INTRODUCTION

In 1994 Unipede's Study Committee on "Hydro Power and Other Renewable Energies," the Hydren committee, decided to set up a task force to work out a policy paper regarding the world's utilisation of water power for the generation of electric energy.

When starting the work in this respect it was early on established that the statistics on hydro development and hydropower potential in the world really leaves a lot to be desired. Reliable information of this nature for great many of the world's countries is hard and even impossible to obtain.

One of the objects of the work was to establish a credible estimate of the world's hydropower potential for electricity generation and this has proved to be a more difficult task than foreseen at the outset.

The data that could be collected by the task force are fragmentary and there are still many and extensive gaps in the information basis. However, numerous attempts have been made to assess the hydropower potential of the world, its use and future prospects for utilisation. The results of many of these studies have been published and from these sources and information gathered from various other sources, as well as a sound judgement, estimates were made that form the basis for the committee's conclusions.

In spite of an evident inaccuracy in the estimates it is believed that these may still be of use as basis for a message to the world's power planning community on the importance of the hydropower potential of the world. Such a message on a mature technology like hydro needs to be heard and heeded before relying too heavily and too early on the so-called "new renewables" (solar, wind, etc.) where the technologies are in many cases still new and unproven. Greater emphasis on hydro in the next few decades would also give more time for their further development.

In the following, several aspects of this study are discussed and followed by the concluding "Message" which the committee wants to send to the world.

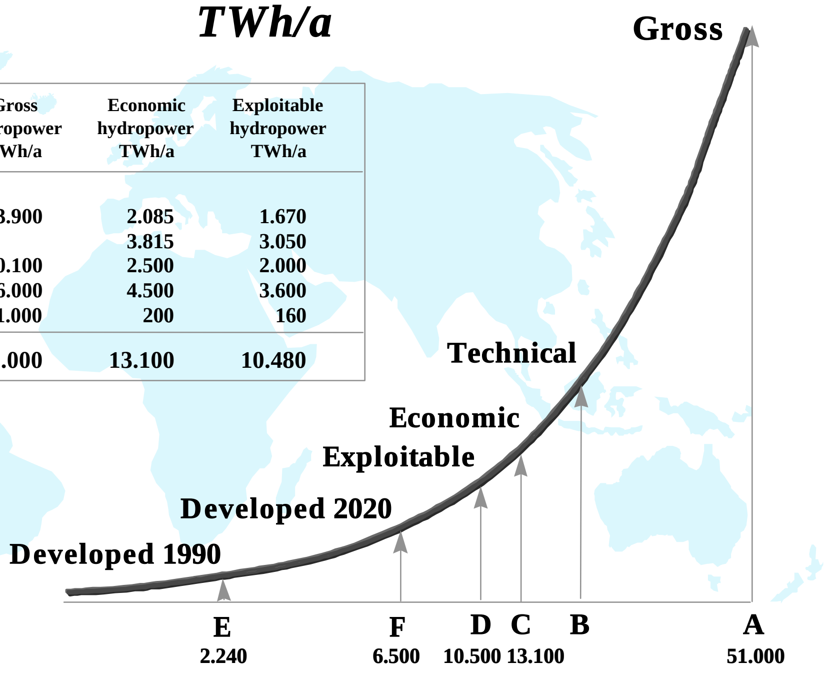
The aim of this study was to analyse and discuss the importance of hydropower as a sustainable energy supply for fulfilling the world's growing electricity demand. This has now been accomplished but only to a limited extent.

Therefore, further work on this important issue is fully warranted and should be carried out by Unipede in order to stimulate and to promote economic development of hydropower for the benefit of mankind.

World's Hydropower Potential

TWh/a

Geographic region	Gross hydropower TWh/a	Economic hydropower TWh/a	Exploitable hydropower TWh/a
Europe inclusive CIS & Turkey	23.900	2.085	1.670
Asia		3.815	3.050
Africa	10.100	2.500	2.000
America	16.000	4.500	3.600
Oceania	1.000	200	160
World total	**51.000**	**13.100**	**10.480**



A: Gross hydropower potential

The annual energy potentially available, when all natural runoff in a country is harnessed down to the sea level (or to the border line of the country) without any energy losses.

B: Technical hydropower potential

The total hydropower potential at a station wall of all sites, that could be, or have been developed, considering current technology, regardless of economic and other restrictions.

C: Economic hydropower potential

That portion of the technical potential, which can, or has been developed, at costs competitive with other energy resources.

D: Exploitable hydropower potential

That portion of the economic potential, which can be expected to be harnessed considering environmental or other special restrictions.

Numerous attempts have been made to assess the hydropower potential of the World, its present use and the future prospects for its utilisation. The results of these surveys reveal striking inconsistencies. The discrepancy is presumably due to both a general lack of data from some regions and differences in responses to questionnaires in the various surveys. Evidently such enquiries must be based on clear and consistent definitions of the different energy terms and classes. Cost limits for assumed energy in class C depend on variable present and expected local economic conditions and very little information is available on energy in class D. Furthermore, the conventional division into technical constraints for class B and economical constraints for class C is clearly arbitrary and in fact quite irrelevant.

The above assumed figures are based on best available evidence today.

Comparison of various Studies on The World's Economic Hydropower Potential

Geographic region	Economic hydropower potential						Hydren	
	WEC [1] 1995 TWh/a	WEC [2] 1974 TWh/a	H&D [3] 1995 TWh/a	WEC [2] 1990 TWh/a	RE 1993 [4] Table 3 TWh/a	Table 2 TWh/a	1996 Economic TWh/a	Exploitable TWh/a
Europe & Asia	**4.390**	**4.450**	**5.580**	**8.155**	**9.230**	**8.960**	**5.900**	**4.720**
Africa	**1.000**	**2.000**	**657**	**1.310**	**1.150**	**3.140**	**2.500**	**2.000**
America	**3.440**	**3.150**	**4.675**	**4.260**	**4.510**	**6.900**	**4.500**	**3.600**
Oceania	**170**	**200**	**213**	**185**	**200**	**390**	**200**	**160**
World total	**9.000**	**9.800**	**11.125**	**13.910**	**15.090**	**19.390**	**13.100**	**10.480**

1) 1995 Survey of Energy Resources. 17th Edition, World Energy Council.
2) 1992 Survey of Energy Resources. 16th Edition, World Energy Council.
3) The International Journal of Hydropower and Dams, Volume Two, Issue One, January 1995 (with addition of the existing hydropower potential around 1990, 2240 TWh/a to the estimated remaining hydropower capability, 8885 TWh/a).
4) RENEWABLE ENERGY, Island Press 1993 (J.R. Moreira, A.D. Poole: HYDROPOWER AND ITS CONSTRAINTS, pp 73 to 119).

Comparison of various estimates of the world's hydropower resources reveals a great inconsistency of the assumed quantities. The world's economic hydropower potential is for example estimated on the interval from approximately 9.000 to 19.000 TWh/a in the above table.

