NORWAY'S
WATER POWER AND ELECTRICITY

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Norway's Water Power and Electricity

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The Watercourse and Electricity Service of Norway

Water Power.

The total amount of power in the water-courses of Norway which can be utilised is estimated to be 12,5 million turbine horse-power, corresponding to 9,2 million kilowatts (kW.). By this is meant all-the-year power, that is to say, power available during all the hours of the day and of the year. The sum total of energy in the Norwegian watercourses accordingly comes to somewhat more than 80 milliard kilowatt-hours (kWh.) per year.

In the calculation of the above figures there have been included only those sources of power which, by reasonable regulation of the water-course, can be brought to yield at least 1000 turbine H. P. of all-the-year power and for which the costs of development do not exceed kr. 500 per turbine H. P., reckoned at pre-war prices. (Excluding regulation expenses, purchase price of waterfall and possible compensation payments.) This *upper limit* for the cost of development corresponds, taking the 1935—1936 price-level, to a price of about kr. 100 per kW. per year, or something less than 1¼ ore per kWh. For most waterfalls, however, the development costs will be considerably lower. This applies especially to the larger falls and those most favourably situated for providing power for industrial purposes.

A general estimate of the costs of construction for a number of such industrial plants, representing altogether about half a million kW., showed that the *average* expense of development at the price-level of autumn 1935 amounted roughly to kr. 420 per KW. per year, corresponding to about 0,5 ore per kWh. It is here assumed that the power would be delivered at places which the presence of ice-free harbours rendered suitable for erection of industrial plants.

There are, of course, many waterfalls in Norway which have not been comprised in the official survey of the country's supply of water power,[1]) either because their yield of power does not reach 1000 turbine H. P. or because the construction costs exceed the appointed limit. Moreover, it is only very seldom that a waterfall is utilised solely for supply of all-the-year power, i. e., for a constant consumption extending over the whole year. Where, as in Norway, adequate reservoirs can be secured, the water is stored up in periods when the consumption is small so that the surplus power can be utilised at other times. Owing to these circumstances we often meet with considerably higher estimates for the available water power in Norway than the official figure of 12,5 million turbine horse-power. Thus an eminent authority in this field reckons with 16 to 18 millions.

Even if we keep to the lowest—the official—estimate it will be seen that Norway in regard to water power occupies an extremely favourable position in comparison with other countries. Reckoning in absolute figures, the European country which according to the existing records has the next largest supply of water power can show only about 65 per cent of what Norway possesses. It might seem interesting here to state figures for the various countries, but as the records for the individual lands are based on highly divergent principles, such a comparison would at present not be of interest. Thus, while the figures for Norway indicate, as above stated, the quantity of all-the-year power, the records from other lands refer to

[1]) «Vannkraften i Det Sydlige Norge» ved Vassdragsdirektoren, 1919.
«Vannkraften i Trondelag og Nordland» ved Vassdragsdirektoren, 1920.
«Vannkraften i Troms og Finnmark» ved Vassdrags- og Flotningsdirektoren, 1922.
(All published by H. Aschehoug & Co., Oslo.)

the power-supply that can be disposable during 9 months of the year, or a still shorter period. For comparison it may be mentioned that, if Norway's water power were to be estimated on the basis of 9 months' consumption, the quantity of power available would be about 30 per cent higher than above stated.

On the accompanying map of Norway (at the end of the book) the waterfalls, including those wholly or partially developed, are indicated by circles with centre at the place where the power-station is or is intended to be located. The quantity of power in the different falls is proportional to the area enclosed by the circle in each case.

It will be seen from the map that the sources of power are rather unevenly distributed throughout the country. Both as regards the number of utilisable waterfalls and the quantity of power in the individual falls the south-western part of the country—the Westland—occupies a special position. Within a region which represents 13,5 per cent. of the total area of the land and contains 19 per cent. of the population we have here no less than 35 per cent. of Norway's total amount of utilisable water power. But it is not only through their number and size that the sources of power in this part of the country call for attention. The topographical formation of the landscape, as well as the meteorological and geological conditions offer all facilities for cheap development. The land rises steeply up from the sea to heights of 1000 metres and more. Consequently the cataracts have in general a large head-height of fall, — so that even with relatively small catchment areas—small volume of flow—considerable quantities of power can be obtained. The moist winds from the sea produce a heavy rainfall with comparatively uniform distribution over the year, at some places reaching up to 3000 mm. annually. As the volumes of water for which the feeding tunnels, pipes etc. have to be dimensioned are as rule relatively small, the costs of the different constructional works will be correspondingly low. The power-plants may in their entirety be built in and on solid rock, and the liming of tunnels and the like may be avoided. The necessary storage basins are mostly situated in mountain areas where the land has little value and the outlay for the acquirement of regulation rights, for compensation to land-owners etc. is therefore small. Moreover it is seldom that regard for other interests in the watercourse—such as floatage, the operations of other power-plants etc.—entails any restriction on the full utilisation of volume of water.

In view of the fact that the sources of water power in the above-mentioned south-western part of Norway are located at or in the immediate vicinity of places excellently suited for large industrial plants, with deep, ice-free harbours, it will not be found surprising that very many of the waterfalls have already been taken into use for industrial purposes. Among these may be mentioned Saude Falls, supplying about 120 000 kW., chiefly for production of ferro-manganese, Tysso Falls, supplying about 100 000 kW. for various electro-chemical and electro-thermic industries, Bjolvo Falls, with 865 m. head, providing power for production of ferro-silicon and ferro-chromium, the Øyre and Jetland Rivers in Hoyanger, which furnish energy for production of aluminium. Both at Bjolvo and Hoyanger large extensions are at present being carried out, whereby the capacity of the plants will be considerably increased.

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Also in the interior parts—in the Eastland—South Norway has many, large sources of hydraulic power. These may be divided into two characteristic groups, both of which have relatively large volumes of water at disposal, as compared with the falls in the Westland.

The first group comprises the power-plants located in the interior of the country at the foot of the steep ranges which mark the transition from the high mountain tracts towards the west to the lowland of south-eastern Norway. It is especially the watercourses which rise on the Hardanger plateau that furnish such sources of power. The head of the largest and best-known of these water falls varies from 300 to 400 m. Reckoning from south to north may be mentioned Tokke, Rjukan, Mår and Nore, of which at present the following are developed (wholly or partly): Rjukan, for supply of power to the Norsk Hydro-Elektrisk Kvælstof-Aktieselskap's factories, and Nore, for general utility power supply to the towns and rural districts of the Eastland.

The second group of large power-plants in this part of the country comprises those situated on the lower courses of the principal rivers, and which utilise heads between 15 and 30 m. These falls are generally provided with an intake dam built across the river, the power-station being situated close to the dam. Among the best-known may be mentioned the falls developed in the lower part of the Glomma: Morkfoss, Solbergfoss, Kykkelsrud, Vamma and the power-plants on the Sarpsfoss Falls. These plants are constructed for large volumes of water. For example, with full equipment of machinery Morkfoss-Solbergfoss can operate with more than 600 sm³.

