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The cost of hydroelectricity

Hydro Power and Other Renewable Energies Study Committee

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THE COST OF HYDROELECTRICITY

CONTENTS

THE COST OF HYDROELECTRICITY

EXECUTIVE SUMMARY

The similarity of generating facilities means that we have to take a look at the costs of each of them.

As for hydroelectricity, it is characterized by :

- a major investment cost,
- a low operating cost due to automation,
- high taxation which tends to be on the rise,
- no fuel cost, except for pumped storage.

A comparative study has been performed on the basis of data available from previous studies : TARGEN for fossil-fired facilities, HYDROPRIX and HYDROPLUS for hydroelectricity and additional information (UNITED STATES and HYDRO-QUEBEC generation mix, power plants under development).

The following has emerged from this study :

- The operating expenses (operation, maintenance, supplementary overheads) of hydroelectricity are generally lower than those of all the other means of generation.

- The total cost (operating expenses and capital costs, excluding tax charges) shows a clear advantage for hydroelectricity (especially with a discount rate of 5%). The weight of the assumptions made in this study considerably affect the result; for example, the fuel share over the utilization time and the investment share over the depreciation time selected.

The comparison is also made for thermal power, concerning facilities under development and for hydro power, concerning power plants in operation.

Globally, the balance remains to the advantage of hydro power, except, of course, for investment costs.

A comparison with the other renewable energy sources proves to be difficult as they are still in a semi-experimental stage.

The conclusion of the study is therefore the following for an operator of a generation mix :

- Observe the advantage provided by the use of existing hydro power facilities for a generally higher service provided.

- Consider any development after having made a full assessment: expenses - service rendered over the long term by taking into account all of the components.

1. THE PROBLEM INVOLVED

Within the scope of competing or complementary generating facilities, one has to focus on each of the generating facilities available apart from the mutual interests of these facilities with regard to the supply of the power systems.

For the operator of the power plants, the price that it costs to deliver energy plays an important role in the decisions that he must make both with regard to the investments to be made and routine operation.

Concerning the other "so-called renewable" thermal generating facilities, the position of hydroelectricity is often characterized as follows :

? capital-intensive investments, a long construction period, the need to amortize the capital invested over a large number of years.

? a relatively low operating cost due to the high level of automation of power plants and substantial maintenance expenses, but a high payoff period *(e.g.: works on civil engineering structures)*.

? high tax and contractual expenses and which currently tend to increase.

? a nil fuel cost (except for pumped storage power plants where generally the electrical energy consumed occurs during use of the least expensive thermal power facilities).

? a lifetime such that very often the depreciation costs are low or nil, which results in a lower cost and often similar to that of operating expenses alone.

It would therefore be worthwhile to see what the situation is now and carry out any comparisons that may be made, it being understood that they are always difficult and have a limited scope due to the difficulty of providing homogeneous and comparable data.

2. DATA SOURCES

The following data were usable for the Valuation and Quantification Sub-Group:

✧ For thermal generating facilities:

The report *"Electricity Generating Cost for plants to be commissioned in 2000"* - 60.02 TARGEN

January 1994 edition ref: 06002Ren9417 - This report will not be updated before early 1997 and only the main trends taking shape for thermal generating facilities were able to be taken into account in this report.

✧ For hydroelectric generating facilities:

Data contained in the studies:

- *"Etude du prix de revient des usines hydrauliques" ("Study of the cost price of hydro power plants")* - 30 HYDROPRIX (91 fr 30.2).

- *"Dynamic service rendered by hydraulic power stations - Definition, quantification and evaluation study of the cost price"* - 30.02 HYDROPLUS (03002 Ren 9315 - Revision A).

They have been supplemented, for hydro power, with the introduction in the samples of each type of power plants already studied, of new facilities representative of utilities or countries not yet taken into account or for the others of new facilities for which data were available.

It should be noted that for either of the facilities, the costs indicated exclude all expenses due to taxes and taxation.