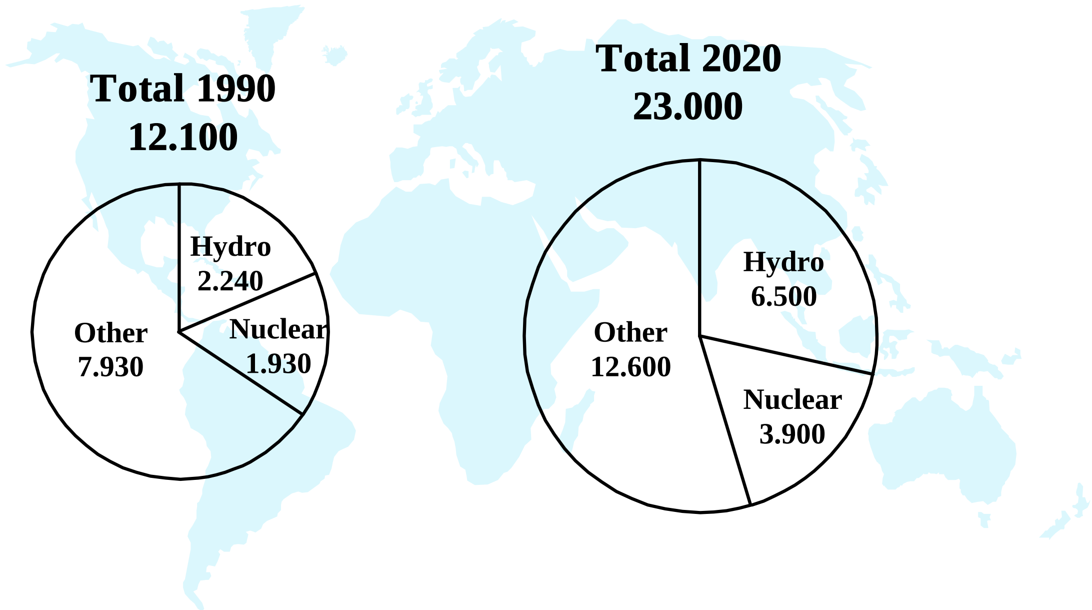
The main reason for this discrepancy is presumably, that effort has often neither been made to correct seemingly unreliable figures nor to account for unavailable figures in regional totals based on information from the pertaining countries. This applies not least to Africa, where the economic potential has been assumed in an especially wide range from some 700 to more than 3.100 TWh/a.

Additionally, distinction between the technical and economic hydropower potential or the economic and exploitable potential is sometimes lacking as in the WEC 1995 Survey, where "estimates of the economically feasible potential may exclude those economic sites where development of a hydroproject would be unacceptable for social or environmental reasons".

By drawing upon some other sources than listed in the above table and using supplementary information on items like the gross theoretical hydropotential of the different regions, the committee has come up with the figures presented in the second last column in the table as a preliminary "Hydren" estimate of the world's economic hydropower potential. An incomplete detailed survey of this potential is to be found in the appendix.

The last column shows an estimate of the exploitable hydropower potential taking environmental and other special restraints into account. This is based on existing figures, quantifying this energy class, from a limited number of countries, assuming the same average ratio exploitable versus economic potential for other countries.

World's Electricity Generation
TWh/a



According to a projection by the World Energy Council, case B*, the total electricity demand in 2020 will be some 23.000 TWh/a, equal to a growth rate of approximately 2,2 % p.a. on the average during the three decades from 1990 to 2020.

An assumption is made that by 2020 about 50 % of the world's economic hydropower potential would be harnessed, or some 6.500 TWh/a, which represents an average growth rate of some 3,6 % p.a. in the period from 1990 to 2020, or a similar rate that prevailed before 1990.

It is assumed that emphasis will be on developing the vast untapped hydro resources of Africa, some of which offer spectacular possibilities, such as the Grand Inga project in Zaire. Similarly, it is believed that the great hydro resources of Latin America could be developed at a fast pace along with energy transmission to North America to cut back increase in pollution from electricity generation in this part of the world. Asia, with an enormous hydropower potential, is bound to develop these resources at a rapid rate to fulfill its fast growing electricity demand. In these regions the growth rate of hydropower development will be much higher than the above assumed world average.

The average growth rate of nuclear electricity is assumed some 2,4 % p.a. from 1990 to 2020, which is a lower rate than prevailed before 1990. The corresponding growth rate of other electricity sources is assumed some 1,6 % p.a. These sources are mainly coal, oil and natural gas. Sources such as geothermal, wind and solar energy etc., are quite negligible in this context.

Based on the above scenario, also taking other measures into account, such as fuel cleaning and clean coal technology, the total electricity related carbon dioxide emission would probably increase by less than 30% from 1990 to 2020 in spite of a 90% increase in electricity production during the same period.

---

*WEC Commission: Energy for Tomorrow's World, St. Martin's Press 1993

Survey of Electricity demand and supply by Hydropower 1990 through 2020

Geographic region	Economic hydropower potential	Exploitable hydropower potential	Internal demand (including losses)		Supplied by hydropower			
			1990	2020	1990		2020	
	TWh/a	TWh/a	TWh/a	TWh/a	TWh/a	%	TWh/a	%
Europe*)	**2.085**	**1.670**	**4.300**	**7.700**	**745**	**17,3**	**1.080**	**14,0**
Asia	**3.815**	**3.050**	**2.900**	**6.500**	**390**	**13,4**	**1.890**	**29,1**
Africa	**2.500**	**2.000**	**400**	**1.300**	**57**	**14,3**	**1.240**	**95,4**
America	**4.500**	**3.600**	**4.300**	**7.000**	**1.005**	**23,4**	**2.195**	**31,4**
Oceania	**200**	**160**	**200**	**500**	**43**	**21,5**	**95**	**19,0**
The World	**13.100**	**10.480**	**12.100**	**23.000**	**2.240**	**18,5**	**6.500**	**28,3**

***) inclusive CIS & Turkey**

The total electricity production in 1990 was some 12.100 TWh/a of which about 2.240 TWh/a were supplied by hydropower, or some 18,5 %. This demand is supposed to increase up to around 23.000 TWh/a in 2020 of which some 6.500 TWh/a might conceivably be supplied by hydropower.

The nomenclature on which statistics are based and the expressions used in questionnaires must be consistent, leaving no ambiguity when the data is processed, and enabling significant information to be gathered. The reliability of enquiries into supply and demand depends essentially on the precision of the nomenclature used in the questionnaires and the tables derived from these.

Thus the necessity of defining without ambiguity the terms to be used in the field of electricity production and usage is evident as for instance described below.

Electricity production

This refers to gross production (generation), which includes the consumption by station auxiliaries and any losses in the transformers that are considered integral parts of the station (production at station wall). Excluded is electricity produced from pumped storage.

Electricity demand vis a vis Electricity consumption

Electricity demand refers to actual consumption, which is equal to electricity production of a country plus imported minus exported electricity measured at the metering points on the lines crossing the frontiers (internal demand).

Electricity consumption refers to final consumption, which represents the amount of energy actually supplied to the consumer. The final consumption is the actual consumption less transmission and distribution losses as well as the electrical companies' own electricity use.