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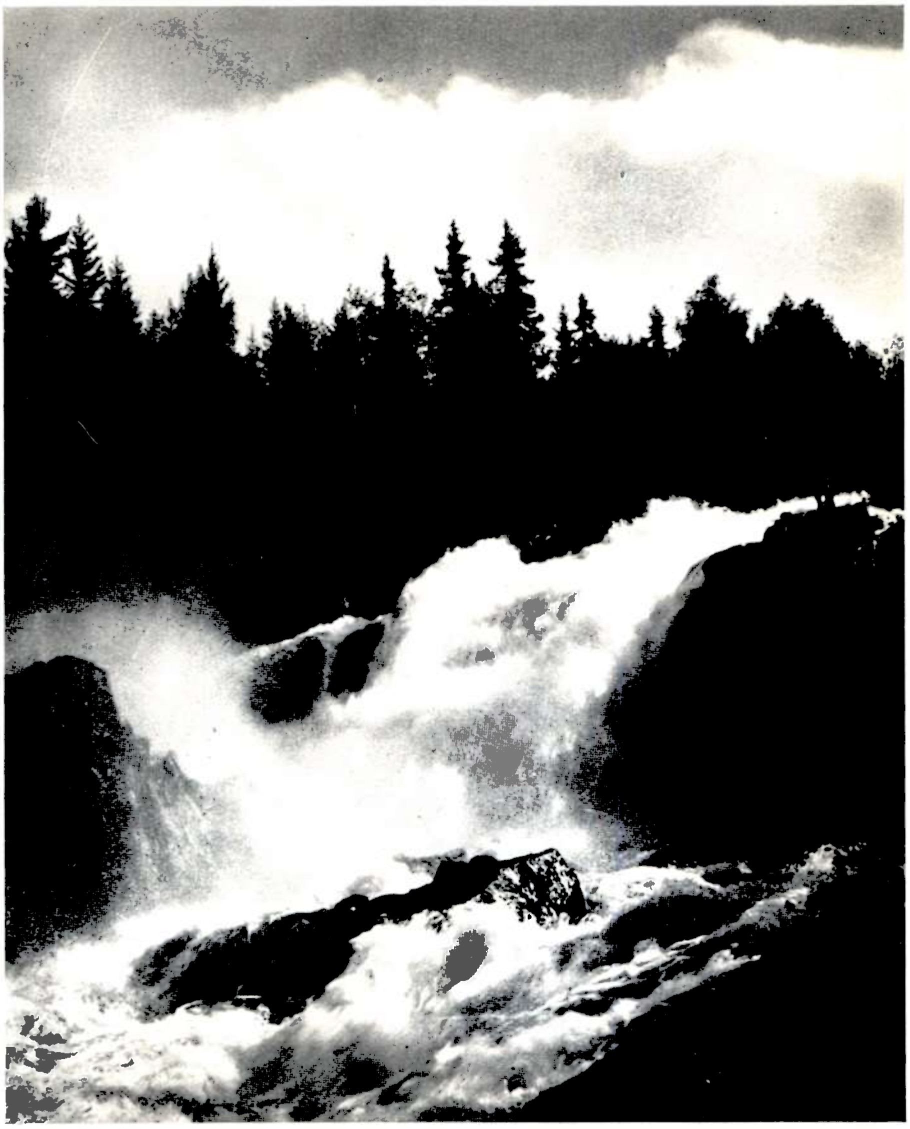
Looking at the sources of water-power in the more northern parts of the country—in Trøndelag and North Norway—the conditions will be found to vary greatly in the different districts, with respect both to number of falls and to possibilities for regulation and development.

In the Trøndelag counties, in a region representing 12,8 per cent of total area of Norway and containing 9,6 per cent of the whole population, we find only 6,2 per cent of the total quantity of utilisable water power. Broadly speaking, the power-plants in Trøndelag may be said to represent a type lying between the aforesaid two Eastland groups. With some few exceptions the natural facilities for providing the necessary regulation reservoirs must be described as relatively poor in the Trøndelag watercourses. Nevertheless the district possesses a few waterfalls with utilisable water power of about 40 000 all-the-year kW. each, a couple of which are situated in the southern county and one—the largest—up near the boundary of Nordland county.

In North Norway, the common designation for the three most northerly counties: Nordland, Troms and Finnmark, there is, as a glance at the map will show, an extremely great difference between the three counties as regards their richness of water power. With respect to the location of the falls the conditions are generally the same as in the Westland. They are situated at or near ice-free harbours, and where the necessary areas for industrial plants are not available in the immediate vicinity of the power-station, the transmission of the power to suitable places is usually a simple matter.



The Mesna Falls

Both with regard to quantity of power and to favourable conditions for regulation and development Nordland county occupies an entirely dominant position in comparison with the other two northern counties. In Nordland we have altogether 1 167 000 kW. of utilisable water power, i. e., 30,5 kW. per km² of area, or 6,2 kW. per inhabitant. The corresponding figures for the whole of Norway are 28,5 kW. per km² and 3,3 kW. per inhabitant. Most of the large sources of power in Nordland county are of more or less the same character as those in the Westland, with heads up to 700 m. Some of them,

Morkfoss-Solbergfoss Power Plant. Head: 22,6 m — Installation: 90 000 kW. used in the General Electricity Supply

wholesale delivery to the separate partaking districts, which then distribute it further to the consumers, or else by direct sale from the works to the consumers. The first-mentioned arrangement has been adopted by 10 of the intercommunal and 3 of the county-communal works.

As already mentioned, also the State and private companies take part in the production of electricity for general purposes In 1936 the communal works together furnished about three-fourths of the power employed for general requirements.

During the last 10 to 20 years a system of collaboration between several electrical works for production and distribution of power has developed, where the geographical situation of the works and the hydrographic conditions render this arrangement advantageous. The interconnected power stations are connected to a specially designed control station equipped with apparatus for remote metering and controlling, and also with carrier current telephone, through which the total load of the co-operating system is distributed between the works concerned. Such collaboration offers many and great advantages, of which may be mentioned the following:

The participating works can act as reserve plant for each other in case of a breakdown or stoppage in any one of them.

Through collaboration it becomes possible to utilise the production capacity of the individual works to the best advantage. The hydrographic conditions—volume of flow at hand and supply of water in reservoirs—usually vary rather much in the different rivers. While the works on one watercourse may have an abundant supply of water without drawing on the reservoirs, the situation may be quite different for works located on other rivers and supplying power to the same geographical area. Now if collaboration has been established between the works on these rivers, it will be natural to transfer as much as possible of the load to those plants which are best supplied with water. These latter are thus enabled to make use of a flow of water which they otherwise could only have partly utilised. At the same time the works on the other watercourses can perhaps be put wholly or partly out of action, so that the stock of water in the reservoirs can be allowed to increase for later use when circumstances render it necessary. What has here been said also applies in high degree as regards the facilities offered through collaboration for the best possible utilisation of the total quantity of power available in the co-operating watercourses in the different years.

As a third advantage arising from collaboration between works within a large territory must be mentioned that, owing to the larger territory to be served, extensions and new constructions will more rapidly attain to full load and thereby to more economical operation.

It is especially in south-eastern Norway—the Eastland district—that collaboration, or joint working, has shown development. The Eastland district may at present be reckoned as being the area comprised within a circle with a radius of 100 km. and with Oslo as its centre. This district has about 1,1 million inhabitants. The 12 largest electrical works in this area have joined together in a collaborating union. Nine of these have their own power-plants and distributing systems, while three of them have only the latter. The State electrical works at Nore, with its transmission lines and substations, participates in the Union. The total generator capacity which these collaborating works have at disposal today amounts, in round figures, to 500 000 kW. including Nore with 100 000 kW.