As concerns the calculation of capital (or investment) costs, it should be mentioned that the calculation method used by the Groups of Experts having worked on hydroelectricity is similar to that of thermal generating facilities since it is transposed by the method used by TARGEN (or COST).

3. DATA USED

3.1 Thermal generating facilities

The following results are drawn from the 1994 edition of the TARGEN report:

- in **XEU 1995** (European Unit of Account for 1995 - the transposition of XEU 1992 to XEU 1995 values being performed by using the corresponding development of this currency between these two dates). The EURO currency is equivalent, of course.

- for a utilization time of thermal power facilities of about 6,600 hours.

5% discount rate

c XEU 95/kWh	Capital	Operation	Fuel	Total cost
Nuclear	1.87	0.77	0.71	3.35
Imported coal	1.30	0.67	1.83	3.80
Natural gas	0.76	0.41	3.16	4.33

10% discount rate

c XEU 95/kWh	Capital	Operation	Fuel	Total cost
Nuclear	3.43	0.76	0.72	4.91
Imported coal	2.32	0.67	1.80	4.79
Natural gas	1.28	0.41	3.02	4.71

(The range of costs among the various countries studied mainly due to investment costs is 1.7 for nuclear - 1.8 for coal - 1.6 for natural gas and this is independent of the discount rate).

The lifetime of the thermal facilities taken into account in the study is 25 or 30 years.

The latest developments show that gas combined cycle power plants have a reduced investment cost and a lower fuel cost, which means that the costs of the 1994 TARGEN survey are certainly overvalued.

3.2 Hydro generating facilities

The following results may be drawn from the two studies referred to:

- in **XEU 1995** (European Unit of Account for 1995 - the transposition of XEU 1992 to XEU 1995 values being performed by using the corresponding development of this currency between these two dates). The EURO currency is equivalent, of course.

- the total expenses are compared with the standard energy capability of the facilities.

5% discount rate

c XEU 95/kWh	**Generation**	**Investment**	**Total cost**
Run-of-river	0.26	2.26	2.52
Pondage	0.31	1.43	1.74
Seasonal	0.51	2.49	2.77
Conventional hydro power plants	0.34	1.97	2.31

As the energy capability is a purely theoretical notion and not representative of the service provided, only the ratio to the installed capacity will be used.

XEU 95/kW	**Generation**	**Investment**	**Total cost**
Pure pumped storage	8.24	28.43	36.67
Mixed pumped storage	8.28	52.64	60.92
Total pumped storage	8.25	36.51	44.76

10% discount rate

c XEU 95/kWh	Generation	Investment	Total cost
Run-of-river	0.26	3.88	4.14
Pondage	0.31	2.54	2.85
Seasonal	0.51	3.99	4.50
Conventional hydro power plants	0.34	3.44	3.78

XEU 95/kW	Generation	Investment	Total cost
Pure pumped storage	8.24	49.59	57.83
Mixed pumped storage	8.28	93.52	101.80
Total pumped storage	8.25	64.25	72.50

It should be noted that the differences between the average value and maximum and minimum values for hydro power plants are substantial and range from:

0.7 to 2.87 times for pondage power plants
0.6 to 1.7 times for seasonal power plants
0.8 to 2.0 times for pumped storage power plants

The samples taken into account represent:

	Capacity MW	**Energy capability GWh**	**Average load factor in h**
Run-of-river	1,910 (4,050)*	10,460 (22,550)*	5,600
Pondage	3,976	13,880	3,500
Seasonal	5,622	12,685	2,200
Total conventional hydro power plants	11,510	37,020	
Pure pumped storage	7,535	**	
Mixed pumped storage	3,775	5,015***	
Total pumped storage	11,310		

* *For run-of-river facilities and for only operating expenses, the sample could be extended to a larger number of power plants.*
** *The pumped storage energy capability is not defined.*
*** *For mixed pumped storage, only the energy capability due to natural inflows is significant.*

The UCPTE generation mix in 1992 represented:	104.2 GW 251.6 TWh
The sample studied is therefore:	22% of the installed capacity 20.5% of the firm energy

It may be considered as representative even though it only consists of relatively large power plants and also a number of facilities outside the UCPTE.