Global Interconnection of Power Grids

Geographic region	Exploitable hydropower potential			
	Total	Existing 1990	Remaining 1990	
	TWh/a	TWh/a	TWh/a	%
Europe inclusive CIS & Turkey	1.670	745	925	11,2
Asia	3.050	390	2.660	32,3
Africa	2.000	57	1.943	23,6
North America	775	587	188	2,3
Latin America	2.825	418	2.407	29,2
Oceania	160	43	117	1,4
World total	**10.480**	**2.240**	**8.240**	**100,0**

To develop the great hydropower potential of many developing countries it would be necessary to look for markets beyond national and even continental borders. For example the only adequate market in the foreseeable future for the Grand Inga project in Zaire (30.000 MW, 240 TWh/a) is considered to be in Europe. Cost of the transmitted energy is believed to be competitive with cost of electricity produced from other sources.

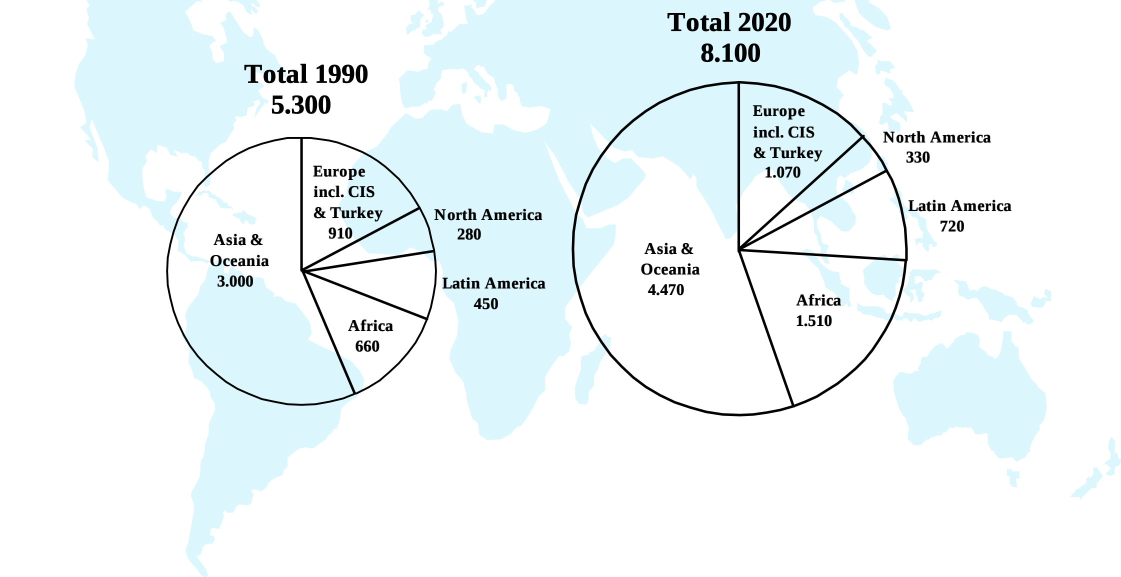
Most of the world's major renewable, non-polluting energy sources, such as the huge remaining hydro resources of Asia, Africa and South America, are in areas remote from demand centres. An international co-operation for energy transfer seems to be the only way for these to be fully exploited.

Many intercontinental transmission systems have already been proposed, such as from South America through Central America linking Latin America with the electricity demand of North America, from Siberia by cable across the Bering Strait to Alaska, from Iceland by cable link to the United Kingdom and the Netherlands, and the HVDC-transmission line over a distance of some 7.000 km from Africa (Zaire) to Southern Europe.

Interconnection projects involving long distances with link-ups and crossing of different countries may present formidable constraints regarding technical, financial as well as environmental and political aspects. However, advances in technology render ever longer transmission links to be economically and technically viable, and visionaries in the world's electric field have pointed out the inevitability of the eventual global interconnection, linking the electric systems of all continents. The question is perhaps therefore not whether this will be accomplished, but when.

It is an established fact that the interconnection of different electric systems can bring about numerous benefits such as peak load and spinning reserve reductions as well as better opportunities to apply economics of scale etc. and last but not least, that linking of hydropower projects to the thermal power systems can lead to considerable economic and operational advantages.

World's Population millions



The world's population in 1960 was estimated some 3.000 millions. During the subsequent 30 years this population increased by about 2.300 millions, reaching 5.300 millions in 1990.

Consequently, the average population growth rate during the three decades from 1960 to 1990 was some 1,9 % p.a., decreasing from 2,0 % p.a. in 1960 down to 1,8 % p.a. in 1990.

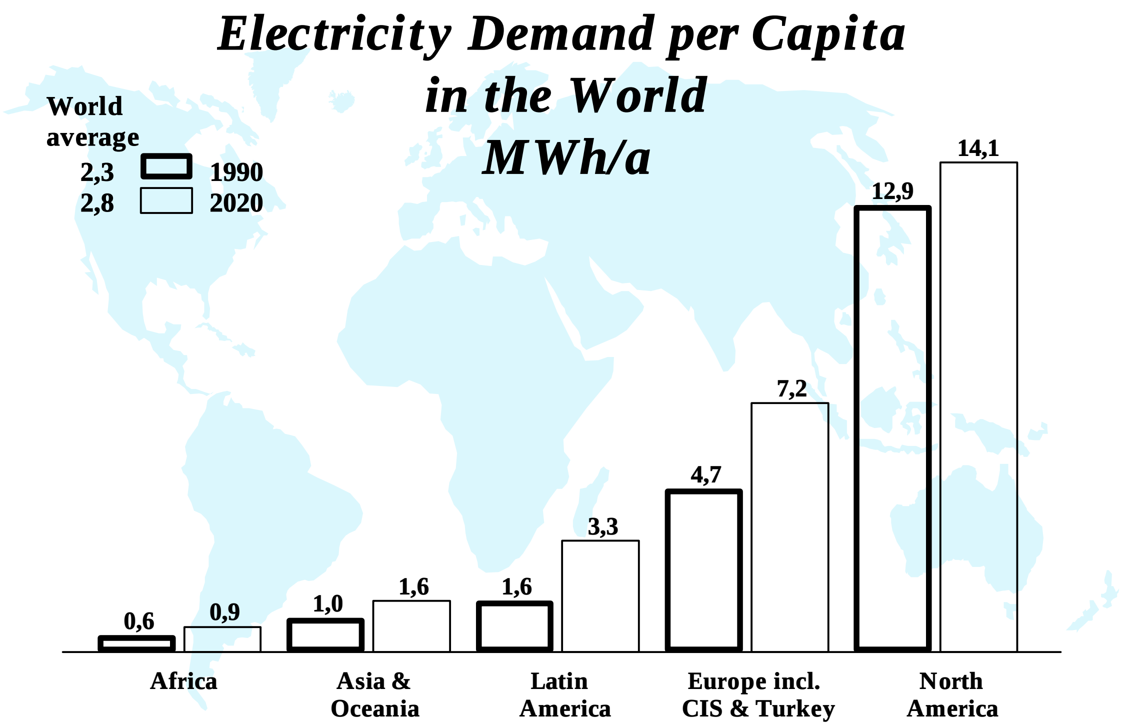
According to a projection based on UN sources, a "median" estimate of the world's population in 2020 is some 8.100 millions, equal to a further decrease in population growth rate down to some 1,4 % p.a. on the average in the thirty years from 1990 to 2020.

