kilen arch dam has a crown length of 170 m and a maximum height of 37 m.

Most of the dams were constructed in the period 1966 to 1970, with an exception for the Svartevatn Dam (1973-1976) and the gravity dam at Øyarvatn around 1980. Hence, the years from 1966 to 1970 was an intensive dam construction period as to the number of dams.
The construction costs for the power stations with the connected waterways made up for more than the half of the total project costs. The contribution of the incurred project costs was as follows:

Cost bearer	Share in %
Power stations and waterways	56
Dams and reservoirs Sira	14
Interests and borrowing costs	12
Common auxiliary facilities	4.5
Dams and reservoirs Kvina	4
Miscellaneous facilities	4
Planning and administration	3.5
Acquisitions and valuation cases	2

Project Financing

Initially the company's equity consisted of the values of the rights which had been acquired by the owners. Compared with the total investment this value was almost insignificant. Except for the investments in water rights, the project was 100 % debt financed.

The capital was raised by the power companies with guarantees from the owners. Since also NVE's investment was financed through the Joint Venture, the SKK project did not burden the State budget. On the other hand, the transmission lines were financed over the State budget.

The debt capital demand exceeded the capacity of the Norwegian loan market at that time. When the license was granted, it was therefore a prerequisite that the predominantly share of the financing of the first stages was depending on foreign loans. Initially the possibilities in the World Bank were examined. However, this failed and then the so-called Eurodollar market emerged. The first loan was taken out in USD in Hambros Bank in London. Gradually the company took out more loans in this market, in USD, DEM (German currency) and CHF (Swiss currency). Later the foreign loans were provided through Kommunalbanken (KBN)[2]. The last loans were provided by Norwegian lending institutions. 68 % of the debt capital was raised in foreign currencies. In average, the loan tenure was seventeen years. The distribution of the debt financing (1965-1987) of the Sira-Kvina hydropower scheme is listed in the table below.

Currency	Share in %
NOK (Norway)	32.0
DEM (Germany	25.3
USD (USA)	22.7
CHF (Switzerland)	12.1
JPY (Japan)	2.9
NGL (The Netherlands)	2.6
EUA	2.4

Due to exchange losses, the loans became about 20 % more costly than originally assumed. The last loan was finally repaid in 2010.

Initially it was urgent to provide loans for stage 1. The three loans were secured with collaterals in the Joint Venture (JV). The JV shareholders agreed to enter into a power purchase agreement with the JV at a price that would cover all costs. Due to other State loans, the Central Government (the owner of NVE) did not provide collaterals. However, NVE guaranteed their financial responsibility for surplus power if any of the three regional shareholders could not afford to fully pay for their share of power. In practice, this was an indirect State guarantee.

The first loan (36 %) was provided by Hambros Bank. This was an annuity loan with a five-year deductible period and thereafter a fifteen-year repayment period. However, the loan did not cover all costs for stage 1 and then a guarantee for the completion was required. The loan decision was declared valid through a Royal Decree in January 1965, and the construction work could start.

The next loan (21 %) for stage 1 was provided in February 1967 through an agreement with Hambros Bank and Stockholms Enskilda Bank (Swedish). The loan was granted with an interest of 6.75 % and a two-year deductible period and thereafter an eight-year repayment period. For the fulfilment of stage 1 a loan (43 %) was provided in August 1968. The lender was a guarantee consortium with Den norske Creditbank (Norwegian) in the lead. The loan had a duration of eighteen years with an initial four-year deductible period and an interest of 5.5 %.

[2] KBN is an important lender to municipals and other public governance institutions. See also the Skogfoss Hydropower Plant.

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12 The Lærdal Hydropower Scheme (1960-1988)

Highlights

- A county (Østfold) with limited available energy resources within or near the mandatory supply areas
- Few publicly owned power plants in the county but some large private plants
- Ownership of public power and distribution companies through municipalities and not through the county
- The municipal distribution companies were dependent on purchasing power from private companies or the State for their supply commitments
- Power purchase versus developing own power plants – or both – for future supply
- Close internal cooperation between the county and a private industry and power company
- Examination of possibilities for hydropower development in other counties
- Development of a hydropower project in a county (Sogn og Fjordane) relatively far away from their home county
- Cooperation between the developing county and the local municipality in the host county
- Taking care of an important salmon river when implementing the hydropower scheme
- Example of transferring a power plant from the developer to the host municipality
- Transmission network controversy

Project Information

The national electricity market in Norway was introduced in 1991. Before 1991 it was compulsory for distribution companies to cover the electricity demand within their supply areas. Østfold County had few options in their own county because almost all large hydropower resources were developed and owned by private interests. Østfold County therefore had to look for hydropower options in other counties for developing its own power plants for public supply.

This example from the 1960s and the 1970s describes how the then Østfold County[1] in southeast Norway secured their own energy supply by the development of the Lærdal hydropower scheme in the western part of Norway. The Lærdal watercourse had large unexploited hydropower resources, and the combination of public power demand in Østfold and the resources resulted in the Lærdal hydropower scheme. The Lærdal watercourse is around 400 km from Østfold County by road and the power needed to be transferred almost 300 km.

The Lærdal hydropower scheme is in the Lærdal watercourse in the Lærdal Municipality, Vestland County[2] in Western Norway. The essential part of the scheme was constructed in the early 1970s. The project area is south of Sognefjorden, which is Norway's longest fiord, with length around 200 km from the coast in west to mountainous areas in the east, and with several fiord arms. The development of the Lærdal hydropower scheme was not primarily trigged by local interests, but by the then Østfold County.

[1] Østfold County was merged with Akershus and Buskerud counties to Viken County in South-East Norway 1 January 2020.

[2] Vestland County in Western Norway is a merger of the earlier Sogn og Fjordane and Hordaland counties from 1 January 2020. The Lærdal hydropower scheme was in Sogn og Fjordane County.

The upper parts of the Lærdal watercourse consist of the two rivers Mørkedøla and Smeddøla with their tributaries. The Mørkedøla River has its origin in the lake, Eldrevatn, at elevation around 1,100 m a.s.l. and flows north-westwards through the steep valley Mørkedalen. Mørkedøla joins the Smeddøla River at around 475 m a.s.l. at Borlaug. The lower part of the Smeddøla River flows south-westwards. From the confluence the river is called Lærdalselvi, which flows around 35 km mainly westwards to the sea at the municipal centre of Lærdalsøyri. The catchment area to the outlet in the fiord is 1,184 km^2 and the mean water flow is 36.3 m^3/s.

The Smeddøla River was included in the national Protection Plan I (Verneplan I) in 1973 and hence its hydropower potential was not exploited. The development of the Lærdal watercourse was thus restricted to the Mørkedøla and the Lærdalselvi rivers, with one exception. The lake, Sulevatn in the tributary Oddedøla River of the protected Smeddøla River is regulated and a diversion facility downstream of the reservoir transfers the water to the Mørkedøla catchment. The map below also shows three other protected areas (included in Protection Plan II/1980 and III/1986) bordering to the Lærdal catchment area. Hence, there are four protected areas in the same mountainous area, in the upper parts of three main watercourses. The protected catchment areas are located in four municipalities in three counties. The total area is 601 km^2, between 1,819 and 470 m a.s.l. This is a result over many years of assessments of national and local values of pristine landscape and environment versus the need for hydropower development.

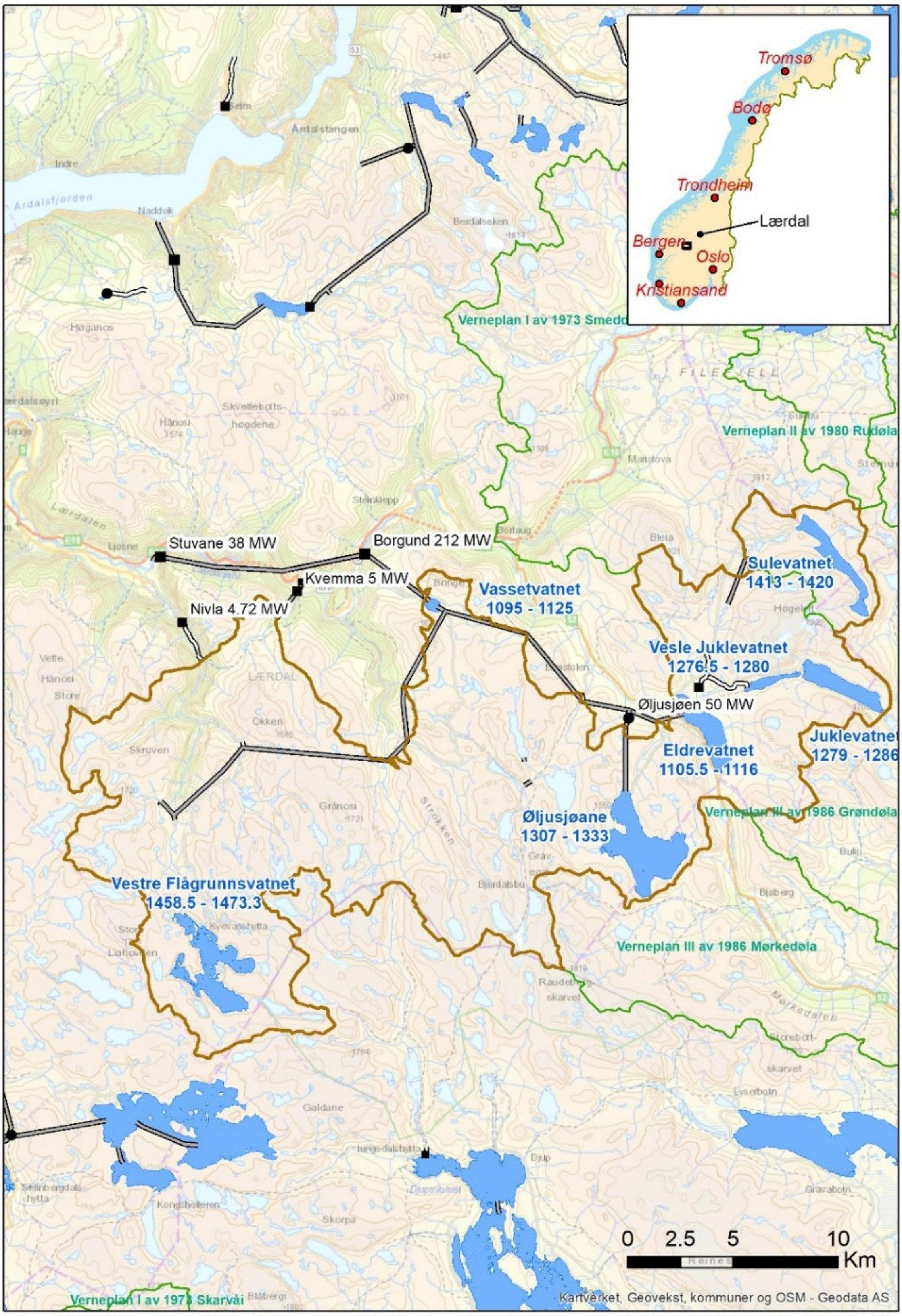
The Lærdal hydropower scheme (see figure) consists of the three power plants Borgund, Øljusjøen and Stuvane. The Øljusjøen power plant is a pump storage power plant upstream of the Borgund power plant. The Borgund power plant is the largest and exploits the head of almost 900 m from the intake reservoir Vassetvatnet to the underground power station. The tailwater tunnel has its outlet directly to the headrace tunnel for the Stuvane power plant. The Stuvane power plant utilises rapids in the Lærdalselvi River. The lower section of the Lærdalselvi River is important for salmon mitigation and spawning and hence there are strong provisions regarding minimum water flows and possibilities to discharge water in the case of a shut-down of the Borgund power plant.