The following standard lifetimes for equipment making up a hydro power plant were used:

* 60 years for civil works
* 30 years for electromechanical equipment
* 15 years for automatic control devices

3.3 Some remarks concerning hydro power

For hydro power first of all, what conclusions may be drawn from the above values?

◆ The investment expenses are 5 to 7 times the operating expenses.

◆ The operating expenses vary according to the types of power plants, the complexity of the facilities and the various operating conditions explain this: 0.3 to 0.7 cXEU 95/kWh from run-of-river to seasonal facilities.

◆ The costs of pumped storage power plants include a non-negligible share from pumped storage facilities and their operation. The values are increased by comparing the costs solely with the capacity in generating mode. Using the equivalent capacity concept defined as the sum of the capacity in generating mode and the capacity in pumping mode should bring us closer to the real situation and consequently reduce the costs by almost half.

◆ The investment of a mixed pumped storage power plant is higher than that of a pure pumped storage (or seasonal) facility, which appears normal very often due to the size of the facilities and the nature of the sites.

◆ The amount of the investment in pondage facilities appears low. However, if compared with the installed capacity, 60.84 XEU 95/kW is obtained for pondage and 62.5 XEU 95/kW for seasonal facilities. The design and operation of this type of power plant are actually similar to those of seasonal power plants.

◆ Pondage power plants thus offer a dual advantage: their cost is lower than that of the other types of power plants and they can supply a daily and even weekly base load and peak load energy.

◆ The amount of initial investments for the construction of hydro power plants induces high capital costs that are all the more substantial as the assumption made for the discount rate plays a major role.

Water as a fuel has no cost (excluding pumped storage).

3.4 Data from the US generation mix

To supplement the UNIPEDE study, the results of a document published in the United States by UDI/McGRAW HILL (Utility Data Institute) "1993 Production Costs: US Hydroelectric Power Plants - UDI - 2037A - 94" were compared with those of European power plants. As the classification is not similar (a single category for conventional hydro power plants and another for pumped storage facilities) and insofar as the cost categories represent the same types of expenses (this was not possible to verify in the American study), the results are as follows:

c XEU 95/kWh	**Production Expenses**	**Capital**	**Total Cost**
Total hydro power plants	0.26	6.22	6.48

XEU 95/kW	Production Expenses	Capital	Total Cost
Total conventional hydro power plants	11.36	267,82	279,18
Total pumped storage	5.63	288,90	294,53

Values converted from US $ 93 to XEU 1995.

The discount rate used in the assessment of investment expenses is unknown, so one may assume that it is rather the rate of financial markets.

A study limited to a dozen or so pure pumped storage power plants of the North American generation mix and using the HYDROPLUS principles shows that capital payments are about 40 to 45 XEU 95/kW at the discount rate of 10%, therefore quite similar to the values calculated for power plants in the European generation mix.

The sample of US power plants thus examined includes:

For conventional hydro power plants: 38 740MW
166 870GWh

For pumped storage power plants: 17 230MW
14 030GWh

or a major part of the generation mix (approximately 70%).

The following may be observed :

❒ that the level of operating expenses is quite similar (possible errors on the exchange and convertibility rates, contents of the categories, etc.).

Conventional hydro: 0.26 (US) to 0.34 (UNIPEDE) cXEU 95/kWh
11.36 (US) to 12.23 (UNIPEDE) XEU 95/kW

Pumped storage: 5.63 (US) to 8.25 (UNIPEDE) XEU 95/kW

❒ that, on the other hand, the capital costs, if a discount rate of 10% is used, are much higher especially for pumped storage (4 to 6 times). Different modes of financing may be involved here. On the other hand, if the calculation is performed with the HYDROPLUS method, there is renewed result consistency, at least as far as pure pumped storage is concerned.