Thus, the world population is expected to rise by some 2.800 millions in the period from 1990 to 2020. More than 90 % of this growth will probably occur in the present developing countries. The highest proportional increase is expected in Africa, some 2,8 % p.a. and the lowest in North America and Europe inclusive CIS and Turkey, between 0,5 and 0,6 % p.a.

World population in 1990 and expected population in 2020 is shown on the above diagram with an approximate division on the different geographic regions.

It should be noted that forecasts of population have in the past been erroneous. Most of the errors have been due to underestimating population growth. According to the above estimate the average growth rate is expected to slow.

Consequently, the estimated total in 2020 and its division on the various geographic regions must be considered with due respect of such uncertainties.



In 1960 the world's electricity demand per capita was approximately 0,8 MWh/a. This demand increased considerably from 1960 to 1990 up to 2,3 MWh/a per capita in 1990.

Thus, the growth rate of electricity per capita in the world was some 3,6 % p.a. on the average in the three decades from 1960 to 1990, gradually decreasing during that period. A further decrease in this growth rate is expected to occur in the 30 years from 1990 to 2020.

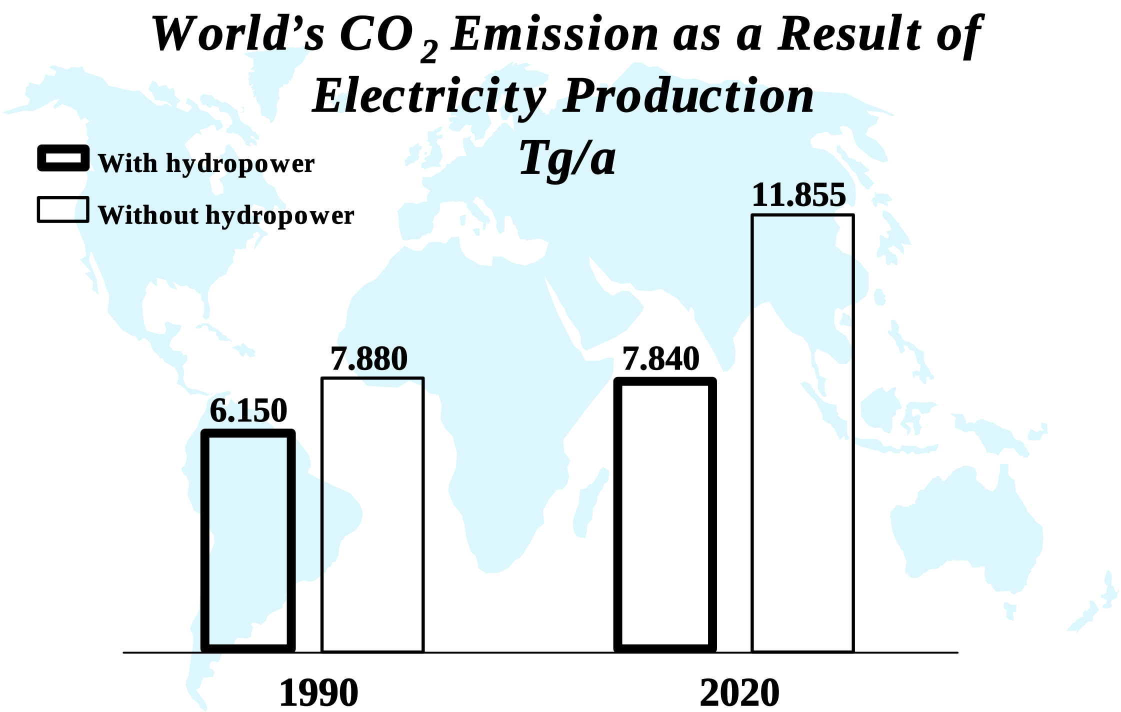
According to the estimated world population and electricity demand, this demand per capita would be some 2,8 MWh/a in 2020.

Thus, the world's growth rate of electricity demand per capita would only be some 0,7 % p.a. on the average in the period from 1990 to 2020. This growth rate is assumed to be lowest in North America, some 0,3 % p.a., and the highest in Latin America, 2,5 % p.a., but some 1,2 to 1,4 % p.a. in the rest of the world.

Electricity demand per capita in 1990 and the expected demand in 2020 is shown on the above diagram divided on the different geographic regions, revealing the great differences of this demand between the various regions.

In general the industrialised countries have electricity per capita demand levels far in excess of the developing countries. Additionally, urbanisation plays a major role in this respect, as electricity supply in urban centres is more accessible than the more diffused supply required in rural areas.

Increase in the world average of electricity demand per capita from 1990 to 2020 reflects a supposed improvement of living standards during that period.



The forecast huge increase of global population might lead to accelerated consumption of the reserves of fossil fuels along with a great risk of global warming resulting from CO_2 emission and other greenhouse gases. For abating these effects a greater reliance should be on developing non-polluting energy resources, such as hydropower, for electricity generation.

The world's electricity production in 1990 was some 12.100 TWh/a. This production is expected to rise up to 23.000 TWh/a in the year 2020, equal to an average growth rate of some 2,2 % p.a.

Divided on the main energy sources this growth rate is assumed as follows, hydropower some 3,6 % p.a., nuclear electricity 2,4 % p.a., coal 1,3 % p.a., natural gas 2,8 % p.a. and oil less than 0,1 % p.a.

The total carbon dioxide emission related to electricity generation in 1990 is estimated some 6.150 Tg/a, almost entirely resulting from fossil fuel burning.

Based on the above assumptions and also taking other measures into account, such as fuel cleaning and clean coal technology, this emission is supposed to increase up to 7.840 Tg/a in 2020, or by less than 30 % during the three decades from 1990 to 2020 in spite of a 90 % increase in electricity production in the same period.

To illustrate the effects of hydropower to reduce pollution, CO_2 emission is shown on the diagram above with and without hydropower, where hydropower in 1990 and assumed hydropower in 2020 is replaced by fossil fuel.

Thus, hydropower reduces worldwide electricity related emission of carbon dioxide by some 22 % in 1990 and 34 % in 2020 through displacement of other modes of electricity generation.

Average Electricity Production Cost

cECU/kWh

Generator	Comparative costs
Conventional hydro	2,6
Fossil fuel & nuclear	3,3 - 4,5

Interest rate : 8% p.a.
Price level : December 1995

Comparison of the various energy costs is aimed at comparing cost of hydropower with energy costs of other facilities, which are most likely to compete with it in the next two to three decades. Therefore, for example cost of energy from gas-fired plants is based on new advanced combined cycle units with high efficiency levels.

