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COMPARISON OF HYDROPOWER UTILIZATION AND ENVIRONMENTAL IMPACTS ALONG THE DANUBE DOWNSTREAM OF VIENNA

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ABSTRACT Hydropower plays an essential role in the Austrian energy supply. About two thirds of the electric consumption are covered by hydropower generation. The objective of this paper is to analyse a pending conflict between hydropower utilization and environmental concerns along the Austrian section of the Danube downstream of Vienna. In the first step the utilizeable hydropower potential of the respective section and the environmental impacts are assessed. In a subsequent step a framework is elaborated to compare and to trade off economic and environmental objectives. Such a procedure requires preference values and is thus subjected to subjectivity, introduced either by decision makers or by involved parties.

INTRODUCTION

The Danube is nearly completely impounded along its Austrian section (Fig. 1). Nine hydropower schemes from which one is jointly operated by the FRG and Austria generate about 30% of the hydropower energy of Austria. To stress the importance of hydropower in Austria it is worth to note that about 2/3 of the electric energy consumption are covered by hydropower generation. Simultaneously, the runoff river schemes along the Danube serve navigation purposes. The respective recommendations for the dimension of the waterway are summarized in the declaration of the Danube commission.
Only a few free flowing sections of the Danube remained within Austria from which the longest and ecologically most attractive is located downstream of Vienna. In 1984 the hydropower company responsible by law for the utilization of the potential of river Danube submitted a project (Donaukraft, 1984) to be authorized by the Supreme Water Law authority which is associated to the Austrian Ministery of Agriculture and Forestry. The goal of the proposal was to implement the last hydropower station along the Austrian Danube a few miles upstream of the Austrian-Czechoslovakian border. The proposed scheme was a runoff river type station with similar characteristics like all the Austrian Danube power stations. The negotiation process performed under the Supreme Water Law Authority, acting as a lead agency, resulted in the approval of the project but several improvements Were additionally imposed to protect the environment.
Due to severe concerns raised by eco-activistic groups who received strong support by the public, especially by some news papers, and who finally claimed the project site the clearing works had to be postponed. Later on the Supreme Administrative Court annuled the water law concession.
To resume negotiations the federal government established an Ecological Advisory Board to elaborate proposals for the future management of the respective Danube section. Although this board was composed of environmentalists, engineers and regional planners it worked surprisingly efficient and the members finally recommended that the last unimpounded section from Vienna downstream to Wolfsthal (Fig. 2) should be prevented from any economic utilization. Until now a final decision is pending.
In this paper an attempt is proposed how a rational comparison of conflicting objectives might be achieved. A framework considering economic, ecological and social criteria is elaborated and a methodology for identifying a compromise solution is explained.