For the working year 1936—1937 the jointly working plants in the Eastland district had a total consumption of 4 400 000 000 kWh. A further 600 000 000 kWh. stood at disposal, but were not utilised. The statistics seem to indicate that there is now a rise of between 10 and 15 thousand kW. per year in the maximum primary power load of the co-operating system.

Besides in the Eastland, collaborative working between power-plants suitable therefor has been introduced or is under preparation in many other parts of the country. The areas here concerned are relatively smaller, but as regards several of them it must be expected that in course of time mutual co-operation will come to be quite a natural development.

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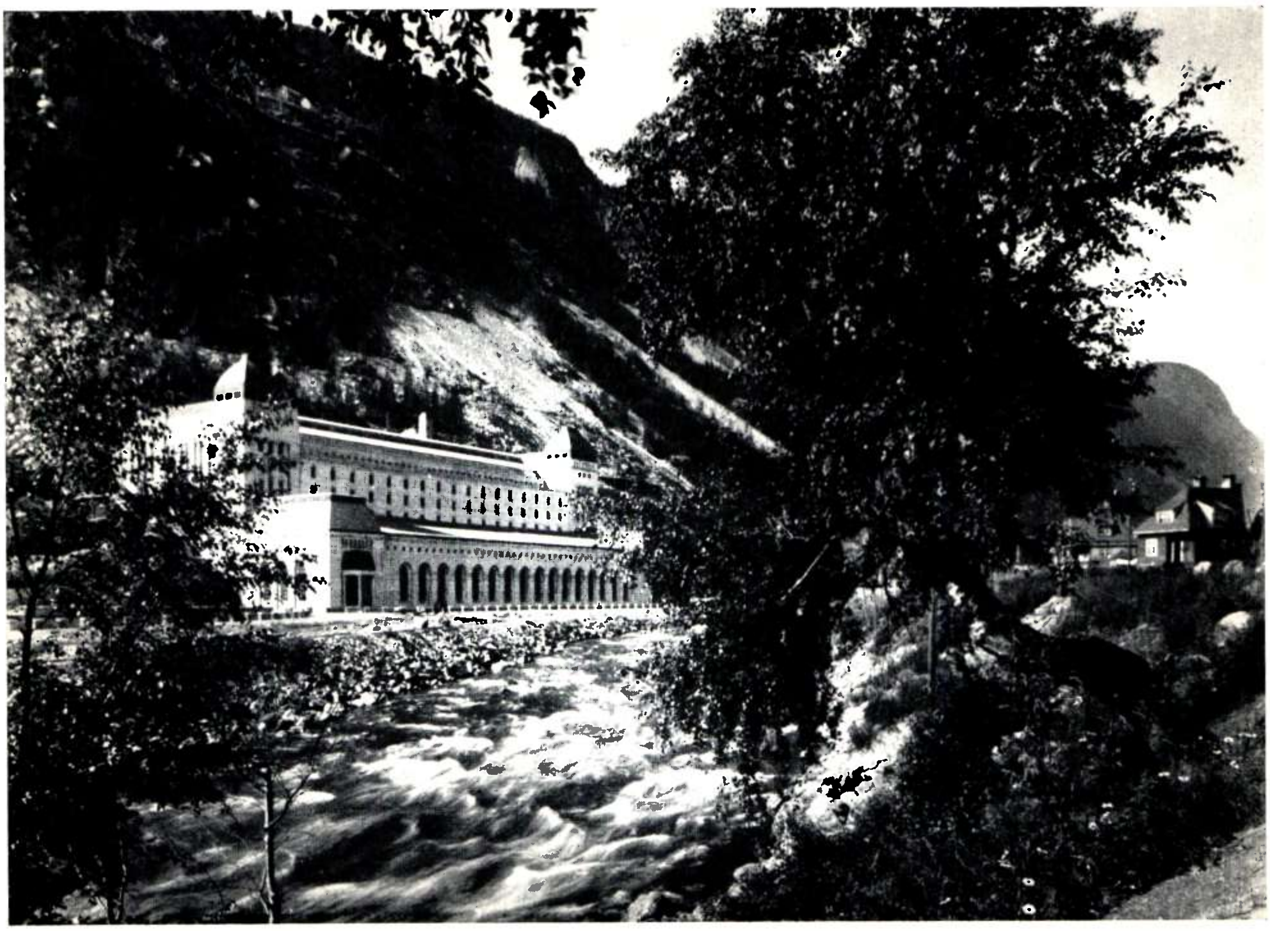
Såheim Power Plant. Head: 275 m — Installation: 118 500 kW. used in the Large-scale Industry



however, are of a type more resembling the first group of waterfalls in the Eastland. Of large falls belonging to the first mentioned category may be noted Fykanåga, which when fully developed can produce about 100 000 kW. Further we have in this group the Skjoma river, in which one plant yields 80 000 kW. Of sources of power belonging to the other category we have Rosåen, which on full development is calculated to altogether 175 000 kW. of all-the-year power of which 115 000 kW. are generated in one of its three power-stations.

The rest of North Norway (Troms and Finnmark counties) is, as stated, far more poor in utilisable water power. The situation here is illustrated by the following data in comparison with the corresponding figures given above for Nordland County and the whole of Norway: Troms possesses altogether 195 000 kW., corresponding to 7,5 kW. per km^2 and 2,0 kW. per inhabitant. Finnmark has 154 000 kW., representing 3,2 kW. per km^2 and 2,9 kW. per inhabitant. The largest source of power in Troms county is the Bardu river, from which can be obtained about 80 000 kW. of all-the-year power, in two almost equally large plants. In Finnmark we have the Alta river, which is estimated to be capable, when fully developed, of yielding up to 80 000 kW., of which 60 000 kW. from the three largest falls. In the Pasvik river, which forms the frontier between Norway and Finland, there is also a good deal of utilisable water power.

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The stream-flow in the rivers varies considerably in the course of the year, chiefly because the precipitation in winter comes largely in the form of snow, which does not melt and replenish the water-courses until later on in the spring and summer. Thus it will immediately be obvious that the existence of natural facilities for providing the necessary reservoirs for regulating the flow of water is an essential factor for the utilisation of Norway's water power. Something has been said above respecting the conditions of regulation. A supplementary view shall here be added.

For providing the total energy before stated to be obtainable from the water courses in Norway—9,2 million all-the-year kW.—reservoirs with a total capacity of about 45 milliard $m.^3$ are required. The reservoirs hitherto constructed have a capacity of about 10 milliard $m.^3$ altogether. — Regarded as a whole, the natural conditions in Norway must be said to offer very good facilities for establishing the storage basins requisite for regulation of the watercourses. But also in this respect the circumstances vary a good deal in the different parts of the country.

As regards the rivers in South-eastern Norway the possibilities for a more extensive regulation of the flow of water are in general relatively limited, seeing that in the lowlands the construction of reservoirs cannot be carried very far, in view of the density of habitation, extensive agriculture, traffic communications etc. As an example may be mentioned the Glomma. This river has in its drainage area the largest lake in Norway, Mjøsa, (area 359 km^2). Below this lake is situated the aforesaid Mørkfoss-Solbergfoss power-plant. The average flow of water is here 665 sm^3, but the regulated water supply can hardly be expected to attain to much more than half of that quantity.