A check is made that the orders of magnitude provided by the study are both acceptable and representative as far as the operating expenses are concerned.

3.5 Data from the HYDRO-QUEBEC generation mix

Data were able to be collected for some facilities in operation, built and managed by HYDRO-QUEBEC. Although these facilities are of major size, some of them are similar to European power plants. The following is obtained, for example:

in cXEU 95/kWh

DISCOUNT RATE 10%	C (MW)	Generation (TWh)	Operating Cost	Investment Cost	TOTAL COST
LA GRANDE 1	1312	7.3	0.11	1.46	1.57
LAFORGE 1	817	4.5	0.16	2.13	2.29
BRISAY	382	2.3	0.20	2.56	2.76
LAFORGE 2	289	1.8	0.19	2.21	2.40

It should be noted that these power plants are of the seasonal type (some located downstream of the lake may be assimilated to this type) and that the investment cost includes that of the transmission lines and the fact that they are remote from demand centres.

It will be observed that these values are lower than those recorded in European power plants, this being explained by the size of the facilities and by the fact that, although classified under seasonal (or downstream seasonal), their number of operating hours (5500 to 6500 hours) makes them closer to run-of-river power plants. In any case, these rough figures remain very similar.

3.6 Forecast costs of power plants under construction or scheduled

Some power plants are under construction or planned in the near future; this is the case in Italy, for example. The forecast costs of these facilities make it possible to check whether any shift in present costs can be foreseen in the short term, both with regard to operation and investment. The sample of various types of power plants: run-of-river and pondage, of average capacity (25 to 60 MW) and pure pumped storage of 1000 MW, makes it possible to check that the forecast costs range from 5.4 to 9.3 cXEU 95/kWh (total cost at the discount rate of 10%), i.e. at values close to those of the study.

The foregoing data indeed confirm that power plants under development, so long as their costs are not weighed down with imposed investments to comply with regulatory and further environmental protection impositions, have approximately the same end costs.

4. COMPARISON OF THE VARIOUS GENERATING FACILITIES

4.1 Operating expenses

The following figures in cXEU 95/kWh are obtained if the various synthetic values are used:

Nuclear **	0.77
Coal **	0.67
Natural gas combined cycle**	0.41*
Run-of-river	0.26
Pondage	0.31
Seasonal	0.51
Conventional hydro	0.34

** River-sited combined-cycle units with a capacity of about 600 MW (forecast costs in most cases).*

*** These costs do not include the corresponding fuel costs.*

The following conclusions may be drawn from the above figures:

❒ on average, conventional hydro power plants remain less expensive than all of the thermal generating facilities, even if seasonal power plants are more costly than natural gas (but the service provided is not the same).

❒ the operating cost of pumped storage is the same as coal.

❒ nuclear remains the most expensive means of generation.

In this field, **hydroelectricity has an advantage but it is a slight one**.

4.2 Total cost

The results are as follows:

cXEU 95/kWh	**Rate 5%**		**Rate 10%**	
Nuclear	3.35	(0.77)	4.91	(0.76)
Coal	3.80	(1.83)	4.79	(1.80)
Natural gas	4.33	(3.16)	4.71	(3.02)
Run-of-river	2.52		4.14	
Pondage	1.74		2.85	
Seasonal	2.77		4.50	
Conventional hydro	2.31		3.78	

(The values in parentheses for thermal generating facilities give the fuel price).

The equipment taken into account provides for flue gas desulphurization and NOX reduction facilities, particularly for coal.

The following analyses may be made:

❒ if one acknowledges that the operating expenses are not very sensitive (over the short term) to the operation life, the same does not hold true for the total cost. The costs of thermal facilities are established for an annual operation time of 6,600 hours (fuel expenses).