The main construction period was in the 1970s and included the Borgund and the Øljusjøen power plants while the Stuvane power plant was planned and constructed in the 1980s.

The power plants are listed in the table below.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Borgund	212	28	874	1 084	1974
Øljusjøen	50	24	212	45	1975
Stuvane	38	28	156	198	1988
Sum	300			1 327	

The Lærdal Hydropower Scheme. Data from NVE's Hydropower Database, December 2020.



The Lærdal Hydropower Scheme and later small hydropower plants in the same area.
The Stuvane power plant is around 15 km upstream the river's outlet to the fiord (Lærdalsfjorden) at Lærdalsøyri.
Amber lines: Catchment area for the hydropower scheme.
Green lines: Protection plans.

The catchment area of the Borgund power plant is 404 km^2. Seven reservoirs with a total capacity of around 273 Mm^3 were established from 1970 to 1978. Today the Borgund and the Øljusjøen power plants are owned and operated by the public power company Østfold Energi.

The Stuvane hydropower plant was constructed by Østfold Energi as part of the then Østfold County's development in Lærdal. The ownership was transferred free of charge to local ownership (Okken Kraft Lærdal KF) in 2013, in accordance with an agreement between the Østfold County and Lærdal Municipality in 1981. Okken Kraft was established to manage values which were created in the municipality. Okken Kraft has the responsibility to follow up the municipality's interests in the Stuvane power plant and the daily operation of the power plant. The company shall also ensure the municipality's interests as to license power, power plants and water rights and also be consulted regarding the watercourse and further power development.

The two turbines in the Borgund power station have been upgraded since the 1970s, and the present capacity and generation are now higher. Rehabilitation of dams has also been undertaken during the last two decades.

Dam safety is important in Norway. Any watercourse facility within defined consequence classes shall be monitored by a person (watercourse responsible, VTA) who is authorized by the Norwegian Water Recourses and Energy Directorate (NVE). The VTA is a person qualified for the responsibility to ensure that the security aspects in a watercourse are in accordance with given standards. NVE has the overall national responsibility and regularly undertakes dam inspections and reviews of the owner's dam security system. NVE has the authority to require more thorough investigations based on an inspection and can also require mitigating measures if deemed necessary.

Four small-scale power plants have been constructed in tributaries of the Mørkedøla and Lærdalselvi rivers but are not included here in the Lærdal hydropower scheme. The total power and generation capacity in the Lærdal area are around 320 MW and 1,400 GWh, respectively.

Østfold Energi continued to harness energy resources in other counties and today also owns the Nyset-Steggje hydropower scheme which was developed in the 1980s in the adjacent Årdal Municipality north of Lærdal. Østfold Energi has today 100 % ownership of seven power plants, of which five are in the Lærdal and the Årdal municipalities (the "guest" district) and two in the "home" district of Østfold. The company is also co-owner of other power companies, among them Siso Energi (see also the Siso hydropower plant). Østfold Energi's total installed capacity is around 500 MW with a mean annual power production of some 2,270 GWh. The company owns two hydro power plants in its home district Østfold, which only contribute 10 MW and almost 50 GWh.

The present publicly power company Østfold Energi was formally founded in late 1980s. However, the company's history goes back to around 1900 through municipal power and distribution companies which were merged to Østfold Energi. Østfold Energi and its precursors had originally its "home supply area" in then Østfold County. Østfold Energi is today organised as a shareholding company owned by Viken County and a majority of the municipalities in the earlier Østfold County. The main office is in Sarpsborg in Østfold.

Project Background

In brief the background for the Lærdal hydropower scheme was Østfold County's need for more power after WW2 and the available hydropower resources in the Lærdal Municipality in a fiord landscape in West Norway relatively far away from Østfold.

Østfold is a lowland area in southeast Norway, southeast of the capital Oslo and east of Oslofjorden (the Oslo Fiord). The area is approximately 4,200 km^2, with population of around 300,000 today. In 1960[3], the population was approximately 200,000, of which around 60,000 lived in the county's four towns and 140,000 in 28 rural municipalities. The most important livelihoods were, and still are, industry and agriculture.

Until 1945, the county's own power resources, mainly in the Glomma River, had met the industrial and public consumption. The Glomma River is Norway's largest river with its lower section in Østfold. The river's power resources in Østfold had early in the 20th century been developed by private industry companies, among them Hafslund[4], and also by the public owned Solbergfoss power plant (owned by Oslo Municipality's power company (67 %) and NVE (33 %)). Hafslund had acquired time-unlimited water rights in the Glomma River before the introduction of time-limited licenses for private companies. In addition to supply its own large industrial establishments, Hafslund was bulk supplier to municipal distribution companies and to other industry in the county.

However, the county's work to ensure sufficient power supply to the municipalities in Østfold was initiated already in the beginning of the 20th century. It was by then difficult for the municipalities to obtain necessary power at a manageable price. Power plants were built early along the Glomma River by Hafslund and other private industrial companies, and the private producers prioritised supplying the town and the industry. A committee was established to evaluate and propose a solution to the public supply situation. This was a difficult task. Hafslund and Oslo Municipality had purchased almost all hydropower resources in the Glomma River in Østfold County. Hence the county had lost its possibility to be self-sufficient in power supply.

The committee submitted a comprehensive recommendation to the Ministry in question. A Royal Decree documented an agreement in April 1914. The agreement had a duration of 60 years (until 1974) and contained a detailed description of the duties and the rights regarding the power supply in Østfold. Furthermore, detailed technical, juridical, and economic conditions were included. Then it was possible for the rural municipalities to buy power from listed suppliers for public distribution within the municipal supply areas. Hafslund also constructed most of the transmission lines. Hafslund was thereby the owner of the regional grid in Østfold, which is still the case (2021). Hence, the private company Hafslund played an important role for the public power supply in Østfold, before the Second World War (WW2), regarding both electricity production and distribution.

[3] Statistisk Sentralbyrå (SSB): Folketelling 1960, Hefte 1 (1963).
(Statistics Norway: Population Census in Norway 1960).
[4] Hafslund is today included in the energy and infrastructure group Hafslund E-CO.
(https://hafslundeco.no-/en/about/om-oss).

This was largely the situation also after WW2, even though a revision of the agreement had been agreed upon in 1931. Some changes were also made during the first years after WW2. However, the public supply was not satisfactory neither as to quantity nor administration. In 1958 involved parts entered into an agreement which opened up for Hafslund to buy power from the State for onward delivery in Østfold. There was a set of six separate to handle, through which the rural municipalities disposed power quanta, with different suppliers and conditions. In total, the contracts included delivery of nearly 60 MW per year, in a strict and given order. The county did not have a common superior power utility and it was demanding for each municipal distribution company to handle correctly.

Hence, the public power supply in Østfold in the first years after WW2 was still almost 100 % based on bulk supply, with private companies or the State as sellers. There were several municipal distribution companies in the county, with the obligation to cover the power demand in their respective supply areas. Only one of the companies had own power production. The power production in the county was in the beginning of the 1960s as shown in the table below.

Ownership	Capacity (MW)	In %	Production (GWh/y)	In %
Local municipalities	8	2	36	1
Private	353	70	2 279	71
Oslo Municipality	77	15	511	16
NVE	66	13	416	13
Sum	504	100	3 242	100
Public	151	30	963	29
Private	353	702	2 279	71

Power production in Østfold County in 1960. The figures are based on data in "Hydro Power Developments in Norway 1.1.1968", NVE, March 1969.

Most of the power plants were located in the Glomma River (471 MW, 3,086 GWh). Some smaller plants were established in the Tista River near the border between Norway and Sweden (33 MW, 156 GWh).

As in other counties in Norway, Østfold County expected to face a power deficit and load shedding within a few years after WW2 unless effective actions were taken within a short time. Due to the foreseen demand growth, Østfold County recognized the need to develop projects outside the county. This was like the situation in the then Vestfold County on the other side of Oslofjorden (see also the Åbjøra Hydropower Project). However, Vestfold County was in a more favourable situation than Østfold. In Vestfold a public power company with experience in planning, construction, and operation of hydro power plants of some size was already established. There was no similar public power company in Østfold, and hence it was more difficult to manage public hydro power development.