As already remarked, the watercourses in the Westland offer very good facilities for construction of the necessary reservoirs. Here can for practically all waterfalls be calculated with fairly complete regulation of the flow of water.

The size of reservoirs necessary for attaining different sizes of regulated stream flow in a river can be expressed in percentage of the total average quantity of water per year which passes the place where the regulated flow is to be utilised. For the establishment of such statements there have for a considerable time been made consecutive—for the most part daily—observations of the flow of water in the rivers throughout the country. At present about 450 of such observation points are erected. A very good basis has thus been obtained for fixing the relation between the regulation reservoir and the stream flow that can be figured on. A comparison between the different parts of the country shows that the Westland rivers have a low percentage, *i. e.* they require relatively smaller reservoirs for regulation of the flow. As already mentioned, the storage basins are here mostly located in the high mountains, where the land has little value, and the construction work can be carried out in and on solid rock. Moreover, as larger heights of fall are here at hand, the costs of regulation, reckoned per kW., are very moderate.

What has been said above respecting the regulation of the Westland rivers also to a large extent applies to those of Nordland county. Special mention must be made, also as regards regulation facilities, of the largest source of power in that county, the Rosåen river. By means of a 10-meter dam in the Rosvatn lake a reservoir of 2 milliard m^3 capacity can be established, sufficient for complete regulation of the watercourse.

As already stated, the Trondelag rivers, with some few exceptions, offer small natural facilities for regulation, since the lakes supplying the larger rivers are here few and of no great size. Partly in view of obtaining power and partly in order to reduce the danger of destructive floods, plans are at present on foot for the construction of artificial reservoirs. In this connection it may be of interest to mention that one of these reservoirs, Sylsjoen in the Nidelv, in case it should be executed, would lie practically in its entirety on Swedish ground. The procedure for the arrangement of the questions arising from this circumstance has been fixed by the convention of 1931 between Norway and Sweden respecting inter-state watercourses.

The Voring Falls

Likewise in the two counties farthest north, Troms and Finnmark, the natural conditions for regulation are small. In Troms county, however, quite good regulation of the Bardu river can be attained. In Finnmark a number of reservoirs can be created by regulation of the lakes along the Alta river. An alternative in utilisation of the water falls in the Pasvik river includes a regulation of the Finnish Lake Enare, and if this comes to accomplishment, the available water power in the Pasvik river will increase from 30 000 kW. to about the double capacity.

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A survey of how the Norwegian water power is distributed, grouped according to the largeness of all-the-year power from each plant, is illustrated in fig. 1. A short explanation of the diagram may be useful:

Taking the group 5001—10 000 kW., for example, and measuring on the right-hand scale the height of the lower black space we find that the total number of plants with a capacity of from 5000 to 10 000 kW. of all-the-year power is about 170. — On measuring in like manner, but on the left-hand scale, the upper black space in column 5001—10 000, it is found that these 170 falls can be developed to yield a total all-the-year power supply of, in round figures, 1 200 000 kW. It must be added that Fig. 1 cannot, of course, furnish exact figures, but can only be regarded as giving a good idea of the situation. — The water power estimated as "available" is distributed among some 1340 falls. Of these about 60 per cent have heads of 300 m. and upwards.

Available Water Power in Norway

(Developed Water Power incl.)

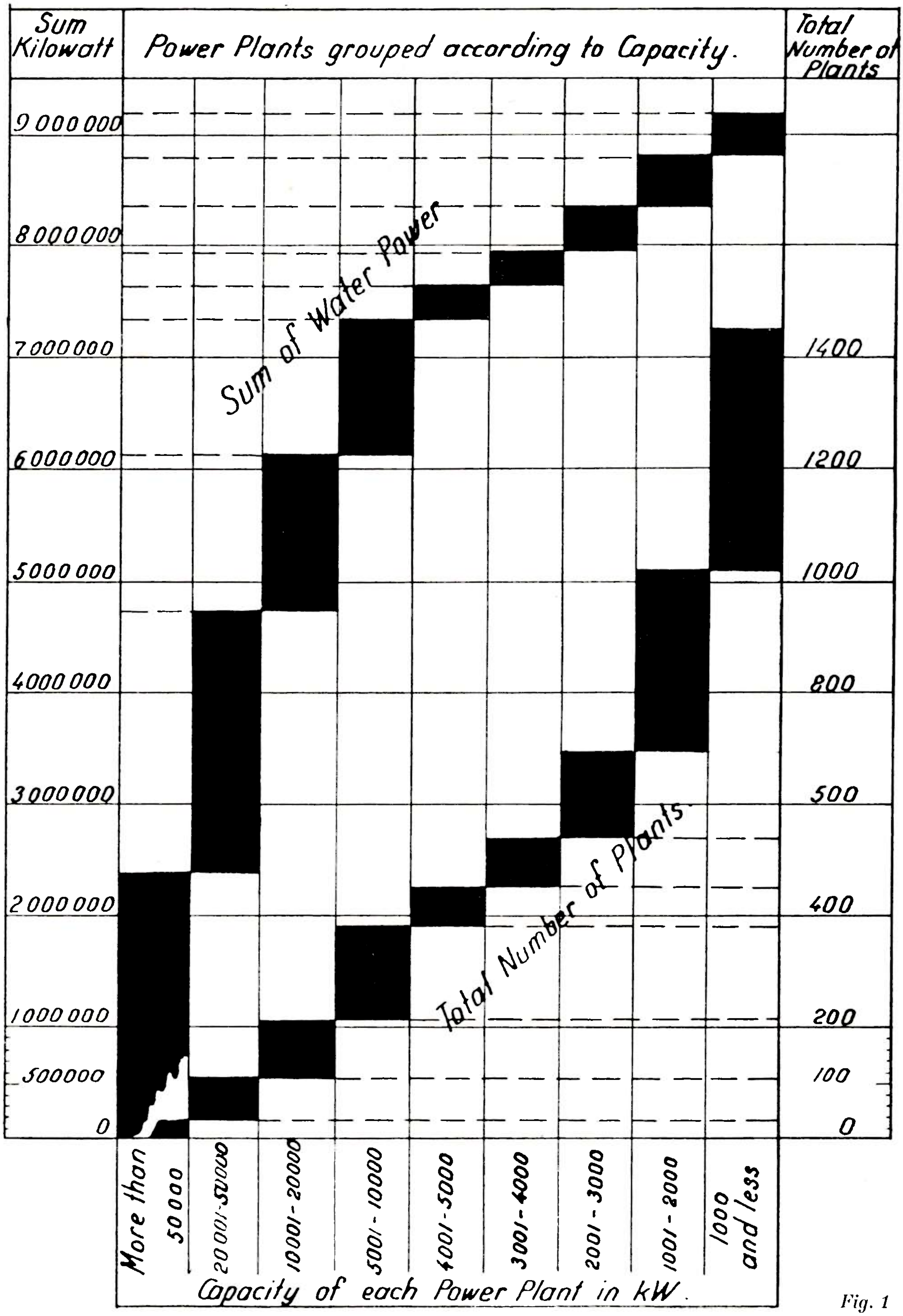

Fig. 1

It has already been mentioned that a number of Norway's largest and most favourable power-plants are or will be developed at or in the near vicinity of ice-free harbours. Of the country's hitherto undeveloped water power we have close upon 150 falls located at or near the sea, each of which can be developed to produce 10 000 kW. of all-the-year power, or more.