Energy cost decreases with increased depreciation time. Therefore, the depreciation period ought to concur with the effective lifetime of the plants, which may be defined as the time which elapses from commission until increased maintenance costs might obliterate the effect of a longer depreciation period. For comparison the depreciation period of hydropower is assumed 60 years, but 25 years for thermal and 30 years for nuclear facilities.

Cost of hydropower is affected by the discount rate to a greater extent than that of thermal and nuclear power. The reason for this being that operation and maintenance costs of hydropower count only for some 10 to 20 % of the total energy cost (depending on the discount rate), compared with up to 70 % for thermal power, inclusive fuel cost. For comparison a discount rate of 8 % p.a. and an equal interest rate during construction is applied for all facilities.

Hydropower plants usually have much lower load factors than thermal and nuclear plants, due to hydropower's ability to respond very rapidly to variable demands. The average load factor of current hydropower plants may be as low as 40 %, but by increased role of hydropower, as well as growing interconnection of power grids, this load factor will probably become higher. In view of this, along with that hydro and thermal facilities ought jointly to share the cost of fulfilling the capacity demand, an average comparative load factor of 60 % is applied for hydropower. Cost of thermal and nuclear electricity is on the other hand based on 85 % load factors.

Tax charges are not included in the above comparison. Introduction of environmental tax charges would be favorable for hydropower, as its effects on the environment are much more benign than those of other major energy options.

Advantages and disadvantages of Hydropower Projects

Advantages

- **Low energy production cost considering the long effective lifetime of the plants and the low operation and maintenance costs**
- **Greater efficiency than of all other major type of plants, using non-renewable and renewable energy resources**
- **Almost complete absence of greenhouse gas emission**
- **Possibility of multipurpose water use and water management, such as irrigation and regulation of river flows both during flood season and low flow periods**
- **Independence of fluctuating fuel prices**
- **Efficient output regulation, facilitating rapid response to variable energy demand**

Disadvantages

- **High investments associated with a long return period**
- **Long lead times for project realisation**
- **Environmental and social problems, mainly due to inundation of areas by large water resevoirs causing possible destruction of unique biotypes and endemic species. Additionally, possible destruction of human habitats, incurring high costs of the necessary resettlements**

Hydropower is a naturally occurring, continuously renewed energy resource (a renewable energy resource) with a vast and widely distributed potential for further development, especially in the developing countries.

Hydropower development is capital intensive. On the other hand the operation and maintenance costs of hydropower plants are generally much lower than those of other major plants for electricity generation.

The effective lifetime of hydropower plants is much longer than the so-called financial lifetime favouring quick pay-back schemes in preference to long term investment. In that case a hydropower plant becomes a virtual gold mine for its owners once the initial investment has been recovered.

Global warming caused by increased release of carbon dioxide and other greenhouse gases is now considered one of the major environmental threats. Global effects of hydropower on the environment are much more benign than those of other major energy options. This fact seems not to have had much influence on the policy of many people that purport themselves to be advocates of bettering the world's environment and generally represent the main opponents to the development of hydropower around the world. Ironically these people do not realise, that by this attitude they are promoting more polluting methods of producing electricity in mankind’s efforts to meet the world’s growing energy demand.

Hydropower is the most important renewable source of energy, which currently reduces worldwide electricity related emission of carbon dioxide by more than 20% through displacement of other modes of electricity generation.

Electricity generation by hydropower is a reliable, proven, “mature” technology with known positive and negative influences.

The Message

1. **Hydropower development is sustainable**
2. **Hydropower development is economic and enables multipurpose water management**
3. **Hydropower development requires long-term planning**
4. **Hydropower development requires the support of Governments**

1. Hydropower development is sustainable

In 1987, the World Commission on Environment and Development presented its findings in a report titled “Our Common future”, more widely known as the “Brundtland Report” after the Commission’s chairman, Mrs. Gro Harlem Brundtland. Perhaps the most novel concept launched in that famous report was that of “Sustainable development”, defined as “a development that ensures humanity that it meets the needs of the present without compromising the ability of future generations to meet their own needs”.

Generating electricity from hydropower is like operating a machine where the sun and gravity keep water in an endless circle from the oceans to the sky, to land and back through turbines to the oceans again, and what could be more sustainable and cleaner than this process.

2. Hydropower development is economic and enables multipurpose water management

According to the Hydren Committee’s studies, production cost of electricity by hydro is significantly lower than electricity generation by any other means when the long lifetime and low operation and maintenance costs are taken into account. This becomes ever more pronounced as lower interest rates are applied. It can also be argued that even if costly transmission is taken into account, since hydropower projects are frequently located farther from the market than other types of electric generators, the hydroelectric energy would generally still be price competitive.

Here it could also be added, that if environmental costs were to be included in the pricing of electricity, hydropower development would present an additional economic edge compared to most other means of generating electricity. Furthermore, hydropower development for generation of electricity offers side benefits, such as flood control, irrigation and recreation possibilities etc.

3. Hydropower development requires long term planning

Hydropower development is very capital intensive. Hydro plants have long operating lives, even up to 100 years or more. The financial benefits to be reaped from hydro developments are therefore slower to materialise than for most other ways of producing electricity. On the other hand the O&M costs for hydro are generally much lower than for any other types of electricity generators and the real lifetime of a hydroelectric project is normally much longer than the financial depreciation time. Therefore, when a hydro is fully depreciated it turns to be a virtual goldmine for its owners.

Hydropower development is a clean process and it is very profitable when the initial investment has been recovered. Therefore, long term thinking is required by the world's power planners in order to pave the way for continued and determined effort to release the inherent great benefits for all mankind that are still bound in unharnessed hydropower.

4. Hydropower development requires the support of Governments

Recovery of investment in hydropower developments takes a long time. Many such projects also require time-consuming investigations before the viability of a project is established beyond reasonable doubt and a decision to go ahead with it can be taken. These factors in combination are likely to discourage private investors. With the power industries of the world on a massive march towards privatisation there is a danger that short-term considerations may predominate these industries with the result that the hydro option may be neglected, even when attractive projects are available.

Here, Governments need to step in. They can do so for instance by undertaking at least the more time-consuming part of the preparatory investigations. Although these investigations may take a sizeable part of the total lead time of hydro projects, their cost is normally only a minor part of total project cost. When the investigations reveal a viable project and have greatly shortened its lead time and reduced the risk associated with it, Governments can offer to the privatised power market a project that may be highly competitive with other more short-term options like fossil-fired plants and thus attract private investors as developers. Governments can then recover the cost of investigations from the developer and use the proceeds to finance investigations of new projects. In this way Governments may be able to overcome the short-term thinking inherent in many private businesses, while retaining the positive attributes of private ownership, and at the same time recover their costs and have them internalised into the power price so that the final repayers will be the customers.

Active involvement by Governments in hydropower developments is all the more justified when the long-term benefits from the operation of such plants for many years after their investment has been recovered are taken into account as well as the benign environmental effects of hydro compared to other means of electricity generation.