Regarding the organisation of the public power supply, the year 1974 was at least a small turning point and the start of a larger future public intervention of power plant construction and power supply in the then Østfold County. The agreement from 1914 expired, which opened for an improved public organisation. The county organisation Østfold Kraftforsyning, ØK (Østfold Power Supply) with the responsibility for organisation of public power supply was established in 1974. ØK was incorporated in the public Østfold Energi when this power company was founded in the late 1980s.

Despite the rather complex organisational power situation in Østfold, positive events had taken place, also before 1974. The Borgund and the Øljusjøen hydropower plants had been planned, licensed and construction was nearly completed in 1974 and 1975, respectively, with Østfold County as licensee. The formal administration of the processing of Borgund and Øljusjøen power plants was then left to ØK. There was close cooperation with stakeholders as central power authorities, municipal political authorities, lenders, Hafslund and local interest groups. However, ØK did not have the role as an executor of planning, construction an operating of the power plants. Hence, there was still a way to go before a satisfactorily public self-sufficiency was in place. Hafslund was therefore an important co-operator for some years, also after 1974.

Obviously, there were large unexploited hydropower resources in the Lærdalselvi River. However, the potential was not interesting for developers at the beginning of the 20th century. At that time water fall rights had been purchased by foresighted persons or organisations other places in Norway. One example is known from the Aura hydropower scheme. Many of the buyers were also mentioned as "waterfall speculators" ("fossespekulanter"), with the purpose to sell further at a profit. Some of the purchasers were also accused of cheating the landowners and farmers. However, purchasers and developers had not been interested in the hydropower resources in Lærdalselvi. A reason for this was allegedly the river profile. There is a relatively long section with a rather low gradient downstream of the much steeper section (which later was exploited in the Borgund power plant). None of the different sections were considered as adequate for a power plant of some size in the early 20th century. The steep section was too far away from the fiord and the access was difficult. The only exploitation in the river was a small power plant (Husum) for public supply from 1936 in the lower river section. The head was 21 m, and the capacity was 400 kW. Thus, before the 1970s there was so to speak negligible hydropower generation in the Lærdal area, which consequently was nearly 100 % dependent on power supply from other places. Østfold County's interest in exploitation was therefore highly welcome and would give both local power supply and economic growth. The population in Lærdal Valley and adjacent areas in 1960 was about 2,300[5]. In 2020 the population was around 2,100.

Around 1960 the hydropower potential in the Lærdal watercourse was seriously considered as interesting for development, and thus also a promising opportunity for Østfold County. The private power company Hafslund purchased the relevant waterfalls in 1960, and around 80 landowners were included in a common agreement. The water rights were soon transferred to Østfold County. Hence, it can be said that Østfold County and the Lærdal Municipality could meet in a common goal, namely the development of the hydropower resources in the Lærdal watercourse.

Already in the mid-1950s, the semi-official "Association for the Study on Norway´s Waterpower"[6] suggested the development of four power stations in the Lærdal watercourse. The resources were also evaluated by other instances. However, none of the first alternatives were compatible with the local community's need to preserve the tourism associated with salmon fishing in the Lærdalelvi River and were rejected. However, a revised plan was prepared as basis for a license application and was accepted by the Lærdal Municipality. Østfold County assisted by Hafslund continued the application and planning processes.

[5] Statistics Norway: Census in Norway 1960

There was no common public power company in Østfold at that time, and none of the several small municipal power companies had the required economic power and the professional knowhow and experience to implement the development in Lærdal. However, the private company Hafslund had the capacity, regarding ownership, project management, engineering and power plant operation. However, since a private company could only get time-limited licenses while Østfold County could be granted a license without time limit, it was decided that Østfold County, rather than Hafslund, should apply for the license and be the formal developer.

Essential preconditions for the hydropower exploitation in Lærdal were the large potential in the Lærdalselvi watercourse, Østfold County's need for power and the Lærdal Municipality's positive response. Modern equipment and construction methods after WW2 opened for the development. The dominant phase was the construction of the Borgund and the Øljusjøen power plants in the early 1970s, which were followed by the Stuvane power plant in the 1980s. Some smaller plants have been commissioned in the early 21st century.

According to NVE's hydropower database as per April 2021 there are now 8 hydropower plants in the Lærdal Municipality, varying from 0.2 MW to 212 MW. The total capacity is 320 MW and mean annual generation is 1,392 GWh. The power plants are listed in the table below.

Name of power plant	Capacity MW	Mean annual generation capacity, GWh	Year commiss-ioned	Owner	Type of ownership	River
Borgund	212.0	1 084	1974	Østfold Energi	Public	Lærdalselvi
Øljusjøen	50.0	45	1975	Østfold Energi	Public	Lærdalselvi
Styvane	38.0	198	1988	Okken Kraft	Public	Lærdalselvi
Vindedal	5.4	15	2005	Vindedal Kraft	Privat	Vindedals. 1)
Kvemma I	0.2	1	2013	Not available	Privat	Lærdalselvi
Eldrevatn	4.9	24	2013	Østfold Energi	Public	Lærdalselvi
Kvemma II	5.0	14	2015	Kvemma Kraft	Privat	Lærdalselvi
Nivla	4.7	11	2016	Nivla Kraft	Privat	Lærdalselvi
Sum	320	1 392				

Present power plants in the Lærdal Municipality. The Lærdalselvi River here includes Mørkedøla River, tributaries and diversions. The Vindedalselvi River is a small river west of Lærdalsøyri, withoutlet to the fiord.

Political Aspects

Østfold County submitted the license application in October 1962, and the license was granted in 1966. An important premise for the license was an agreement between the Lærdal Municipality and the formal developer Østfold County regarding benefit sharing. Based on an agreement in 1966, the Lærdal Municipality had the right to acquire 15 % of the power at cost-price. In most other cases, the local community only acquires 10 % of the power. The local accept of the project,both by the municipal authorities, local interest groups and the society in general, was based on the requirements that salmon fishing was not seriously affected.

[6] A brief review of the "Association for the Study on Norway´s Waterpower" is given in the Sira-Kvina Hydropower Scheme.

The Lærdal Municipality would not welcome industrial development in Lærdal. One reason for this was that an aluminium smelter was already in operation in the adjacent Årdal Municipality. Another reason was that the municipal authorities as well as the local society feared that industrial pollution could damage the rich salmon fisheries in the lower section of the Lærdalselvi River. To develop the salmon fishing further, the developer also financed salmon ladders and a hatchery.

The construction works started in 1970, four years after the license being granted. The relatively long delay was caused by financial problems. The project was calculated to be rather expensive, and possible lenders were reluctant. Since the development was relative costly, the central government did not prioritize this project in terms of allowing credit financing, and other hydropower projects were prioritized before the development in Lærdal. However finally, the financing was in place by 1970.

It was agreed that the Lærdal Municipality also took over around 60 km of the 22 kV lines. Moreover, a considerable part of the municipality's 11 kV distribution network was upgraded to 22 kV. The Husum power plant in the Lærdalselvi River from 1936 with capacity 400 kW was dismantled in exchange for an annual supply of 4.2 GWh. Local public roads were constructed as a part of the project implementation.

Like many other hydropower licenses in Norway during the first decades after WW2 there were provisions demanding that the licensee preferably should use Norwegian products and services for the construction works and operation. These provisions were included in the license for the Borgund and the Øljusjøen power plants in 1966 and for the Stuvane power plant license as late as in December in 1984.

The Stuvane power plant (commissioned in 1988) was implemented and paid for by Østfold Energi. The license was given in 1984. Based on an agreement which was signed in 1981, the Lærdal Municipality took over the power plant free of charge in 2013.

Project Organisation

The Borgund hydropower scheme was formally developed by the then Østfold County. This was before the formal establishment of Østfold Energi, and Østfold County was formally represented by the public association Østfold Kraftforsyning during the preparatory and construction phases as well as during the first years of operation. Hafslund, with more than half a century's experience with hydropower plants, acted as the Owner's Engineer with tasks such as liaising with contractors and suppliers. Besides this, Hafslund assisted in technical matters and some other practical aspects of the implementation.

According to the license provisions most of the electrical and mechanical equipment was manufactured by Norwegian suppliers. All major construction contracts were undertaken by Norwegian contractors. The Borgund and the Øljusjøen power plants were operated by Hafslund on behalf of Østfold County for 10 years. Østfold Energi has operated these two plants since 1985, as well as operating Stuvane from its commissioning in 1988 to 2013.

Economic and Technical Aspects

The Lærdal hydropower scheme was constructed with reservoirs, dams, transfer tunnels, stream intakes, head and tailrace waterways (tunnels and pressure shafts) and underground power stations.

Construction power was secured by a 25 km 66 kV line from the Gjuva power plant (owned by Oslo Municipality's power company), which was commissioned with 10 MW in the neighbouring municipality Hemsedal in the then Buskerud County (Viken County today) in 1957.

The Borgund power plant with gross head 874 m has intake in the Vassetvatnet reservoir. A transfer tunnel with length around 13,700 m leads water from the Eldrevatnet reservoir to the intake reservoir.[7] A tunnel with length of approximately 2.5 km followed by a steel lined pressure shaft with length 1,260 m and inclination 1:1 leads the water from the intake reservoir down to the two Pelton turbines in the underground station. The capacity when constructed was 2 x 93 MW, but later upgrading has increased the capacity to 2 x 106 MW. According to the license provisions the turbines, generators and transformers were manufactured by Norwegian suppliers Kværner, National Industri and Asea Per Kure, respectively. The length of the tailrace tunnel is approximately 3,650 m. The length of the access tunnel to the power station is almost 2 km. The original plan was to utilize a larger head down to the outlet of the subsequent Stuvane power plant. However, this alternative was abandoned because of constraints with salmon migration. As a consequence, the unit costs increased significantly. Today the tailrace tunnel leads the water directly to the Stuvane power plant.