In connection with the question of establishing ironworks in Norway plans have been prepared, with estimates of cost of developing a number of waterfalls belonging to the State which are deemed specially suited for supplying power for such a purpose. In the following table is given a survey of quantities of power, construction capital and prices of power. It is to be remarked that the developments are planned for the production of all-the-year power (*i. e.*, available in 8760 hours per year) and that the estimates are based on the price-level of August 1935. Further it must be pointed out that several of the falls can furnish larger quantities of power than stated in table. The question under consideration, however, was limited to the giving of a technical-economic survey with respect to the furnishing of at most 60 000 to 70 000 kW. from the different sources of power.

	Quantity of power in kW. at the sea		Cost of power at the sea		
Sources of power	All-the-year power	Reserve	Construction capital in million kr.	Kr. per kW.-year	Power transmitted to:
Bardu River	84 100	19 300	37 240	43,60	Salangsverk.
Skjoma	63 500	13 400	35 580	54,70	Sea at Elvegård.
Fykanåga, Glomfjord	82 000	16 800	28 775	33,40	Spildra.
Bjerka	33 500	17 500	14 900	44,00	Finneidet.
Rossåen	62 500	16 600	20 910	33,30	Finneidet.
Namsen	45 000	15 000	19 080	41,80	Mellingfoss.
Ullo	67 000	16 900	20 650	30,80	Haugenesset at Vadla.
Kvina, lower	52 000	5 800	28 379	54,50	Oie at Fedefjord.

It appears from the table that the production cost of the power varies from kr. 30,80 to kr. 54,70 per kW.-year, which corresponds to a price of 0,35 to 0,63 ore per kWh.

The Norwegian Society of Civil Engineers in 1936 prepared for publication a booklet entitled: "Some Water Power Resources available in Norway". In this are given brief accounts of the power sites entered in the above table, as well as of several others which are in private ownership, in some cases with statement of the production price of the power. The booklet is accompanied by a map showing the location of Norway's most important deposits of iron, pyrites, copper, zinc, lead, nickel and limestone.

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Contrary to what is the case in other European countries, the water power in the Norwegian rivers is subject to the law of private property. The owner of the land adjoining the river also owns the water therein and therewith the water power. If there are different owners on each side of the river they share the water-rights. As a power-producing watercourse is usually composed of rapids and falls extending over a considerable distance and as the rivers moreover often form the boundary between the properties on each side, there may be rather many owners of such a power source. In many of the utilisable sources of power—and especially in those most favourably situated—the rights of ownership are, however, now assembled in one hand, the owners of the land having sold the water-rights originally pertaining thereto.

By far the greater part of Norway's water power is still in private hands, but both the State and the different municipal corporations and counties are large owners of water power. Thus the Norwegian state at present possesses somewhat more than 2 million kW. About one half of this power pertains to state properties throughout the country and the other half has been acquired by purchase. The object of these purchases has been partly to secure for the State a regulatory influence as regards the attainment of sufficient supplies of electric energy at reasonable prices for the general electricity supply of the country and partly to ensure for the state railways suitable sources of power on their changing over to electric traction.

The transfer of ownership rights in water power is subject to the provisions of the so-called Acquirement of Property Act (Concession Act) of 14th December 1917, with supplementary Acts of 14th August 1918, 21st May 1920, 22nd June 1928, 24th June 1931 and 24th March 1933. According to these Acts only the State and the local authorities have full liberty to acquire the right of owning and using waterfalls. All others must have permission from the Crown (consession). Such concession is necessary for the acquirement of any waterfall which alone or when developed together with other water power owned by the purchaser can by regulation be brought to yield more than 1000 natural horse-powers, or for the acquirement of water power which, when regulated, may be estimated, together with other falls owned, rented or used in Norway by the purchaser and his family, to amount to more than 5000 natural horse-power. The concession is given for a period of up to 50 years, or with the consent of the Parliament up to 60 years, whereafter the fall, together with all land, rights, machinery, buildings and other appurtenances belonging thereto, reverts to the Norwegian state without payment of any consideration. All that does not so revert the State can take possession of at a valuation or it can be ordered to be removed. The State is further accorded the right of redeeming the whole plant when 35 years of the concession period have elapsed.

The Acts further contain prescriptions as to time-limit for commencement of development work, as to delivery of power and payment of imposts to state and local authorities, as to preferential right of employment for Norwegian workmen and officials and as to the allotment of funds to ensure fulfilment of the district's obligation to afford relief in case of need to the hands employed in the work of development.

Of legislation respecting rights of ownership in Norwegian water power may further be mentioned: The Act of 15th August 1911, with supplementary Act of 12th July 1912, respecting compulsory surrender of waterfalls to the local authorities for certain purposes and the Act of 6th July 1917 respecting compulsory surrender of waterfalls to the State. The purpose of these laws is to secure for the public authorities and for the community at large the water power that is deemed requisite. Both Acts apply alike to developed and non-developed waterfalls. The first-mentioned Act, however, can be applied only to falls which have not been developed to produce more than half of the quantity of power they can be brought to yield on suitable regulation.

Production of Electricity.

As early as in the thirteenth century the water power in the Norwegian rivers was employed for working the corn-mills. From the sixteenth century it finds a further and by degrees greatly increasing application as driving force for the saws used in cutting up timber. Then in the first half of the nineteenth century we find along the rivers water-driven paper-factories and later pulp-mills. The number of these latter gradually increased, and it was here especially that the new invention, the water-turbine, was taken into use from the 1860's onwards.

In all the above-mentioned operations only small heads of water and limited quantities of power were employed. And it was only a small proportion of the country's water power that had been utilised. As late as in 1895 it is reckoned that only about 75 000 of the available 9 200 000 kW. had been developed. Of these 75 000 kW. about three-fourths found employment in the wood-products industry, *i. e.*, in undertakings that obtained their raw-materials from Norway's great wealth of forests. The water power was for the most part employed direct in the form of mechanical energy. In only very few cases was it used to drive dynamos for generating of electricity, and then only for the particular undertaking's own requirements.

About the end of the last century, however, the work of developing the country's water power began to accelerate. This was partly due to newly discovered methods of production based on the employment of electricity on a large scale, and of the raw materials to be found in rich abundance within the land. Partly—and not least—it was due to the fact that the problem of conveying electric energy over long distances had been solved. Utilisation of water power was no longer confined to the site of the power-station. The electric power could be transmitted to places best adapted for the pursuit of industrial operations and it could be brought into the homes to provide light and heat.