Some References

HYDROPOWER RESOURCES

SURVEY OF ENERGY RESOURCES 1974, United States National Committee of the World Energy Conference.

Emil Mosonyi: LOW HEAD HYDROPOWER PLANTS, Budapest 1987.

1992 Survey of Energy Resources, 16th Edition, World Energy Council.

R. Kvamsdal & A.H. Teigland: An Assessment of the World's Practical Hydropower Potential, 15th World Energy Conference, Madrid 1992.

J.R. Moreira & A.D. Poole: HYDROPOWER AND IT'S CONSTRAINTS, RENEWABLE ENERGY, Island Press 1993.

Water Power & Dam Construction Handbook 1994.

The International Journal of Hydropower and Dams, Volume Two, Issue One, January 1995.

1995 Survey of Energy Resources, 17th Edition, World Energy Council.

ELECTRICITY DEMAND

WEC Commission: Energy for Tomorrow's World, St. Martin's Press 1993.

HYDROPOWER DEVELOPMENT

QUÉBEC ÉCONOMIC INTERNATIONAL, Volume 9, Number 4, December 1991.

H.R. Sharma: Accelerated hydropower development - The best option for India, HYDROPOWER ´92, A.A. Balkeman, Rotterdam 1992.

CERTAIN ASPECTS OF UTILISING SOME OF THE WORLD'S ENERGY RESOURCES FOR SUSTAINABLE DEVELOPMENT, Iceland's Contribution to the World Energy Conference, Tokyo 1995.

COST OF HYDROPOWER

Emil Mosonyi: WATERPOWER DEVELOPMENT: LOW HEAD HYDROPOWER UTILISATION, Developments in Hydraulic Engineering - 5, Elsevier Science Publishers Ltd., London and New York 1988.

STUDY OF THE COST PRICE OF HYDRO-ELECTRIC POWER STATIONS, UNIPEDE Copenhagen Congress, June 1991

Charles T. Wong: Determining O&M Costs Over The Life of a Hydro Station, Hydro In The '90's, HCI Publications, Kansas City USA 1993.

INTERCONNECTION OF POWER GRIDS

IEEE Power Engineering Review, June 1992.

N. Yldirim & F. Ivak: IMPORTANCE OF ENERGY NETWORK IN REGIONAL AND INTERREGIONAL CO-OPERATION, World Energy Council 16th Congress, Tokyo 1995.

H, Manfred, M. Grenon, El-Said Issa & M. Tawila: A NEW ROLE OF ENERGY TRANSIT FOR THE MEDITERRANEAN: LONG DISTANCE AND LONG TERM NATURAL GAS AND ELECTRICITY SUPPLY FOR THE MEDITERRANEAN AND EUROPE, World Energy Council 16th Congress, Tokyo 1995.

Appendix

Survey of the Hydropower Potential of the World and its Utilisation

***I:	Europe incl. CIS and Turkey***
***II:	Asia***
***III:	Africa***
***IV:	America***
***V:	Oceania***

In the following tables I through V are detailed surveys of the economic and exploitable hydropower potential of the world, the electricity demand in 1990 and the assumed demand in 2020. Additionally, the electricity supply by hydropower in 1990 is surveyed along with its conceivable supply in 2020.

Reliable information on hydropower development and hydropower potential for great many countries of the world is hard or even impossible to obtain. Therefore, there still exist numerous voids in the database due to unavailable or seemingly unreliable figures concerning individual countries, but estimates of these are included in the pertaining totals.

However, these totals must be regarded as rather cursory, albeit based on best available evidence today on the hydropower potential, its present utilisation and attainable development for fulfilling the world's growing electricity demand. It should also be emphasised that many registered figures in the tables are preliminary estimates, which need to be revised.

As mentioned above, the data which could be collected is very fragmentary. Therefore, further studies of the hydropower potential and its reasonable utilisation seems to be a very important task of energy related international institutions such as Unipede and the World Energy Council.

The data for such surveys, presumably provided from a wide range of sources, must be carefully analysed, cross-checked and evaluated before being compiled into the statistical tables.

Also, it is of a vital importance, that expressions used in questionnaires, enabling significant information to be gathered, are based on clear and consistent definitions of hydropower resources and electricity usage.

Alphabetical codes for names of countries are in accordance with ISO 3166:1993.

Table I

Europe incl. CIS and Turkey Country		Economic hydropower potential	Exploitable hydropower potential	Internal demand (including losses)		Supplied by hydropower			
				1990	2020	1990		2020	
		TWh/a	TWh/a	TWh/a	TWh/a	TWh/a	%	TWh/a	%
Albania	AL	17,0				5,2			
Andorra	AD	-							
Armenia	AM	6,0		**11,3**		**1,5**	**13,3**		
Austria	AU	53,7		50,5		34,0	67,3		
Azerbaijan	AZ	7,0		**21,5**		**1,1**	**5,1**		
Belarus	BY	1,0		**48,9**					
Belgium	BE	**0,6**		**62,6**	**95,6**	**0,5**	**0,8**	**0,6**	**0,6**
Bosnia & Herzegovina	BA	22,0							
Bulgaria	BG	10,5				2,5			
Croatia	HR	**11,8**		**15,0**	**25,0**	**3,8**	**25,3**	**8,5**	**34,0**
Cyprus	CY	17,0							
Czeck Republic	CZ	**3,4**	**1,6**	**56,0**	**95,0**	**1,5**	**2,7**	**3,1**	**3,3**
Denmark incl. Faroe Islands	DK	0,3		**30,7**	**38,0**	0,1	0,3		
Estonia	EE	0,4		**7,2**	**21,0**				
Finland	FI	19,7	**14,1**	**60,0**	**81,0**	13,3	**22,2**	**14,1**	**17,4**
France	FR	74,3		370,9	**540,0**	64,0	17,3	**66,5**	**12,3**
Georgia	GE	32,0		**17,4**		**7,0**	**40,2**		
Germany	DE	**24,0**	**20,0**	**449,0**	**570,0**	**18,3**	**4,1**		
Gibraltar	GI	-							
Greece	GR	**20,0**	**16,0**	35,5	**53,5**	3,2	9,0	**4,0**	**7,5**
Hungary	HU	3,5		39,0		0,2	0,5		
Iceland	IS	40,0	**30,0**	4,4	**15,0**	4,2	95,5	**24,0**	**160,0***
Ireland	IE	1,2	**0,8**	**13,9**	**40,0**	**0,9**	**6,5**	**0,8**	**2,0**
Italy	IT	**70,0**	**65,0**	**235,1**	**490,0**	43,0	**18,3**	**65,0**	**13,3**
Kazakhstan	KZ	27,0		**65,8**		**7,2**	**10,9**		
Kyrgyzstan	KG	48,0		11,9		9,2	77,3		
Latvia	LV	**5,0**	**4,0**	**8,6**	**17,0**	3,0	**34,9**	**4,0**	**23,5**
Liechtenstein	LI	-							
Lithuania	LT	2,2	**2,0**	**13,0**	**26,0**	0,4	**3,1**	**2,0**	**7,7**
Luxembourg	LU	**1,9**	**1,8**	**5,3**	**7,8**	**0,8**	**15,1**	**0,8**	**10,3**
Malta	MT	-							
Moldova	MD	0,7		**12,6**		**0,3**	**2,4**		
Monaco	MC	-							
Netherlands	NL	**0,2**		**66,7**	**102,5**	**0,1**	**0,1**	**0,2**	**0,2**
Norway	NO	**178,0**	**143,0**	**105,9**	**170,0**	**105,9**	**100,0**	**143,0**	**84,1**
Poland	PL	6,0		**135,4**	**267,0**	**3,5**	**2,7**	**3,7**	**1,4**
Portugal	PT	**19,8**	**13,8**	**26,3**	**58,0**	**8,4**	**31,9**	**15,1**	**26,0**
Romania	RO	**32,0**	**24,0**	**73,8**	**107,2**	**11,0**	**14,9**	**20,5**	**19,1**
Russia	RU	852,0		**1047,4**		**172,6**	**16,5**		
San Marino	SM	-							
Slovak Republic	SK	**7,0**	**3,5**	**22,5**	**45,0**	**2,5**	**11,1**	**5,2**	**11,6**
Slovenia	SI	**7,9**	**7,4**	**10,1**	**14,3**	**2,8**	**27,7**	**6,3**	**44,1**
Spain	ES	**45,4**	**36,6**	**143,3**	**273,2**	**26,2**	**18,3**	**30,0**	**11,0**
Svalbard & Jan Mayen	SJ	-							
Sweden	SE	**90,0**	**66,0**	**140,0**	**182,0**	**71,5**	**51,1**	**66,0**	**36,3**
Switzerland	CH	37,0		**50,0**	**84,0**	**30,1**	**60,2**	**34,0**	**40,5**
Tajikistan	TJ	85,0		**19,3**		14,0	**72,5**		
Turkey	TR	122,4		**57,7**	**271,5**	**22,2**	**38,5**	**77,7**	**28,6**
Turkmenistan	TM	1,7		**9,6**		**0,7**	**7,3**		
Ukraine	UA	17,0		**268,0**		**11,9**	**4,4**		
United Kingdom	GB	**5,6**	**5,3**	327,9	**475,0**	**5,1**	**1,6**	**5,3**	**1,1**
Uzbekistan	UZ	15,0		**54,1**		6,0	**11,1**		
Yugoslavia [o)]	YU	40,0		**40,0**	**50,0**	**14,0**	**35,0**	**20,0**	**40,0**
Total		2085,0	1670,0	4300,0	7700,0	745,0	17,3	1080,0	14,0