A tunnel with length around 20.7 km from the southwest transfers water from several stream intakes to the transfer tunnel between the Eldrevatnet and the Vassetvatnet reservoirs. One of the intakes is the Nivla River, with the established Kvevotni (Flågrunnsvatnet) reservoir in its catchment area. The Øljusjøen pump storage power plant is connected to the transfer tunnel between the Eldrevatnet and the Vassetvatnet reservoirs. There are seven reservoirs in the scheme. The reservoirs were established with a usable capacity in 1973-1974 and are listed in the table below.

Reservoir	Natural level (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Capacity (Mm^3)
Vassetvatnet	1102	1125	1102	6.7
Eldrevatnet	1112.5	1116	1105.5	27
Vesle Juklevatnet	1278	1280	1276.5	2
Juklevatnet	1282.5	1286	1279	18.1
Øljusjøen	1309.1	1333	1307	161
Sulevatnet	1415	1420	1413	18.3
Kvevotni (Flågrunnsvatnet)	1458.5	1473.3	1458.5	40
Sum				273.1

Reservoirs in the Lærdal hydropower scheme.

The Øljusjøen pump storage power plant with gross head 212 m has headwater in the Øljusjøen reservoir and tailwater in the Eldrevatnet reservoir. The water can also be transferred directly to the Vassetvatnet reservoir. The power station is underground, with a Francis pump turbine with acapacity of 50 MW. The maximum discharge in the producing modus is 24 m^3/s while the capacity in the pumping modus is lower. The operation depends on the runoff and the reservoir situation as well as the prices in the power market.

The Vassetvatnet, Eldrevatnet, Øljusjøen and the Kvevotni reservoirs are mentioned above. Vesle Juklavatnet and Juklavatnet have natural runoff to Eldrevatnet. Sulevatnet is in the protected catchment of the Oddedøla River. However, the runoff is diverted from elevation 1,375 m a.s.l. to the Eldrevatnet catchment by a tunnel with length around 2.5 km.

[7] The lengths of waterways as given in this chapter are based on data in NVE Atlas.

Dams were constructed on all reservoirs. Three of them are sizeable and are rockfill dams with a moraine core. These dams are:

- Dam Vassetvatnet with height 30 m and length 195 m
- Dam Øljusjøen with height 38 m and length 480 m
- Dam Kvevotni with height 37 m and length 170 m

The Kvevotni dam at around 1,460 m a.s.l. is the highest located rockfill dam in Norway. The dams on the four other reservoirs are smaller and are of both the rockfill and the concrete dam types.

The power stations were connected via a 300 kV west-east transmission line with length 60 km to the national backbone transmission grid at the Hemsil II power plant in the neighbouring Hemsedal Municipality in another county. The transmission costs amounted to about 7 % of the total project costs. The transmission project met considerable resistance in Hemsedal, which was heavily dependent on tourism. This community faced the disadvantages of the transmission line and received only negligible benefits and compensation.

To safeguard the salmon, the license provisions state requirements regarding minimumwater flows as well as the release water past the turbines in case of production shutdown. The fish ladders have increased the salmon production reach of the river from 26 km to 41 km, although this has not been a particular success.

The Stuvane power plant was constructed by Østfold Energi and was commissioned in 1988. The ownership was transferred to local ownership in 2013. The power plant utilizes a head of 156 m with outlet to the Lærdalselvi River around 15 km from the outlet in the fiord. The headrace tunnel with length around 6.3 km is connected directly to the upstream tailrace tunnel from the Borgund power station. A tailrace tunnel of length 470 m leads the water to the outlet in the fiord. The power station with two Francis turbines of the same size is located underground. These turbines were also manufactured by Kværner while the generators and the transformers were delivered by NEBB and Asea Per Kure, respectively.

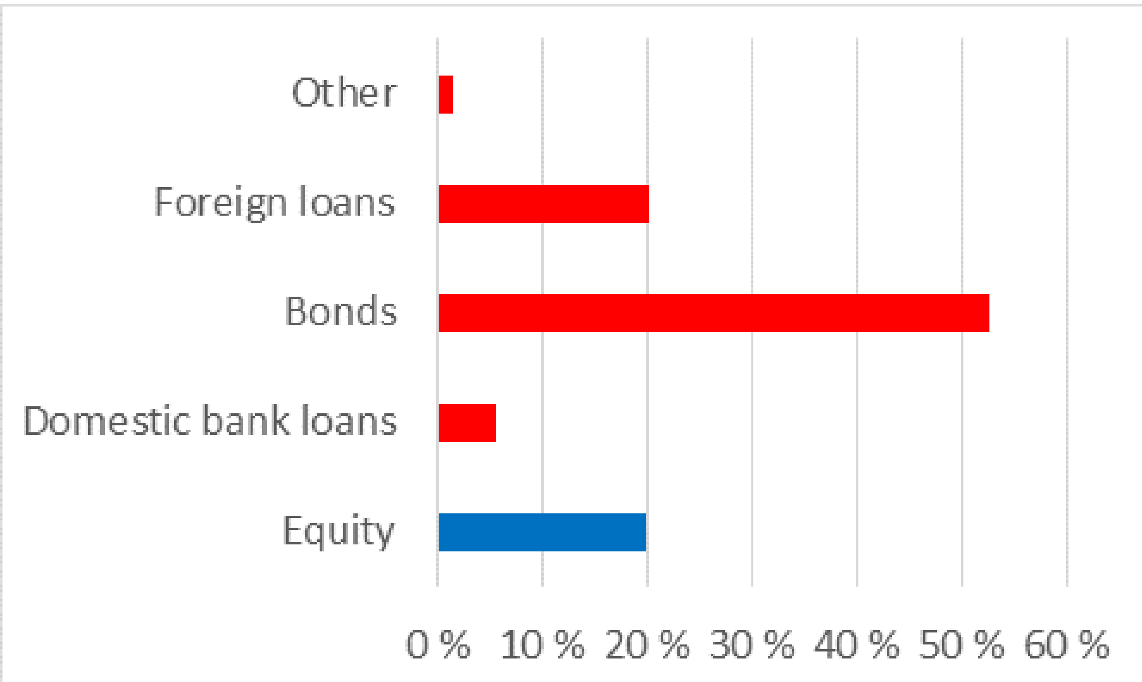
Project Financing

The Central government did not prioritize the project in terms of allowing credit financing, among other factors because the project was comparatively expensive (referred to tight control over the credit market). There was a State requirement for significant self-financing.

In order to finance the Borgund and the Øljusjøen power plants the Østfold County Council unanimously approved an earmarked fee onto electricity utility tariffs in the county. The fee was imposed over a period of six years and helped to raise 20 % equity financing. As can be seen, 20 % of the budget was raised in foreign loans, while more than 50 % was raised through domestic bond issues (see figure below). The Government Pension Fund Norway provided debt financing in 1972, which made up around 16 % of the bonds and 9 % of the total financing.

The construction of the Stuvane power plant was a later phase of the Lærdal hydropower scheme, with more straightforward financing, and is not described here.

The lower Lærdal area, with Lærdalsøyri, then lower power plant Stuvane and the adjacent fiord system. Source: NVE Atlas.



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13 The Siso Hydropower Project (1962 – 1973)

Highlights

- A political targeted industry development in economically less developed districts
- The initial power supply to a ferrosilicon plant was secured through successful cooperation between four companies
- The cooperation between a private industrial company and a municipal power company reduced investment risks for the industrial company
- The cooperation enabled the power company to postpone capital-intensive investments
- In the study period 1946-1990, the Siso hydropower project is one of relatively few projects where the project financing was secured through share emissions
- Public purchase of hydropower from private companies

Project Information

The Siso hydropower plant is located in the Sørfold Municipality in the Salten district in Nordland County in North Norway. The location is about 100 km east of Bodø and 100 km north of the Arctic Circle. Salten is a district in mid-Nordland, with area 10,400 km^2. In 1960 there were 13 municipalities in Salten with approximately 55,000 inhabitants. Today these have been reduced by mergers to 7 municipalities, with some 75,000 inhabitants.

The power plant was constructed by the industrial company Elkem for power supply to their ferro-silicon factory, Salten Verk. Today, Salten Verk is one of many factories in the large, worldwide Elkem Concern. Over the years, the operation has been upgraded towards higher silicon purity. Elkem Salten is today one of the world's largest end most modern silicon plants exporting silicon and silica fume products worldwide and is uniquely positioned in the market through full ownership of the value chain.

The Siso hydropower plant utilizes the head between the intake reservoir in Lake Sisovatnet, to the outlet of Lake, Straumvatnet. The power plant consists of reservoirs, dams, diversion tunnels, waterways (tunnels and pressure shaft), underground power station with two units with Pelton turbines, and an access tunnel. The plant was planned, constructed, and commissioned in the late 1960s and the early 1970s, with the first unit in operation in 1968 and unit number two in 1970.

The development area is primarily the upper part of the Fagerbekkelva watercourse. Elkem was granted license in 1966 for the regulations and for transferring water from neighbouring rivers and streams. Lake Straumvatnet is in the neighbouring watercourse Røyrvasselva.

The catchment area is approximately 235 km^2, of which the glacier Blåmannsisen makes up 90-100 km^2. The mean annual runoff to the power plant is 645 Mm^3. Lake Sisovatnet together with a smaller reservoir in Lake Løytavatnet provides a favourable total reservoir capacity of 606 Mm^3, which is 94% of the mean annual runoff. Lake Straumvatnet with water level 5 m a.s.l. is unregulated, with surface area 6.7 km^2.

The large reservoir capacity and intake of rivers fed by Blåmannsisen glacier makes the power plant extremely flexible and robust to changes in weather conditions. In addition, water from several rivers and streams is also diverted to the reservoirs through tunnels. The plant data are listed in the table below.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Siso	180	33.7	650	916	1968

Data from NVE's Hydropower Data Base, December 2020.

The power plant is now connected to the central grid, but the connection to a transmission system was a challenging process when the power plant was planned and commissioned in the 1960s.