In Fig. 2 is given a survey of developed water power in Norway in the years from 1895 to 1937,

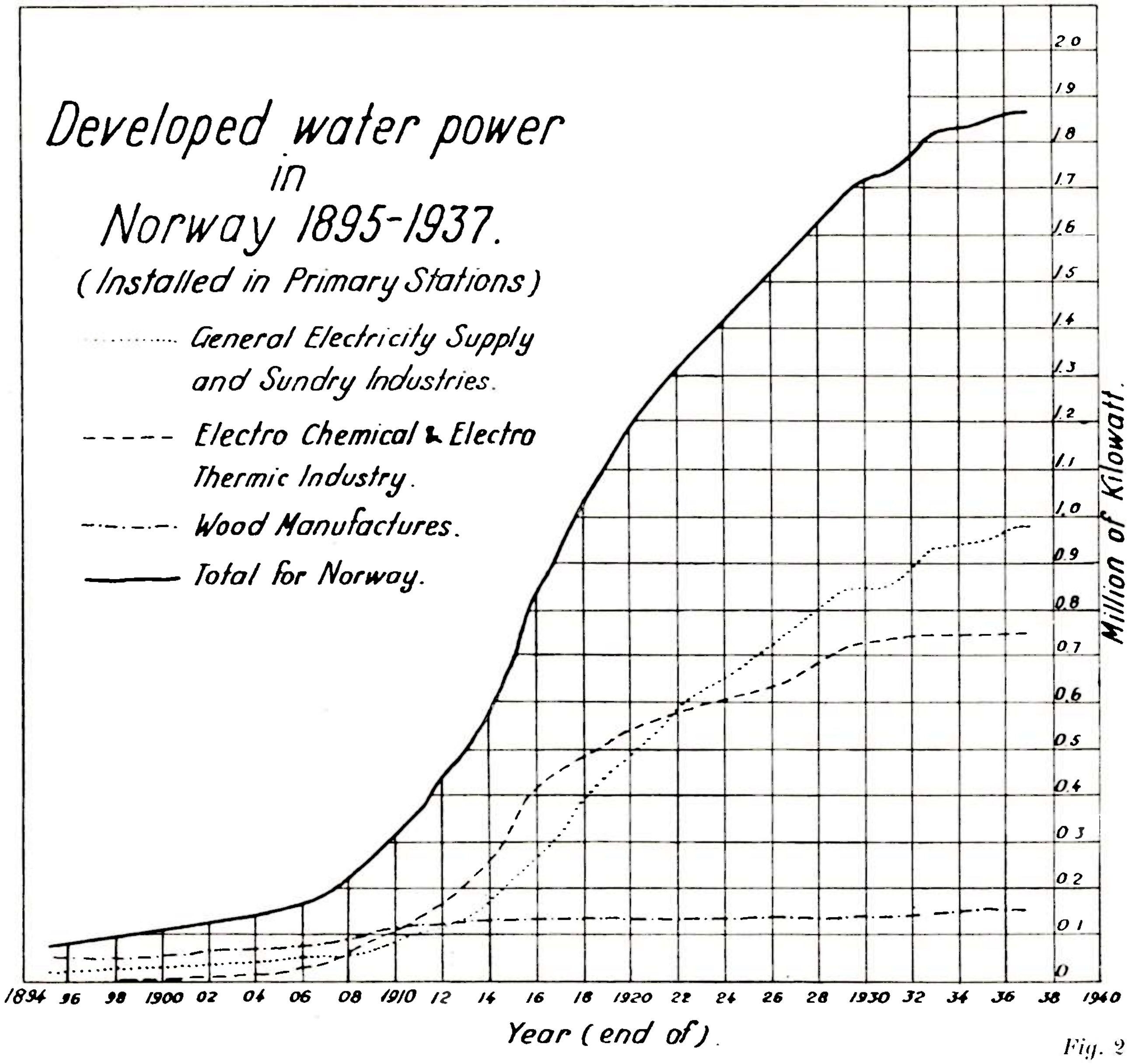

Fig. 2

with curves showing the quantity of power developed and its distribution between the different large consumption groups. As will be seen from the figures, the increase in development of power was very great in the decade 1910—1920 and somewhat less in the years 1920—1930. From 1930 up to and including 1937 the rate of increase in quantity of developed power has, as the figure shows, been materially reduced. A number of development operations are, however, at the present time in progress throughout the country, partly for the establishment of large new power-plants, partly for enlargement of already existing plants and partly for modernisation of older works. From the survey one now has of the situation, it may be assumed that the next few years will again show a very large increase in the development of water power in Norway.

The amount of electric energy produced in Norway by other agencies than water power is quite inconsiderable. At most, it may be estimated at about 2 per cent or so of the total production of energy.

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At the end of 1936 there had been developed and put into operation in Norway 1477 water power plants, with a total installation of 1 860 000 kW., roughly corresponding to 650 watts per inhabitant. Reckoning in all-the-year power the developed power-plants represented in round figures 1 290 000 kW. That is to say, at that time 14 per cent of the available water power in Norway had been developed.

Of the aforesaid quantity of developed power almost exactly 60 per cent is intended for delivery to industrial undertakings. With the exception of the Glomfjord power-plant and the Kongsberg Silverworks plant, which are owned by the State, all plants which supply power for industrial purposes in Norway have been constructed by private enterprise. The remaining 40 per cent of the developed power is based on general electricity supply, comprising delivery of electric power for lighting, for household use, for motor-driven machinery in agriculture, industrial handicrafts etc. This business of supplying electricity for general purposes has since it began in the 1890's become more and more the task of the local authorities. It is these which lead the way, separately or in co-operation, in this field. During the last decades, however, the State has also taken a hand, either by development of waterfalls or by construction of transmission lines. In 1936 the supply of electricity for general purposes amounted altogether to 3 160 000 000 kWh. Of this quantity about 17,5 per cent was produced by private power-plants, about 11,5 per cent by the state-owned and about 71,0 per cent by district-owned power-stations. The distribution of the power to the individual consumers was, to the extent of about 91 per cent, effected by the local authorities.

As an interesting little detail in this connection may be mentioned that the first municipal electrical works in the country was built by the most northerly town in the world, Hammerfest, which in 1890 developed the Storelva river in order to provide the citizens with electric light and power.

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The total production of electricity in Norway, measured on the meters of the larger consumers, amounted in 1936 to 7 985 000 000 kWh., or 2750 kWh. per inhabitant. According to the records available this is the largest production per inhabitant which any country in the world can show. It is twenty per cent higher than in the land which comes nearest and almost double as large as for the country coming third in succession.

As already stated, most of the electricity produced is used for industrial purposes. For instance, in 1936 about 4150 million kWh. went to the electro-chemical and electro-metallurgic large-scale industries, about 950 millions to the cellulose-, paper- and pulp mills and some 95 millions to the mining industry.

The electric power to industries is, with some few exceptions, delivered from plants constructed specially for that purpose.

No detailed account respecting the supply of power to industries—amount of capital employed in development constructions, production price of the power, period of use etc.—has been prepared, as the necessary particulars have not been at disposal.

It has previously been mentioned that extensions are at present being made at the Bjolvo and Hoyanger power-plants. At the latter place a further supply of power is being secured by development of the Eriksdal water course. Also in the Trondelag district the production of power for industries is being increased through the development of the Funna river by the Meraker Smelting Works. In addition to the extensions and new developments of water power plants which are in progress for already existing industries there are plans on foot for providing power for eventual new industries. Thus a committee has been appointed by the government to investigate the question of establishing iron-works based on the employment of electric power.