❒ the 5% discount rate corresponds fairly well to European reality and favours capital-intensive investments with a high utilization duration (such as nuclear).

❒ at the 5% discount rate, hydro power is largely less expensive globally in all the cases concerned and the comparisons are still more so if one observes the various generating facilities with their potential utilization durations in **total costs**:

Demand time in hours	Thermal power facilities (1)	Type of hydro power plant of same utilization (2)	Cost ratio (1)/(2)
6600	Nuclear	Run-of-river	0.78
5000	Coal	Pondage	0.48
1500	Gas	Seasonal	0.66

❒ At the 10% discount rate, the differences are less clear because of the major weight of investments in hydropower costs.

❒ The above data must nevertheless be relativized because these costs are highly sensitive to calculation assumptions: utilization time for thermal generating facilities due to the share of fuel cost and depreciation time for hydro power facilities.

If one only looks at the investment (or capital) cost, hydro power loses its competitiveness (2 cXEU 95/kWh to be compared with, for example, 0.8 cXEU 95/kWh for gas and 1.3 cXEU 95/kWh for coal - discount rate 5%). This conclusion is fairly normal as hydroelectricity requires capital-intensive investments whereas, for example, gas combined cycle units benefit from standardization, simplified facilities and modest civil works equipment.

It is therefore much more on a **balance between costs and service provided** and on **the long term** that the study of the **competitiveness of the various generating facilities** should be based.

❒ The costs presented for thermal power are costs for facilities under development, which is not the case for hydro power, except perhaps for countries, such as Canada and the United States. In Europe, in general, the sites that remain to be harnessed are those involving the greatest construction difficulties and the highest investment costs.

❒ It should be mentioned that combined cycle power plants equipped with gas turbines currently have both reduced investment and fuel costs due to the present development of this type of means of generation. The costs shown above therefore have to be lowered (by about 10 to 20%, which reduces the cost for natural gas to 3.5 or 3.9 cXEU 95/kWh at the 5% discount rate, still higher than that of conventional hydro power plants).

❒ Hydro power plants with an age such that most of the investments made have been amortized therefore have a real cost that is closer to the operating cost than the total cost, which gives them a certain advantage over thermal power facilities that have not yet been amortized.

4.3 Cogeneration

Cogeneration is a means of generation apart. It is neither a convention thermal means of generation nor really another renewable energy, so it is dealt with in a specific way here.

The following total costs are to be found in French studies for a supply of about 6,000 hours:

cXEU 95/ kWh	Discount Rate 5%	Discount Rate 10%
40 MW Coal steam turbine	3.0 to 3.30	3.6 to 3.85
40 MW Gas combustion turbine	3.75 to 4.40	4.15 to 4.75
5 MW heavy oil fuel motor	5.25 to 6.50	5.85 to 7.05

Only the 40 MW steam turbine operating on coal has a cost that is less than hydro power facilities (10% rate), but it should be mentioned that this is a decentralized facility the economic justification of which should take into account the saving of the corresponding network. This type of facility is designed for the steam requirements of major industrial sites and, as a result, is limited in its use and cannot ensure control in the network to which it is connected.
Furthermore, tariff incentives are granted to the investors: fixed charge and price of delivered energy (from 4 to 7.2 cXEU/kWh).

In Belgium, various facilities have been built or scheduled, either for space heating or industrial processes (refineries, paper mills, drying plants, etc.). The total costs (O & M, investment and fuel) vary from:

- 2.71 to 2.91 cXEU/kWh for 40 MW gas turbine-steam turbine and cogeneration (discount rate 5 and 10%).
- 2.42 to 4.04 cXEU/kWh for gas motors with cogeneration with a capacity from 4 x 5.5 MW to 1 MW (discount rate 5 and 10%).