One characteristic of the Norwegian hydropower sector has been the right of reversion to the State for licenses granted to private developers after 1917. The right of reversion means that the State assumes ownership of waterfalls and any hydropower installations free of charge when a license expires. As the date of reversion stated in the license approaches, private power plants will either be sold to publicly owned companies, or the ownership will revert to the State on the specified date. This provision has been a legal obligation for more than a hundred years. The purpose was to ensure public control over important and everlasting hydropower recourses.

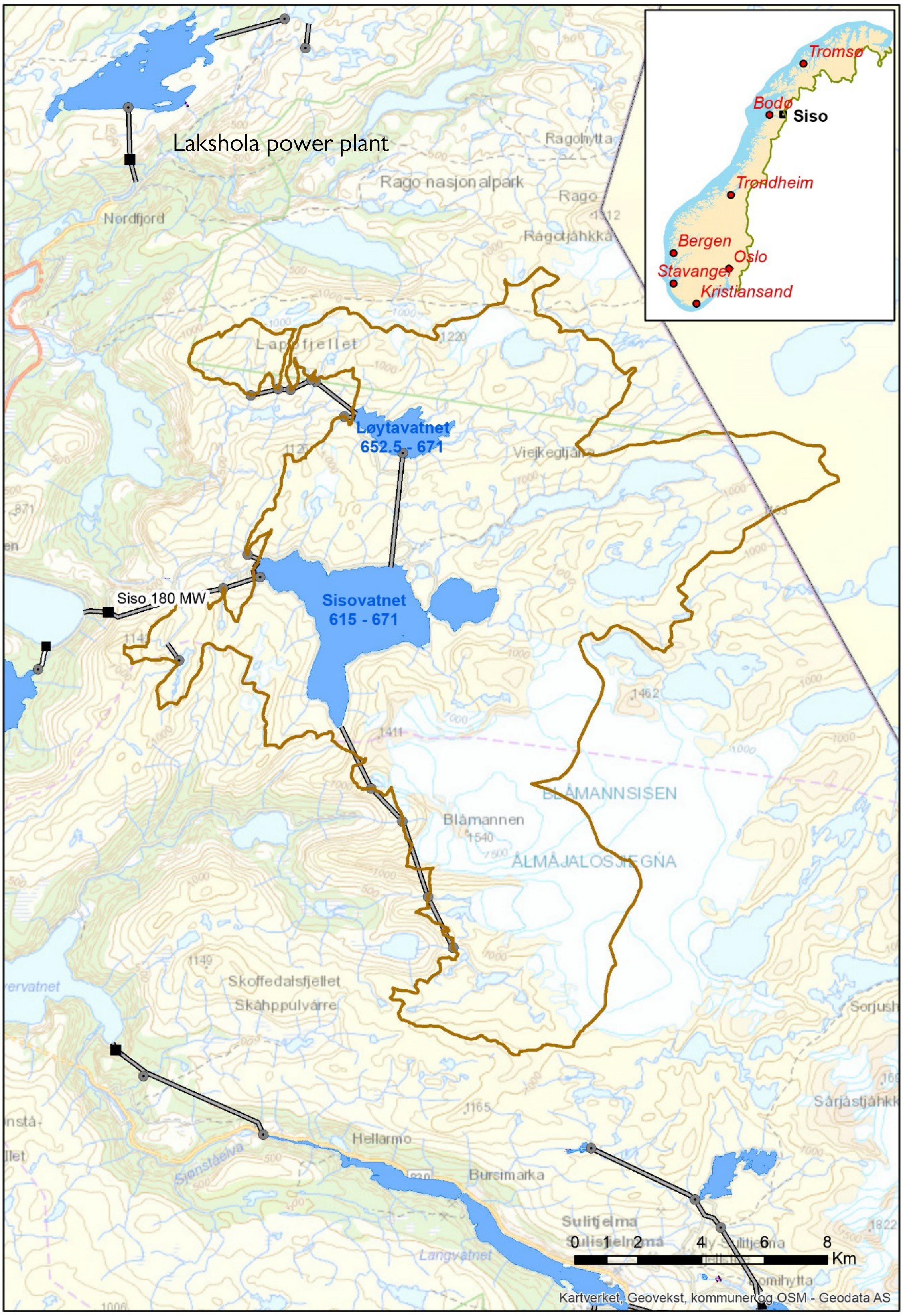
Elkem was granted a regulation license for the Siso hydropower plant in 1966. Elkem is a private company, and the license was time-limited to 60 years, with expiry and consequently a started reversion of the Siso power plant in 2026 if the plant was not sold before.

Since Elkem had a time-limited license, the company had an incentive to sell the power plant and a competitive bidding process was issued. Seventeen years before the license expired, Siso power plant was purchased by a Joint Venture on a 50-50 basis by two public power companies Østfold Energi and Nord-Trøndelag Elektrisitetsverk (NTE) in 2009. The two companies are owned by municipalities and counties and have thus been granted an eternal license.

Østfold Energi has originally its "home supply area" in the earlier Østfold County[1] in southeast Norway, nearly 1,300 km by road from the Salten district. The company was founded in 1900 and has all the time been owned by the county and associated municipalities. Since the 1970s Østfold Energi has broadened its focus and has both established and bought power plants in other counties.

NTE's "home supply area" was Nord-Trøndelag County[2], which borders to the Nordland County in north. The distance from NTE's main office to Siso is near 600 km by car. NTE was founded in 1919 and was 100 % owned by Nord-Trøndelag County until 2018. Since 2018 NTE has been owned by the municipalities in the earlier Nord-Trøndelag County. NTE's hydropower development has traditionally and nearly 100 % taken place in their home county. The involvement in the Siso Power plant can be said to be a new investment philosophy.

[1] Østfold County was merged with two other counties to Viken County from 1 January 2020.
[2] Trøndelag County is a merger of the earlier Sør-Trøndelag and Nord-Trøndelag counties from 1.1 2018.



The Siso Hydropower Plant.

Siso Energi owns also the Lakshola hydropower plant (30 MW), which was commissioned in 1999. Lakshola HPP is also located in the Sørfold Municipality and Nordland County.

Project Background

The Norwegian-based industrial Elektrokemisk (later Elkem) was founded in 1904.

In the 1960s, Elkem expanded its metal smelting and silicon production business. Elkem´s decision in 1965 to invest in a ferro-silicon plant in the Salten district was a step in that expansion. The location was, among others, selected due to the proximity to the attractive Siso hydropower project.

Elkem was already in 1961 on a survey in the Salten district with the purpose of finding a favourable location for the construction of the ferro-silicon plant. Valjord in the Sørfold Municipality was selected, together with the Siso hydropower plant for power support.

Elkem's decision to develop its own power supply was based on the conclusion that power purchase from other suppliers was not an option. In the 1960s, the Salten district constituted a limited, separate power system (power plants as well as the grid), and the power balance was tight. The district faced load shedding during the winter of 1966-67.

The license application for the Siso hydropower plant was submitted already in 1962 and the necessary water rights were acquired in 1963. NVE (the State Power Utility) also considered to acquire the water rights for a State power plant. However, NVE waived this opportunity and decided to prioritize other State projects because of Elkem's interest, will and ability to develop the Siso power plant together with the ferro-silicon plant. The license was granted in 1966. Contrary to public power companies that have everlasting licenses, Elkem was granted a time-limited license of 60 years.

Political Aspects

The foreseen first construction stage would provide 75 MW and about 420 GWh in mean annual production, while the demand for the first furnace in Salten Verk was estimated to be 30 MW and 150 GWh. The Salten district was an isolated power marked at that time, and it would be difficult to find customers for the surplus power in the first years of operation. It was therefore considered to construct a transmission line for transferring the surplus power from the State power plants in the Rana district further south in the county and postpone the construction of the Siso power plant. However, after assessments of different transmission routes, production, and demand for industry supply in Rana and further southwards, the authorities changed the plan. The recommendation was to postpone the construction of the transmission line and rather accelerate the construction of the Siso power plant.

It was too early to deliver power from the Siso power plant when Salten Verk started its production. The ferro-silicon plant started with the first furnace in June 1967, which was one year before the commissioning of the Siso power plant. The solution was an agreement between Elkem, the large industry company (Norsk) Hydro, NVE and the regional power company Salten Kraftsamband (SKS). Until commissioning of the Siso HPP, Salten Verk was supplied with power from the Sundsfjord power plant. SKS agreed also to construct the remaining 50 km of the 132 kV transmission line to Salten Verk. The power supply was possible because Hydro agreed to reduce the power demand to its ammonia plant in Glomfjord south-west of Salten Verk. The ammonia plant was supplied from the Sundsfjord power plant. This was equalized through increased power supply from NVE to a Hydro factory in Southern Norway.

SKS's role in the agreement was to ensure the energy transfer from Sundsfjord to Salten Verk. This was mainly to construct the remaining transmission line. The State contributed with favourable financing in a challenging economic period for SKS caused by heavy investments. The transmission line was in operation in June 1967. The Siso power plant was commissioned in the autumn of 1968 for the power supply to Salten Verk. The line was then also useful for public supply in the local area.

The public owned SKS contributed to the establishment of Salten Verk and the Siso power plant. SKS was established in 1956 and was the first step to solve conflicting interests in power production and distribution in the Salten district. The Siso power plant's production was larger than the demand in Salten Verk, also after installation of furnace no. 2. The power surplus could then meet the increasing demand in the district for some years. Then SKS could postpone investments in new hydropower capacity. The Sundsfjord hydropower plant was commissioned in 1960 with a capacity which was a little less than 100 MW and with a mean annual generation of approximately 520 GWh. The plant is located about 100 km south-west of the new ferro-silicon plant and was, and still is, owned by SKS.