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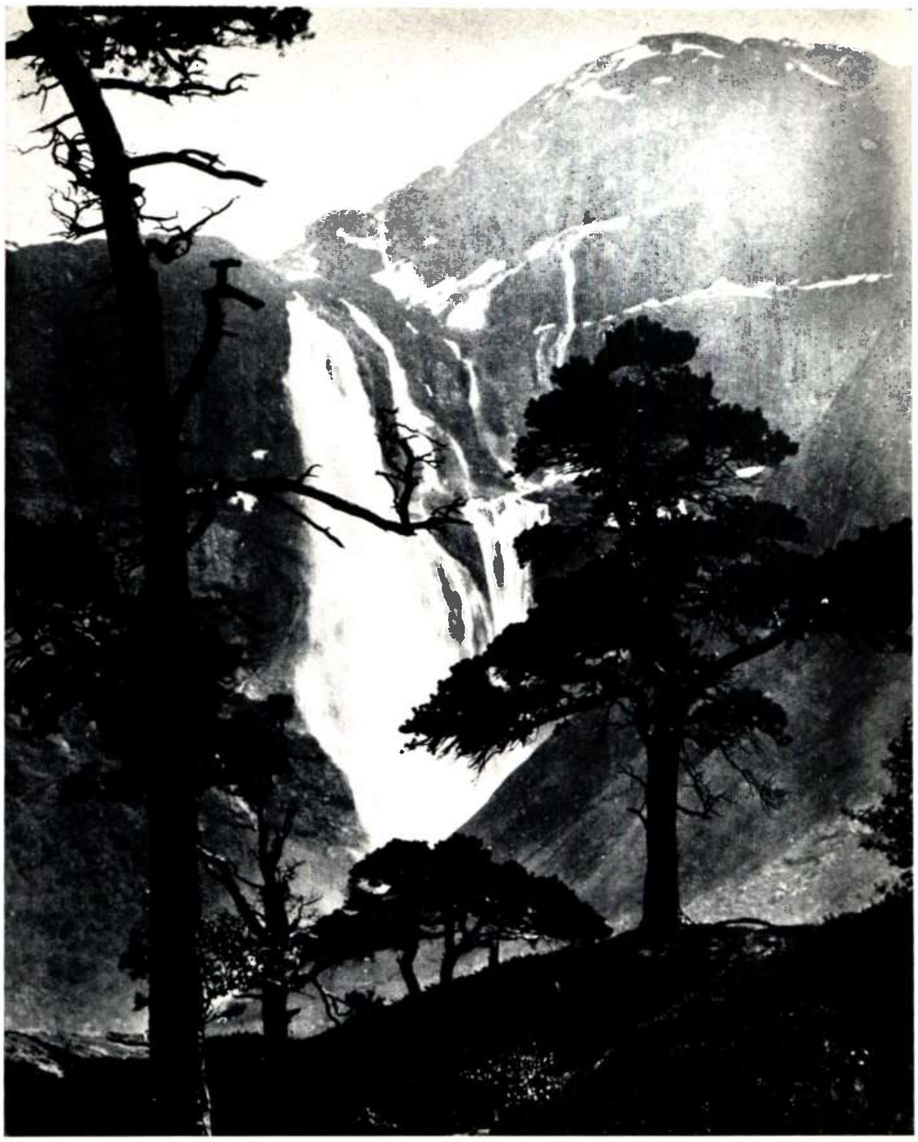
The general electricity supply in Norway is highly developed. No less than 75 per cent of the population was in 1936 provided with electric power. All Norwegian towns are supplied with electricity and about 66 per cent of the population of the rural districts. Taking into consideration the sparseness of the population —9 inhabitants per km²—it will be realised what a vast amount of labour has been devoted to supplying the country with electricity for general utility.

A good idea of the extent of these efforts will also be gained by considering the amount of capital employed. On the 1st January 1916 the capital devoted to general electricity supply is reckoned at about 127 million kroner. By January 1st 1923 the amount had risen to 780 millions and by January 1st 1936 to 1121 millions. The population at these dates was respectively 2,5, 2,7 and 2,9 millions. Deducting the sums written off in the course of years, the power-works erected for general electricity supply represent as per 1st January 1936 a capital of 694 million kroner.

From the above figures it appears that especially during the War and in the years immediately following very large amounts in proportion to the population of the country were invested in the furnishing of electrical power. This finds its explanation in two circumstances: In the first place, the supplies of coal and oil from abroad during the War were greatly restricted, or else entirely stopped. — It was therefore necessary to make use as far as possible of the country's own resources in order to cover the requirements. — In the second place, owing to the enormous rise in prices in all fields during the War the costs of development operations were greatly increased. This latter circumstance, indeed, led to the result that, when normal conditions returned, many of the power-works were unable to cover their annual payments of capital and interest. Some of them were therefore compelled to seek arrangements with their creditors, while in some cases the State had to lend assistance by grants and guarantees. Taking all the electricity supply works together, however, the financial situation is now restored to a sound condition. The electrical works in the towns show a combined annual surplus which exceeds the total deficits shown by the rural works.



The Skjeggedal Waterfall

As stated above, about 66 per cent of the rural population has access to electrical power. Somewhere about 700 000 of the land's inhabitants are, however, still without such advantages. Efforts to reach as many as possible of these have now been initiated by the State authorities with the object of trying within 10 or 15 years to supply electricity to a further half million of those who are still without it. The intention is that the State shall meet on an average about 40 per cent of the expenses of construction.

It has been mentioned that the supplying of electricity for general purposes has mainly been taken up by the local authorities of the respective districts. This task is in some cases accomplished by the individual districts ("communes", as they are designated in Norway) through "communal" electrical works. Sometimes, however, districts which are conveniently situated with respect to each other collaborate for the supplying of power by establishing so-called "intercommunal" electrical works. In other cases, again, the larger administrative unit, the county, undertakes the power supply for its subdistricts through a "county-communal" electrical plant.

These different types of works for general electricity supply have successively arisen in the above-named order. In the whole country there are at present 24 intercommunal and 6 county-communal electrical works. In both of these types the sale of power takes place either as

Experiences from Norway show that the mode of payment adopted—the form of tariff—plays an important rôle as regards the development of the general electricity supply. Originally the fixed-price tariff, *i. e.*, a fixed subscription price per kW. per year, was practically the sole form in use. This form of tariff is also called "vippe" tariff, because the supply to the consumers is controlled by a current-limiter, or "vippe" as it is named in Norway. The price may vary according to circumstances between kr. 100 and kr. 300 per kW. per year. The consumer is then entitled to use the number of kilowatts he has subscribed for uninterruptedly during all the 8760 hours of the year, if so desired. Even without constant use of current the prices offered by this form of tariff will under ordinary circumstances be so low that the consumers are stimulated to employ electricity for a great variety of purposes. It can hardly be doubted that it is largely owing to this tariff arrangement, which is very popular and is widely adopted, that the supplying of electricity for general purposes in Norway is to-day so highly developed.

The desire to extend the possibilities for an economic use of electricity for domestic cooking has in recent years led the electrical works to try to find new tariff forms suitable for that purpose. The quantity of power required for electrical cooking is so large that the expenses with use of the limited current tariff (the "vippe" tariff) alone will usually be too high for most of the Norwegian households. Several electrical works have tried to meet this difficulty by introducing other forms of tariff, the so-called mixed tariffs. Several kinds of such mixed tariffs are in use, two of which shall here be mentioned: the excess consumption tariff and the basal charge tariff.

The excess consumption tariff allows the consumer a fixed minimum quantity of energy, for example, 500 W. Any additional energy required is paid for at a certain rate per kWh.

The basal charge tariff prescribes a fixed preliminary payment, often calculated according to the size of the residence. To this comes a supplementary charge per kWh. consumed.