It should be noted that the same costs for 360 to 480 MW gas and steam turbines vary from about 2.3 to 3.01 cXEU/kWh at the 5% rate and from 3.13 to 3.28 cXEU/kWh at the 10% rate.

These costs do not include HV network connection costs required for high capacity units.

4.4 Other renewable energy sources

The studies used did not deal with the case of the other renewable energy sources: biomass, cogeneration, wind, solar. Although it is still too soon to successfully carry out an in-depth study of these energy sources, because they are only at the beginning of their commercial operation, there is some economic data on the subject. The HYDRONEW group of experts has indicated a number of cost values in a report and these figures are shown in the table below.

Wind

The operating cost ranges on the average from 5.5 to 7.5 cXEU 95/kWh with differences ranging from 4 to 65 cXEU 95/kWh. An investment amount of 2,100 XEU 95/kW appears to be a common value for high capacity units (5 to 700 kW in sets of 5,000 kW).

The direct comparison with the costs of the other means of generation cannot be made because wind power plants provide neither firm energy nor firm output because of the lack of knowledge concerning wind conditions over the long term.

This is only an indicative value which makes this type of facility only profitable in regions with stable winds and with installations grouping large wind power plants on the same site.

Solar

The investment costs are high here for low installed capacities and which make these facilities only worthwhile in remote areas for which the costs of supply by transmission and distribution networks prove to be prohibitive. A sum of from 10,000 to 15,000 XEU 95/kW is common, with the operating cost ranging in this case from 25 to 85 cXEU 95/kWh.

Biomass

There is a wider range of costs here due to the technique used and the nature of the fuels (municipal waste, agricultural by-products, etc.).

Operating costs range from 5 to 17 cXEU 95/kWh.

General comments

By basing oneself solely on the costs, it can be seen that none of these means of generation really competes with hydroelectricity:

- the operating costs are 10 to 100 times higher,
- the investments are generally lower (except for photovoltaics), but the lifetime is not very well known and in any case will be lower than hydropower,
- as these energies are not guaranteed or guaranteed only to a small extent and as they cannot be stored (neither in the form of fuel and less for that matter in the form of potential energy), they cannot be compared directly with hydropower. To provide a better guarantee of output, they would require additional means of another nature providing dynamic service, operational

reserve and system regulation , such as hydropower, combustion turbines, diesel generating sets, etc.

Furthermore, it should be noted that a great many countries, either through the national utility responsible for electricity demand, or the power system regulator, use subsidized purchasing tariffs to favour the generation of other renewable energy sources and sometimes hydroelectricity from mini power plants, but never hydroelectricity in general. This incentive sometimes concerns the use of by-products, such as waste and blast furnace gas.

5. CONCLUSIONS

As concerns solely cost prices based on a similar approach, the comparison of hydroelectricity and thermal power facilities present in generation mixes makes it possible to conclude:

- ⇨ particularly attractive operating costs (excluding tax expenses),

- ⇨ advantageous total costs for a discount rate of 5% and a little less for a discount rate of 10%.

It may therefore be stated as concerns the manager of a generation mix that:

- ⇨ the calling up of existing hydro generating facilities (for a generally higher quality provided service: response, kinetic performances, etc.) provides a substantial gain in direct operating expenses and, in addition, requires no fuel expenses.

- ⇨ the investment in hydro power facilities cannot be decided by a simple comparison of total generation costs of a kWh, but rather by the examination of individual balances of expected economic costs (operating expenses plus investment costs) with regard to the service provided (energy generation, dynamic operation, reserves, response times, etc.). Each generating facility thus has its place in a diversified generation mix, through its own capacities and the costs incurred by its construction and operation.

- ⇨ this is all the more true for pumped storage power plants which are not really autonomous generating facilities. They rather provide specific services for and according to the power system in which they are placed (energy transfer, frequency and voltage control, dynamic reserves). For such power plants and even more so for the other conventional hydro power plants, the technique and costs depend on the site, whereas valuation depends on the power system.

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