Elkem's license for a large hydropower development and the mix between industry and public power supply was subject to political debates at that time. There was disagreement on carrying out the large developments - the State or private interests. Furthermore, how fast the development should be. However, the combined ferro-silicon plant and a hydropower project had strong local backing because it would provide much needed employment opportunities. Besides, according to the license conditions, the district would receive up to 10 % of the annual generation at self-cost price.

The 1960s was a period with comprehensive plans for industry establishment in Nordland County and other places in Norway. The hydropower resources were large and were important for the selected localities. District policy instruments were also essential, such as the possibility to set aside profit for later investments in the district in question.

Governmental incentives encouraged industrial development in Northern Norway and other economically less developed areas. A State development bank, the District Development Fund[3], provided concessional capital. Investors also benefitted from favourable tax and depreciation rules.

Similar to many other licenses in Norway at that time, there was a provision demanding that the licensee preferably should use Norwegian products and services for the construction works and operation. For further conditions, see the KØN hydropower scheme.

Project Organisation

Elkem had established a competent engineering department over the years and was highly qualified to supervise the works both for the ferro-silicon factory and the power plant. Elkem was a company which designed and constructed furnaces, including the Salten Verk. The factory was designed by Elkem's engineers while the civil construction works were carried out by a contractor and supervised by Elkem's own engineers. The first furnace was ready for operation in 1967, number two in 1970 and the third and largest in 1973.

[3] Today, the fund is a part of Innovation Norway (https://www.innovasjonnorge.no/en/start-page/).

The hydropower project was developed in three continuous stages. Stage 1 comprised the power station and waterways and a 75 MW unit with an annual generation of about 420 GWh. The next stage comprised unit no. 2 with 105 MW and a diversion tunnel from Lake Løytavatnet to Lake Sisovatnet. The last stage was diversion of additional neighbouring rivers and streams. This gave the final exploitation of the resources, and mean annual generation is 916 GWh in 2020. The engineering department also organized and supervised the implementation of the power plant.

For the Siso power plant all design tasks were contracted to a consultant company, Berdal Strømme (Norconsult today). According to the license conditions a significant part of the electro- and mechanical equipment was manufactured in Norway, to a large extent by subsidiaries of international companies. Turbines and generators were designed, constructed, and installed by the Norwegian companies Kværner and NEBB (Norsk Elektrisk & Brown Boveri), respectively. NEBB was incorporated in the multinational concern ABB (earlier Asea Brown Boveri) in 1988.

The civil contractor was the Norwegian company, Høyer-Ellefsen, which since 1991 has been incorporated into Veidekke ASA.

Economic and Technical Aspects

When the first stage of the Siso power plant was commissioned, the new transmission line established a market for surplus power from Siso. Initially, the ferro-silicon plant needed 30 MW and 150 GWh in mean annual consumption, i.e., significantly less than 420 GWh as generation capacity. The demand increased when the second furnace started operation in early 1970, but was still lesser than the generation capacity, which also was increased after installation of unit no. 2. A power surplus agreement between Elkem and SKS entailed that SKS could postpone capital-intensive investments in new hydropower capacity. Moreover, this agreement also provided economic security for Elkem to continue the construction works of stage two of the power project immediately upon completion of stage one.

The power plant has a very large reservoir capacity. See data in the table below.

Reservoir	Natural level (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Capacity (Mm^3)
Sisovatnet	662.5	671	615	557
Løytavatnet	652.5	671	652.5	49
Sum x)				606

x) NVE's Database gives only the total volume. A reasonable distribution is 557 and 49 Mm^3. Although this is not precise, it is assumed that the table gives a reasonable idea of the respective reservoir capacities.

The reservoirs were established by dam construction and lake tapping. Lake tapping also enables utilization of a volume below the natural water level. Lake Sisovatnet has two rockfill dams with moraine core and a flood discharge arrangement (concrete weir) in between. The dams were completely rehabilitated in 1992 and 2000. There is one dam on Lake Løytevatnet. A tunnel with a length of 3,650 m conveys water from Lake Løytavatnet to the intake reservoir in Lake Sisovatnet.

The headrace tunnel from Lake Sisovatnet to the surge chamber, sand trap and mechanical arrangements is approximately 5 km long with a cross section of 25-30 m^2. From this area there is a pressure shaft with length 880 m with an assumed declination of 45 degrees down to the underground power station area where there is a forking arrangement to the two vertical Pelton turbines. The turbine capacities are 75 MW (1968) and 105 MW (1970). A tailrace tunnel with length 556 metres and a cross section area of 25 m^2 leads the water to the outlet in Lake Straumvatnet.

Project Financing

Two thirds of the initial investment concerned the first stage of the Siso power plant. The ferro-silicon plant and the hydropower project were financed through a combination of accumulated profits, share emissions and bond issues. In the study period, this is one of relatively few examples where a hydropower developer raised capital in the stock market. Elkem made considerable profit in most years in the 1960s.

Elkem issued new shares in 1965, 1966 and 1967 to co-finance Elkem's expansion in the 1960s. The share emissions raised capital for this project as well as for Elkem's other industrial projects. The shares were traded on the Oslo Stock Exchange.

About 22 % of the total investments for the power plant and the ferro-silicon plant were financed through bonds which were issued in 1967 and 1968. The capital was raised in the Norwegian capital market. A bank consortium conveyed the loan. After a three year's grace period, the bonds were amortized through semi-annual repayments.

The investment in the 132 kV transmission line was co-financed by a concessional loan from the Central Government. The financing was provided by the District Electrification Support Scheme through an earmarked electricity tax.

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14 The Orkla Hydropower Scheme (1973-1985)

Highlights

- The hydropower development was based on a comprehensive master plan for the watercourse
- The project was developed during a period with increasing environmental concerns and was controversial
- The project had positive impacts on flood control and maintenance of discharge during droughts
- The river supports a wild salmon population and technology solutions focused on preserving and developing this resource in cooperation with a local river association
- The operation of the plants is carried out in close cooperation with other user interests, like the famous salmon fishing industry
- Together with other factors, a new Working Environment Act increased project costs
- 80 % of the financing was raised in the domestic capital market
- The low interest rate on the 20 % share of foreign loans compensated for foreign exchange losses
- One of the Joint Venture partners ran into financial difficulties, due to among others changes in the regulatory framework
- The financial risk was mitigated because assets were tradeable and there was an existing transmission network in place

Project Information

The Orkla Hydropower Scheme was planned and developed for hydropower production in the 1970s and 1980s.

The main river is in the southern part of the present Trøndelag County[1] and the northern part of the present Innlandet County[2], south of Trøndelag[3]. The main river originates from a small lake at level 1,058 m a.s.l., in Trøndelag and flows northwards to the mouth in the sea at Orkanger at the south end of Orkdalsfjorden. Orkanger is located 40 km south-west of Trondheim. Orkdalsfjorden is a side fiord to the large Trondheimsfjorden. The total length of the Orkla River is 182 km and the catchment area at the mouth is 3,053 km^2. The river has about 25 tributaries of some size. There were no natural large lakes in the main river course, which caused violent floods. However, there were some small natural lakes in some of the tributaries, and two of the lakes are now regulated and serve as reservoirs. In addition, large artificial reservoirs were established in two other tributaries. The artificial reservoirs and the dams were controversial and led to objections and widespread demonstrations during the planning, application and construction periods.

[1] Trøndelag County is a merging of the earlier Sør-Trøndelag and Nord-Trøndelag counties from 1January 2018.
[2] Innlandet County is a merging of the earlier Hedmark and Oppland counties from 1 January 2020.
[3] The watercourse was originally located in the Sør-Trøndelag and Hedmark counties.

The Orkla River is famous for salmon fishing. Thus, mitigating measures to preserve the biological life in the river were included. These concerns were already taken care of at an early planning stage through an initial overall development plan for the whole watercourse (Watercourse Master Plan). The plan was a basis for subsequent plans although changes were made during the later planning and the application process.

The Orkla hydropower scheme consists of five power plants which have a total installed capacity of 320 MW and a mean annual generation of 1,398 GWh. The power plants were commissioned between 1982 and 1985. The power is transferred to the regional 132 kV and 66 kV grid. The five power plants in the scheme are listed in the table below.

Name of power plant	Capacity MW	Max Discharge m^3/s	Gross Head m	Mean annual generation capacity, GWh	Year commissioned
Ulset	35	12	320	152	1985
Litjfossen	75	30	285	167	1982
Brattset	80	36	269	402	1982
Grana	75	19	455	332	1982
Svorkmo	55	69	96	345	1983
Sum	320			1 398	