Energetic efforts are otherwise being made to bring about a more extensive employment of electricity. Thus it is being sought to find a satisfactory solution of the problem of electrical heating in the homes. This question is at present the subject of comprehensive experiments and investigation both by special committees and by many of the electrical works. No definite result of these investigations has, however, as yet been attained.

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It might perhaps be expected that the Norwegian railways would mainly employ electrical power. That such is not the case is due to several causes. In the first place, the density of traffic is with few exceptions small. Moreover, many parts of the country are still without any railway communications at all. Consequently the grants which can be made to the state railways are preferentially employed for extension of the system rather than for improvement of existing lines. Electrification of these latter is proceeding, however, although the rate of progress is not so rapid as could be desired.

At the present time somewhere about 9 per cent of the total mileage of railways in Norway, or 320 km., is worked by electricity. These lines take about 25 per cent of the traffic. The power is supplied partly from plants especially erected for this purpose, partly from the ordinary power supply network. The consumption amounts to some 35 million kWh. per year, measured at the contact connection.

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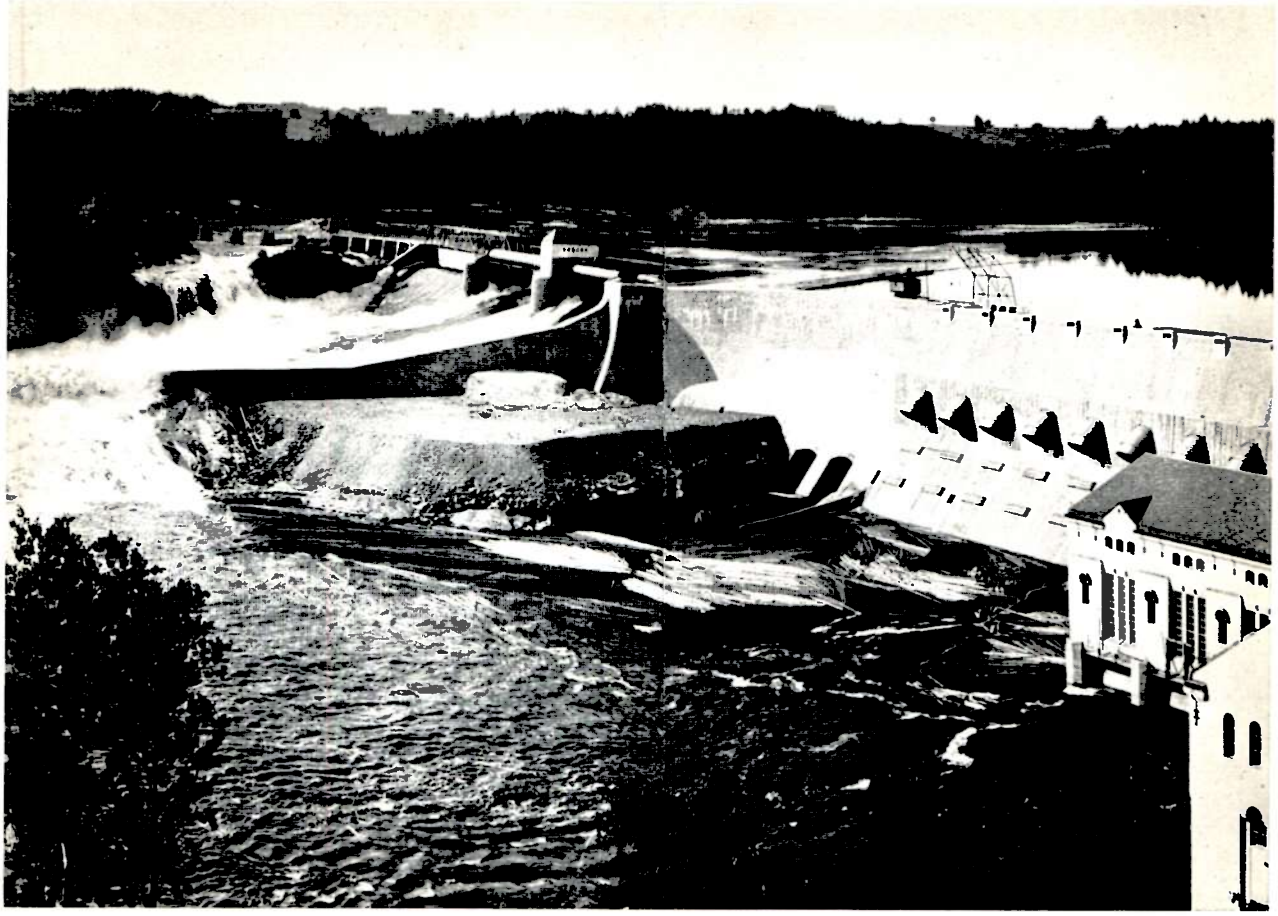
Of legislation respecting the production, leasing and distributing of electricity in Norway may be mentioned:

The aforesaid Acquirement of Property Act (Concession Act) of 14th December 1917 prescribes conditions for the leasing of electricity produced by water power. When the quantity to be leased exceeds 500 (in exceptional cases 200) horse-power a concession is required, except for leases to the Norwegian state or local authorities. An Act of 23rd July 1894, with supplementary Act of 26th July 1916, contains provisions regarding compulsory cession of ground etc. for transmission lines for electrical power. Further we have the Act of 16th May 1896, with amending Acts of 26th July 1916 and 16th July 1920, respecting measures for safeguarding against dangers and inconveniences from electrical plants etc. According to the Prescriptions for Electrical Plants contained in this latter Act direct current of over 500 V. and other forms of current of over 250 V. tension are to be regarded as high-voltage electricity. (The great majority of the distribution apparatuses in Norway employ 3-phase alternating current of 220—230 V. tension.) An Act of 24th May 1929, with amending Acts of 7th April 1933 and 7th May



Vamma Power Plant. Head: 26 m — Installation: 81 600 kW. used in the General Electricity Supply

1936, provides for official supervision of electrical plants. Finally, we have the Act of 1st July 1927 respecting registration of electrical transmission lines. This Act contains rules for the registration of high-voltage power transmission lines in a special register.

In this article the metric system of weights and measures is employed. For conversion to the English system the following data are given:

1 metre (m.) = 3,2808 feet.
1 kilometre (km.) = 1000 m. = 0,6214 miles.
1 km^2 = 0,3861 sq.-mile.
1 m^3 per sec. (sm^3) = 35,315 cu.-feet per second.
1 kilowatt (kW.) = 1,3417 Eng. horse-power.
1 kilowatt-hour (kWh.) = 3414,2 British thermal units.
1 Norwegian krone = 100 ore = 1 shilling or 0,25 dollar (1935 exchange).


NORWAY
Map showing the Water Power Resources of the Country.
0 20 40 60 80 100 KM.
Scale for Water Power in All-the Year kW.
Diam. of Circle.
5000 20000 40000 60000 80000 100000
State Property
Municipal and Private Property.
Developed Water Power.
Desember 1937.
N.
FINNMARK
TROMS
NORDLAND
NORD TRØNDELAG
SØR TRØNDELAG
MØRE
SOGN OG FJORDANE
HEDMARK
OPLAND
AKERS HUS
OSLO
BUSKERUD
ØSTFOLD
VEST-FOLD
TELEMARK
HORDALAND
ROGALAND
AUST-AGDER
VEST-AGDER
SVERIGE
FINLAND