[o)] Serbia, Montenegro, Macedonia *) export

Bolded figures are present estimates of Unipede's Hydren Committee

Table II

Asia exclusive CIS and Turkey Country		Economic hydropower potential	Exploitable hydropower potential	Internal demand (including losses)		Supplied by hydropower			
				1990	2020	1990		2020	
		TWh/a	TWh/a	TWh/a	TWh/a	TWh/a	%	TWh/a	%
Afghanistan	AF					0,8			
Bahrain	BH			3,5					
Bangladesh	BD					0,7			
Bhutan	BT					2,0			
Brunei Darussalam	BN								
Cambodia	KH								
China	CN	1260,0		621,0		125,0	20,1		
Hong Kong	HK			27,0					
India	IN	450,0		291,0		72,0	24,7		
Indonesia	ID	709,0		60,0		5,7	9,5		
Iran	IR	56,0		59,0		6,0	10,2		
Iraq	IQ	70,0		24,0		2,6	10,8		
Israel	IL	1,0		20,9		0,0	0,0		
Japan	JP	114,3		850,0		90,0	10,6		
Jordan	JO	0,1		3,6		0,0	0,0		
Korea, DPR of	KP			54,0					
Korea, Rep. of	KR	4,0		108,0		6,0	5,6		
Kuwait	KW			18,5					
Lao PD Rep.	LA	42,0				1,0			
Lebanon	LB	1,0		2,0		0,6	30,0		
Macau	MO								
Malaysia	MY	60,0		21,0		4,0	19,0		
Maldives	MV								
Mongolia	MN								
Myanmar (Burma)	MM					1,2			
Nepal	NP	144,0		0,7		0,7	100,0		
Oman	OM			4,5					
Pakistan	PK	120,0		38,0		22,0	57,9		
Philippines	PH	18,2				4,3			
Qatar	QA								
Saudi Arabia	SA								
Singapore	SG								
Sri Lanka	LK	6,8				2,6			
Syrian Arab Rep.	SY	4,5				1,6			
Taiwan	TW	8,6		90,0		8,0	8,9		
Thailand	TH	8,2		45,0		5,0	11,1		
United Arab Emirates	AE								
Vietnam	VN	6,5							
Yemen	YE								
Total		3815,0	3050,0	2900,0	6500,0	390,0	13,4	1890,0	29,1

Table III

Africa		Economic hydropower potential	Exploitable hydropower potential	Internal demand (including losses)		Supplied by hydropower			
Country				1990	2020	1990		2020	
		TWh/a	TWh/a	TWh/a	TWh/a	TWh/a	%	TWh/a	%
Algeria	DZ	*20*				0,3			
Angola	AO	70,0			*4*	1,4			
Benin	BJ	*10*							
Botswana	BW	0,0			*4*				
Burkina Faso	BF	*80*							
Burundi	BI	1,5				0,2			
Cameroon	CM	*160*				2,4			
Cape Verde	CV	-							
Central African Rep.	CF	*60*							
Chad	TD	*15*				0,1			
Comoros	KM	-							
Congo	CG	*80*				0,2			
Côte d'Ivoire	CI	12,4		2,3		1,3	56,5		
Djibouti	DJ	-							
Egypt	EG	*20*		42,0		10,0	23,8		
Equarorial Guinea	GQ	*15*							
Eritrea	ER	-							
Ethiopia	ET	*200*		2,1		1,1	52,4		
Gabon	GA	32,0		0,9		0,7	77,8		
Gambia	GM	-							
Ghana	GH	10,6		5,8		5,8	100,0		
Guinea	GN	14,5				0,2			
Guinea-Bissau	GW	0,3							
Kenya	KE	*50*				2,8			
Lesotho	LS	2,0			*1*				
Liberia	LR	*40*				0,3			
Libya	LY	*1*		10,2		0,0	0,0		
Madagascar	MG	*430*				0,3			
Malawi	MW	7,0			*4*	0,6			
Mali	ML	*15*				0,2			
Mauritania	MR	*10*							
Mauritius	MU	-				0,1			
Mayotte	YT	-							
Morocco	MA	4,0		8,8		1,3	14,8		
Mozambique	MZ	60,0			*3*	0,1			
Namibia	NA	7,0			*4*	1,1			
Niger	NE	1,3							
Nigeria	NG	30,7		14,0		5,0	35,7		
Reunion	RE	-				0,5			
Rwanda	RW	*4*				0,1			
Saint Helena	SH	-							
Sâo Tomê Principe	ST	-							
Senegal	SN	*25*		0,8		0,0	0,0		
Seychelles	SC	-							
Sierra Leone	SL	*15*							
Somalia	SO	*1*							
South Africa	ZA	*20*		143,0	*440*	1,1	0,80		
Sudan	SD	1,9				0,5			
Swaziland	SZ	1,8			*2*				
Tanzania	TZ	20,0		1,6	*8*	1,5	93,8		
Togo	TG	*3*				0,2			
Tunisia	TZ	-		5,5		0,1	1,8		
Uganda	UG	10,0				0,6			
Western Sahara	EH	-							
Zaire	ZR	750,0		5,3		5,1	96,2		
Zambia	ZM	21,4		6,3	*12*	6,3	100,0		
Zimbabwe	ZW	13,3		9,5	*24*	3,6	37,9		
Total		2500,0	2000,0	400,0	1300,0	57,0	14,3	1240,0	95,4