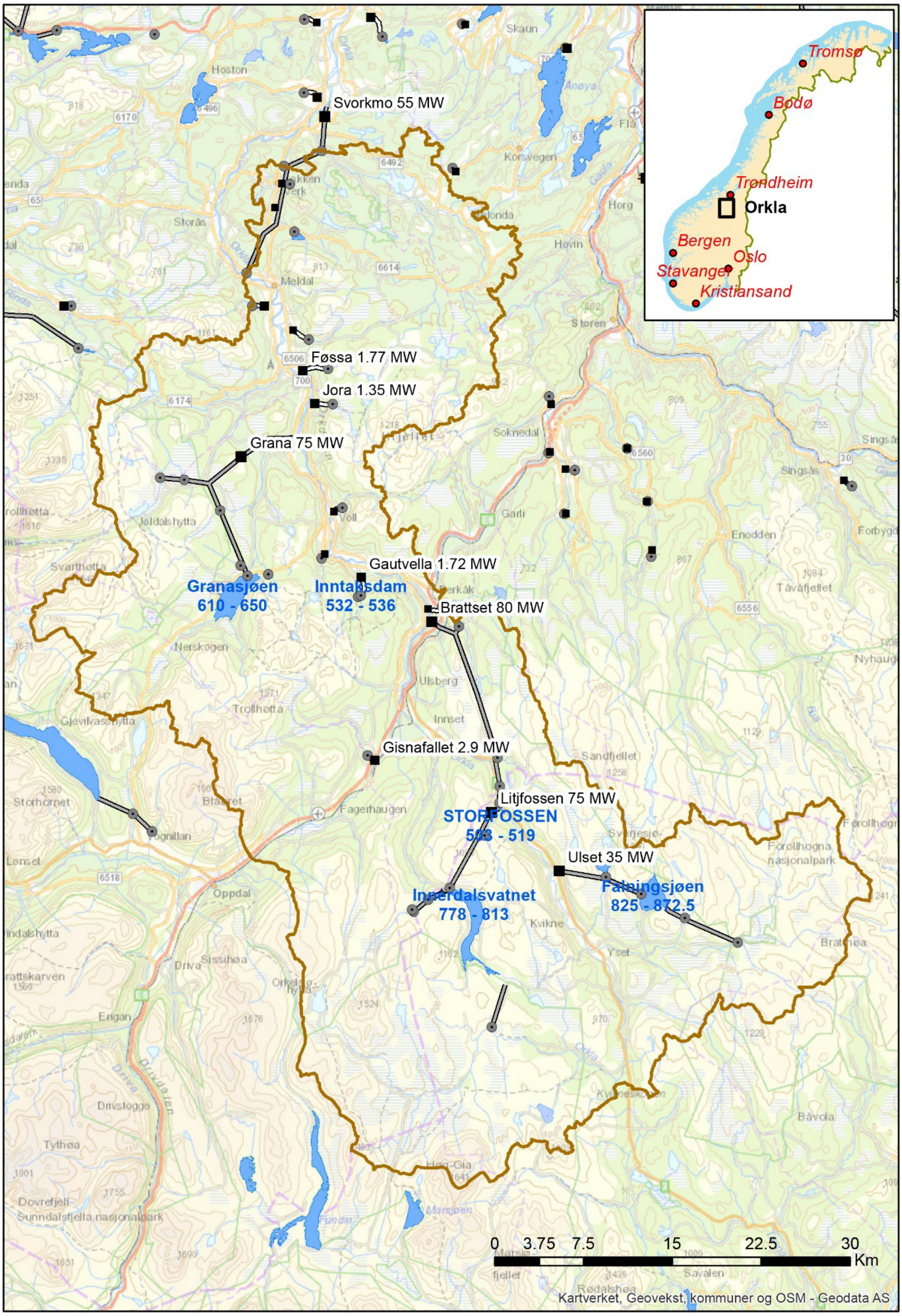
Data from NVE's Hydropower Database, December 2020.

The power plants are listed from the uppermost plant and further downstream. The Ulset and Litjfossen power plants are in the Tynset Municipality and Innlandet County, Brattset and Grana power plants in the Rennebu Municipality and the Svorkmo power plant in the Orkland[4] Municipality. Rennebu and Orkland are municipalities in Trøndelag County.

The reservoirs in the schemes are all on tributaries. Three of the power plants (Ulset, Litjfossen and Grana) have their intake reservoir in a tributary and outlet to the main river. The two others (Brattset and Svorkmo) have their intake in small ponds in the main river. Hence the two plants are of the run-of-the-river type. However, the power plants take advantage of the upstream reservoirs (see also Economic and Technical Aspects).

The present owner is Kraftverkene i Orkla DA (KVO) which is a Joint Venture with four shareholders. The owner's name is often abbreviated to KVO. Statkraft Energi and TrønderEnergi Kraft AS (Ltd.) have the largest stocks of shares, with 48.6 % and 35.0 % respectively. The two other shareholders are Hafslund Eco Vannkraft AS (12 %) and Nord-Østerdal Kraftlag Andelsverk AS (4.4 %) The ownership has changed since the implementation period.

[4] Orkland Municipality is a merging of the Orkdal, Melda and Agdenes municipalities and a part of the Snillfjord Municipality from 1 January 2020. Svorkmo power plant was originally located in the Orkdal Municipality.



The Orkla Hydropower Scheme (1973-1985). The small scale HPPs are constructed later.

Project Background

Three public owned power companies in the then two neighbouring counties Sør-Trøndelag and Hedmark had acquired water rights in different sections of the Orkla watercourse. The companies were:

- Trondheim Elektrisitetsverk (TEV), on behalf of its owner Trondheim Municipality,
- Sør-Trøndelag Kraftselskap (STK), which was owned by Sør-Trøndelag County, and
- Hedmark Kraftverk (HKV), on behalf of its owner Hedmark County

In 1971, TEV submitted a license application for a development in a lower part of the river catchment. The idea was to utilize the water resources in the tributary Grana River. The plan comprised the construction of a dam and the establishment of a relatively large and controversial reservoir by impounding the existing Lake Granasjøen. The exploitation of Grana was later a part of the Orkla hydropower scheme. STK and HKV had started preparation of plans for a development in the upper sections of the watercourse. The main driving force for the projects was power supply for public consumption in the respective supply areas.

The three parties formed later a Joint Venture (JV), which was organized as a shared responsibility company, originally with a share-holding structure with TEV (35 %), STK (35 %) and HKV (30 %). However, the structure of the ownership has been changed since then and is shortly described here.

Trondheim Elektrisitetsverk (TEV) was founded in 1901. The name is changed during the 20th century. However, the essential point is that the company was 100 % owned by the Trondheim Municipality from 1901 to 2009. The abbreviation TEV is a well-known and incorporated term. From 2007 the name was Trondheim Energi Kraft AS. Trondheim Energi Kraft was completely incorporated in Statkraft SF (the State Power Utiity) on 1 January 2009. The formal owner of the shares in the JV is Statkraft Energi, which is 100 % owned by Statkraft SF.

Sør-Trøndelag Kraftselskap (STK) was established in 1950 and the name was TrønderEnergi in 1997. TrønderEnergi Kraft is a subsidiary company since 1998. In 2020 TrønderEnergi is owned by 18 municipalities in the earlier Sør-Trøndelag County and two other stakeholders.

Hedmark Kraftverk (HKV) gradually transferred their holdings in the JV. The transfer started in the early 1990s, caused by financial problems. HKV has later, together with other small power companies in the present Innlandet County, merged with Eidsiva Energi.

Political Aspects

The Power Sector Authority (NVE), which processed TEV's license application, said neither yes nor no, but urged the three parties to undertake a coordinated development of the Orkla watercourse. Among others, this was due to the concern to optimise the power generation and environmental issues. In 1973, the three parties entered into a statutory agreement for this purpose: "The parties shall together acquire the property rights and/or the right of use to waterfalls, and so on, in the Orkla watercourse in the municipalities Tynset, Rennebu, Meldal, Melhus and Orkdal as well as construction and operation of power plants."

In 1974, an integrated hydropower development plan was prepared as a basis for a license application. The license application was submitted in 1975. NVE recommended the license to be given. However, this was a comprehensive and difficult case, with five power plants, two controversial reservoirs and reduced water flow in the Orkla River as serious impacts, along with increased ice problems in the river. Thus, there were hard discussions in public opinion and in the Parliament. The Ministry of Petroleum and Energy recommended the approval of the application license. Finally, the Norwegian Parliament approved the development in June 1978. 96 Members of Parliament voted for the development while 41 voted against.

The Orkla hydropower scheme was developed in a period when the public opinion focused more on environmental protection and less on the need for further industrialization than earlier. For the Orkla scheme, the flooding of the valley Innerdalen with mountain farming and pristine vegetation was particularly controversial. The police were mobilized to remove demonstrators who chained themselves together when the access road was constructed.

The councils in the affected municipalities supported the project. Among other things, this was due to the benefit sharing and compensation arrangements. The project has contributed to significant local employment during the construction phase and later in the operation phase. A control centre was also established in one of the municipalities. Some of the affected municipalities also benefitted from new roads and reinforcement of the electricity distribution network.

The Orkla River as a salmon resource has, since the approval was given, received R&D funding for preserving the natural salmon migration. The operation of the power plants has a focus on the river flow, and this is valuable in avoiding the worst results of natural dry periods.

Like many other licenses in Norway at that time there was a provision demanding that the licensee preferably should use Norwegian products and services for the construction works and operation. For further conditions see the KØN hydropower scheme.

In 1991, a new Energy Act was passed in the Parliament. The power market was deregulated (liberalised), meaning that end-users could change their supplier. This occurred at a time when the project developers were still burdened with high interest and amortization costs. The JV partner HKV run into financial difficulties, caused by a combination of high capital costs[5], reduced income due to low tariffs caused by stagnating electricity consumption, wet years and loss of an anchor customer. Thus, HKV sold more than 50 % of its assets in the JV (from 30 % to12 %). This risk-mitigating measure was possible because the assets were tradeable and there was an existing transmission network.

Project Organisation

The construction works took place from 1978 to 1985. TEV was responsible for the construction of the Grana and Svorkmo power plants, while STK was responsible for the three other power plants and the transmission network. STK was also responsible for the later operation of the hydropower plants. More than a thousand workers were employed in the most intensive construction periods. In addition, there were workers from the supplier companies for the installation of the turbines, generators, transformers and other equipment. There were tight deadlines and high activity. The contractors' permanent work force consisted of experienced workers and for that reason there were very few accidents.

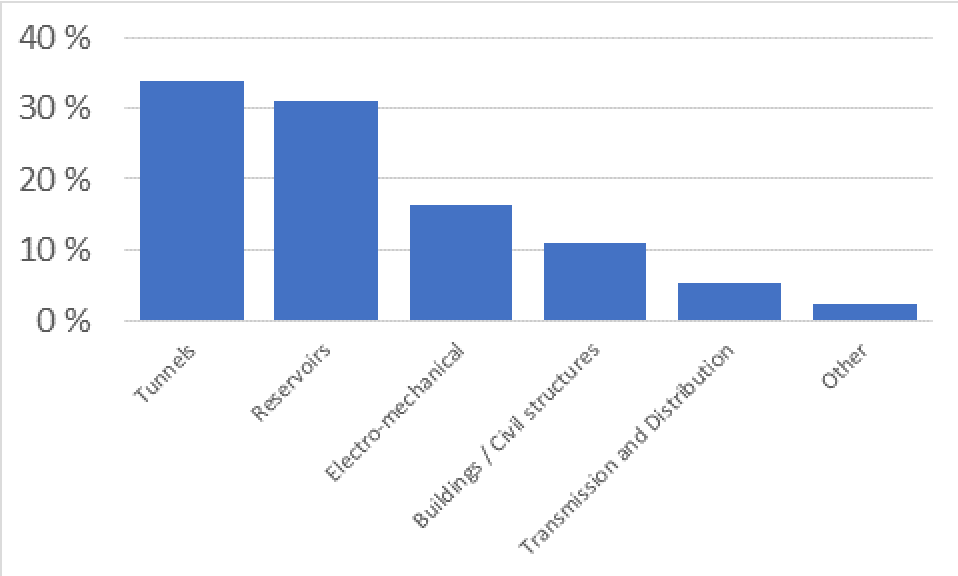
[5] From the Orkla project as well as from other newly commissioned hydropower projects.

The construction period was also beneficial for local companies within heavy equipment, transport and mechanical fields, and for local workers.

According to the license conditions a significant part of the electro and mechanical equipment was manufactured in Norway.

Economic and Technical Aspects

The project was developed and constructed during a period with significant inflation. Thus, in nominal terms, the project became much more expensive than indicated in the original plans. When adjusting for inflation, the cost overruns were 14 % compared to the budget in 1978. A new Working Environment Act, which among others forbid construction works at night, contributed to the increased costs. The main cost elements were tunnels and reservoirs, which contributed to about 60 % of the total construction costs (see the table below).



The costs for the planning and design are most likely not included and are assumed to represent at least 10-15 % of the construction costs.

Opponents of the development strongly criticised the cost overruns. KVO was accused of presenting misleading calculations in order to be awarded the license. Economists and other experts were more focused on the real economy and expressed accusations of bad investments and low profit.

There were also costs beyond the direct construction costs. The concerned municipalities received significant amounts of money as grants for miscellaneous purposes and receive also annual fees and license power ("konsesjonskraft")[6]. KVO was also required to execute comprehensive mitigation measures to minimise damages to nature and environment. The mitigation works were such as release of environmental water flows, construction of weirs, design and vegetating of spoil deposits, measures for wild animals and the fishery resources and financing of scientific investigations.

[6] An owner of a hydropower plant larger than a given size is obliged to deliver a given share of the producedpower to the host municipality. The license power shall be delivered at a price decided by the Ministry or negotiated by the parties.

The reservoirs have undoubtedly reduced the floods[7]. The license requirements regarding minimum water flows have secured water flow during droughts and have thus been valuable for salmon migration. The Orkla River is a rich salmon producing river. Studies have shown that the project has been beneficial for the salmon stocks. The river has been the subject for many research projects. The combination of reservoirs and lowering of the riverbed have also enabled cultivating of more land at a particular location.

All reservoirs are on tributaries. The Nerskogen reservoir is also known as Granasjøen, which was the name of the impounded lake. The reservoirs are listed in the table below.

Reservoir	Natural WL (m a.s.l.)	HRWL (m a.s.l.)	LRWL (m a.s.l.)	Volume (Mm^3)
Sverjesjøen	867.7	872.5	867.7	7
Falningsjøen	847	872.5	825	125
Innerdalen	765	813	778	153
Nerskogen	603	650	610	144
Sum				429

There are in addition two intake ponds in the main river.

The connections between the reservoirs, the main river and the power plants are shown below.

Power plant	Intake	Tailwater
Ulset	Falningsjøen	Orkla
Litjfossen	Innerdalen	Storfoss pond in Orkla
Brattset	Storfoss pond in Orkla	Orkla
Grana	Nerskogen	Orkla
Svorkmo	Bjølset pond in Orkla	Orkla

As seen, three of the power plants have their intake reservoir in a tributary and outlet in the Orkla River while two of the plants utilize heads in the Orkla River. Only the Litjfossen hydropower plant has outlet in a deregulating pond and can be operated flexibly with less concern for the river flow.

The Ulset power plant exploits the head from the main reservoir in Lake Falningsjøen to an outlet in the Orkla River. A rockfill dam provides the maximum water level and tapping through the headrace tunnel also gives a reservoir below the natural water level. A shaft connects the reservoir in Lake Sverjesjøen with the headrace tunnel, which is approximately 7.5 km long. There is one unit with a Francis turbine in the underground power station. The length of the tailrace tunnel to the outlet in Orkla River is 500 m. The power plant is constructed with an air cushion surge chamber.

The next power plant is Litjfossen with intake in the artificial reservoir Innerdalen, which is created by the construction of a rockfill dam with a moraine core. A diversion tunnel with intake in the upper part of Orkla River leads water to the Inna River and hence to the reservoir and further on to the Litjfossen power station.

[7] An example is a period with intense rain in the summer of 1991.

The reservoir was operational in 1982. The headrace tunnel has a length of 7,450 m to the underground power station where one unit with a Francis turbine is installed. A tailrace tunnel with length 90 m leads the water to the Storfoss pond in the Orkla River. The pond is constructed as a balancing facility to avoid ice problems caused by intermittent discharge from the power station in the winter season. Storfoss is the intake pond for the Brattset power plant.

The Brattset power plant has its intake in the Storfoss pond in the main river. The intake pond has natural water level 496 m a.s.l. and is regulated between 519 and 503 m a.s.l. which provides a storage of 1.7 Mm^3. The pond was established for short time regulation (day and night; 24 hours). The dam is of the concrete slab type. The water is transferred from the pond through a headrace tunnel down to the underground power station and further on through a tailrace tunnel with length 600 m to the outlet in the Orkla River. The water from four side rivers is lead into the headrace tunnel. The length of the tunnel is approximately 16.6 km, of which around 12 km was drilled by a tunnel boring machine with a diameter of 3.5 m.

An air cushion surge chamber is constructed as a junction to the headrace tunnel. Two units are installed with Francis turbines in the power station. The Brattset power plant is the largest of the five power plants in the Orkla hydropower scheme. The Brattset power station is open for visitors, and every year school classes, tourists and other interested groups make up an enquiring audience.

The Grana power plant has its intake in the reservoir in Nerskogen (Lake Granasjøen). The reservoir is artificial with a regulation amplitude of 40 m, which is established by the construction of a rockfill dam with a moraine core. The dam length is 1,080 m with a maximum hight of 52 m, and the total volume of the dam mass is approximately 1.5 Mm^3. The reservoir covers an area which originally consisted mainly of bogs on both sides of the Grana River and a small lake. The lower air side of the dam is covered by a layer of earth, which has permitted the growth of vegetation (grass and a small stand of trees). When the dam was built it was ranked as Norway's largest dam founded partly on uncompacted material. Measurements of pore pressure, seepage, subsidence and deformation have been carried out regularly and have demonstrated that the dam structure is very good and stable.

The reservoir was operational in 1982. From the reservoir the water is lead through the tailrace tunnel with a length of around 11.5 km to the underground power station. There are transfers of water to the reservoir as well as to the headrace tunnel. The power station has one unit with a Francis turbine. The tailrace tunnel to the outlet in the Orkla River has an approximate length of 5 km. For the lowest located power plant, Svorkmo, a separate regulation reservoir has not been established.

The intake pond at Bjølset is regulated 0.5 m between the levels 129.5 and 129.0 m a.s.l., with a volume of 20,000 m^3. The catchment area upstream the intake is about 2,640 km^2 which is 87 % of the total area of the Orkla watercourse. The upstream reservoir capacity is 429 Mm^3 which is equal to 23 % of the mean annual inflow to the power plant of the approximately 1,840 Mm^3. The water is led from the intake through a 15.5 km long headrace tunnel in parallel with the Orkla River to the underground power station with two units of different capacities (35 MW and 20 MW). The turbines are of the Francis type. A tailrace tunnel with a length of 1,080 m leads the water to the outlet in the main river.

The power plant is constructed with a solution that reduces the formation of ice in the rapids due to the increased discharge during the winter. The pond shall primarily lead the water into the headrace tunnel. However, it was important to provide sufficient facilities for flood diversion so that the water level is not higher than earlier, release the required minimum water flow and ensure passing of fish (fish ladder). In order to meet the set requirements, gates are installed throughout the width of the river just downstream of the intake.

Project Financing

The project was financed entirely with loan capital which was taken out by the JV while the three owners provided guarantees. The financial responsibility was regulated in the agreement between the partners, which provided municipal and county municipal guarantees for the dept. About 80 % of the financing was raised in the Norwegian market and 20 % in a foreign market[8]. The foreign loans were provided through Kommunalbanken (KBN)[9]. A commercial bank issued bonds on behalf of the JV.

At that time, the interest rate was considerable higher in Norway compared to other OEDC countries. Analysis showed that the lower interest rate on foreign currencies compensated for foreign exchange losses. All loans were repaid by 2010. The construction, with more than 60 % of expenditures in rock excavation and rockfill dams, has a lifetime of more than 100 years. However, impacts from climate change with higher precipitation and changes of licence obligations (example dam safety etc.) can impose reconstruction works at an earlier stage. Electro and mechanical equipment are exposed to wear and tear which requires expensive upgrading 2-3 times during a 100 years' period.
To finance their parts of the investment, both TEV and STK increased the electricity tariff by more than 50 % in the early and mid-1980s.

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[8] The Central Government encouraged foreign financing of hydropower projects in the 1960s and the 1970s. However, access to foreign financing was restricted in the 1980s.
[9] Kommunalbanken; KBN (The Norwegian Agency for Local Governments) is a public bank and is an important lender to municipalities and other public governance institutions. The bank was founded in the mid-1920s as a governmental establishment.

NVE

Norwegian Water and Energy Directorate

MIDDELTHUNS GATE 29
P.O. BOX 5091 MAJORSTUEN
N-0301 OSLO
TELEPHONE: (+47) 22 95 95 95

www.nve.no