Italic figures are cursory estimates

Table IV

America Country		Economic hydropower potential TWh/a	Exploitable hydropower potential TWh/a	Internal demand (including losses) 1990 TWh/a	2020 TWh/a	Supplied by hydropower 1990 TWh/a	%	2020 TWh/a	%
Anguilla	AI								
Antigua & Barbuda	AG								
Argentina	AR	172,0				16,0			
Aruba	AW								
Bahamas	BS								
Barbados	BB								
Belize	BZ								
Bermuda	BM								
Bolivia	BO	50,0				1,4			
Brazil	BR	1115,0				250,0			
Canada	CA	593,0		485,0		295,0	60,8		
Cayman Islands	KY								
Chile	CL	130,0		18,4					
Colombia	CO	415,0				25,0			
Costa Rica	CR	35,0				3,7			
Cuba	CU								
Dominica	DM	0,1							
Dominican Rep.	DO	2,5				1,0			
Equador	EC	120,0		6,1		5,1	83,6		
El Salvador	SV	4,0				1,3			
Falkland Islands	FK								
French Guiana	GF								
Greenland	GL	14,0							
Grenada	GD								
Guadeloupe	GP								
Guatemala	GT	40,0				2,1			
Guyana	GY	60,0							
Haiti	HT	0,4				0,3			
Honduras	HN	24,0				2,0			
Jamaica	JM	0,2		2,0		0,1	5,0		
Martinique	MQ								
Mexico	MX	160,0		124,0		29,0	23,4		
Montserrat	MS								
Netherlands Antilles	AN								
Nicaragua	NI	6,5				0,3			
Panama	PA					2,9			
Paruguay	PY	40,0		2,4		25,0 [a]	1041,7		
Peru	PE	410,0				11,0			
Puerto Rico	PR					0,3			
St. Kitts & Nevis	KN								
Saint Lucia	LC								
St. Pierre & Miquelon	PM								
St. Vicent & Grenadines	VG								
Suriname	SR					0,9			
Trinidad & Tobaco	TT								
Turks and Caicos Isl.	TC								
United States	US	376,0		2983,0		292,0	9,8		
Uruguay	UY					5,1			
Venezuela	VE	260,0		60,0					
Virgin Islands (British)	VG								
Virgin Islands (US)	VI								
Total		4500,0	3600,0	4300,0	7000,0	1005,0	23,4	2195,0	31,4

[a] Inclusive half generation of Itaipu and Yacyreta power plants (export)

Table V

Oceania Country		Economic hydropower potential	Exploitable hydropower potential	Internal demand (including losses)		Supplied by hydropower			
				1990	2020	1990		2020	
		TWh/a	TWh/a	TWh/a	TWh/a	TWh/a	%	TWh/a	%
American Samoa	AS								
Australia	AU			155,0		15,7	10,1		
Christmas Island	CX								
Cook Islands	CK								
Fiji	FJ					0,4			
French Polynesia	PF								
Guam	GU								
Kiribati	KI								
Marshall Islands	MH								
Micronesia	FM								
Nauru	NR								
New Caledonia	NC					0,3			
New Zealand	NZ	40,0		32,0		23,0	71,9		
Niue	NU								
Norfolk Island	NF								
Northern Mariana Isl.	MP								
Palau	PW								
Papu New Guinea	PG					0,4			
Pitcairn	PN								
Samoa	WS								
Solomon Islands	SB								
Tokelau	TK								
Tonga	TO								
Tuvalu	TV								
Vanuatu	VU								
Wallis and Futuna Islands	WF								
Total		200,0	160,0	200,0	500,0	43,0	21,5	95,0	19,0

Detailed estimates as percentages of estimated totals

Geographic region	Economic hydropower potential			Internal demand 1990			Supply by hydropower 1990		
	Total estimate	Detailed estimate		Total estimate	Detailed estimate		Total estimate	Detailed estimate	
	TWh/a	TWh/a	%	TWh/a	TWh/a	%	TWh/a	TWh/a	%
Europe incl. CIS & Turkey	2.085	2.082,2	99,9	4.300	4.244,1	98,7	745	733,7	98,5
Asia	3.815	3.084,2	80,8	2.900	2.341,7	80,7	390	361,8	92,8
Africa	2.500	2.345,7	93,8	400	258,1	64,5	57	55,1	96,7
America	4.500	4.027,7	89,5	4.300	3.680,9	85,6	1.005	969,5	96,5
Oceania	200	40,0	20,0	200	187,0	93,5	43	39,8	92,6
World total	13.100	11.579,8	88,4	12.100	10.711,8	88,5	2.240	2.159,9	96,4

Unavailable and omitted unreliable figures concerning individual countries are accounted for in the pertaining total estimates.

The detailed estimate of Africa's economic hydropower potential is based on cursory figures concerning many of its countries.

CONTENTS

page

Introduction 1
World's Hydropower Potential 2
Comparison of various Studies on The World's Economic Hydropower Potential 3
World's Electricity Generation 4
Survey of Electricity demand and supply by Hydropower 1990 through 2020 5
Global Interconnection of Power Grids 6
World's Population 7
Electricity Demand per Capita in the World 8
World's CO_2 Emission as a Result of Electricity Production 9
Average Electricity Production Cost 10
Advantages and disadvantages of Hydropower Projects 11
The Message 12
Some References 14

APPENDIX

Survey of the Hydropower Potential of the World and its Utilisation 15

I: Europe incl. CIS and Turkey 16
II: Asia 17
III: Africa 18
IV: America 19
V: Oceania 20

In accordance with ISO Standards the comma has been used throughout this report as the decimal marker.

XXIV CONGRESS unipede 18 - 22 MAY 1997

HYDROPOWER AND OTHER RENEWABLE ENERGIES
STUDY COMMITTEE
"HYDREN"

Study on the Importance of Harnessing the Hydropower Resources of the World

Prepared by

Jóhann Már Maríusson
Deputy Managing Director of
Landsvirkjun (The National Power Company), Iceland
and
Loftur Thorsteinsson
Senior Engineer
VST Consulting Engineers, Iceland

April 1997