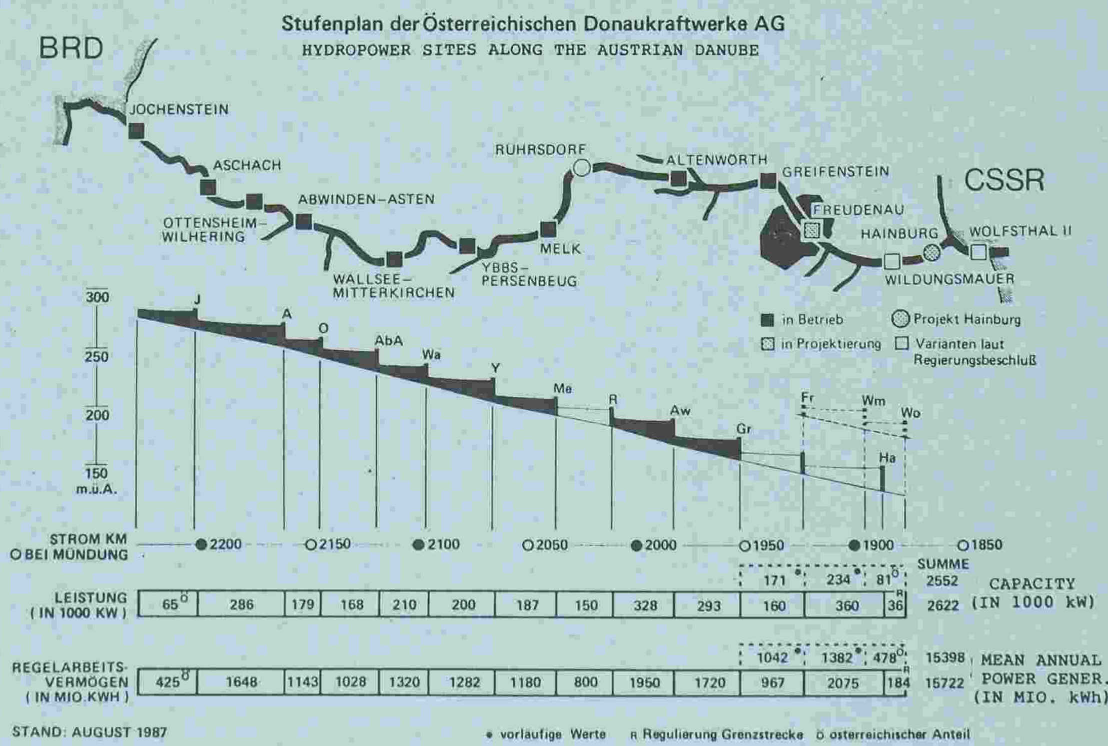

Fig. I Hydropower utilization along the Danube in Austria

DESCRIPTION OF REGIONAL RESOURCES

Hydropower

The raw energy potential which refers to the complete utilization of the discharge over the full head along the section is given in Table 1.

It is worth to note that in the lowest subsection in the Danube constitutes the border between Austrian and CSFR and thus the hydropower potential has to be properly allocated to both countries.

Floodplain forests

In Austria more than 75% of water bodies typical for flood plain areas are located along the Danube. They cover an area of 1540 ha from which 730 ha are found in and downstream of Vienna (Gepp, 1985 a). The importance of this flood plain area becomes more evident when only surface waters are considered which still exhibit a natural dynamics and which are subjected to frequent flooding.

Preliminary investigations and preparatory planning activities to establish a national park in this region indicate a total area of 230 km² to be protected. The "kernel area" is about 110 km² which should be excluded from any economic utilization. Additionally, 94 km² of riverine zones along the tributary March should be integrated into the planned national park (Schulz, 1986).

With respect to biological diversity it is estimated that approximately 12000 species (faunistic and floristic) are abundant in the Austrian flood plain areas (GEPP, 1985 b). In the concluding paper of the Ecological Advisory Board (1985) an estimate of 5000 faunistic species is given for the region. Several of them are enumerated in the list of endangered species.

About 80% of the birds hatching in Austria are native in the flood plain areas. Further, this region is of essential importance in serving as a resting place during the migration of birds.

Oxbowlakes and stagnant shallows waters constitute the spawning grounds for numerous fish species. 57 species (Jungwirth & Rehahn 1986; Schiemer, 1986) are observed in the Danube from which 32 species are abundant. These backwater areas serve also as a spawning ground and habitat for amphibia which require shallow water zones, bank line vegetation and sunny patches. Flood events stimulate their reproduction and subsequently enhance the cyclic migration into the remote back water areas.

Groundwater system

The Danube recharges a groundwater-system extending on the left bank over 1000 km²

On the left bank domestic and agricultural water requirements are covered by groundwater pumping and on the right bank some well are also dependent on the Danube watertable.

Table 1. – Raw energy potential downstream of Greifenstein in GWh/a (Donaukraft, 1990).

Subsection	Stream location (km)	Raw energy potential (GWh)
Greifenstein-Vienna (Reichsbrücke)	1948.9 - 1929.1	1281
Vienna (Reichsbrücke)-Hainburg	129.1 - 1883.9	3022
Hainburg-Mouth of river March	1883.9 - 1880.1	311
Mouth of river March-border	1880.1 - 1872.7	524
Greifenstein-Border	1948.9 - 1872.7	5138

Table 2. – Goals, criteria and units.

Goals	Subgoals	Criteria	Units
maximization of economical utilization of resources	maximize power generation	annual power output	GWh
		investment costs	Mrd öS
	minimize costs	operation costs	ordinal
increase social welfare	increase of employment rate	jobs created during construction	manyears
	increase of recreational opportunities	recreational facilities	ordinal
	improved navigation	duration of restricted navigation	days/year
	protections of the medicinal spring	risk	ordinal
preservation of the specific ecosystem in this region	preservation of the flood plain forests	losses due to construction	ha
		area of initial vegetation	ha
		losses of inundated area	%
		area of flood plain forests	ha
		forest edges	km
		forest galleries	km
	preservation of typical faunistic populations	impact on water fowl	ordinal
		impact on other populations	ordinal
		compatibility with national park requirement	ordinal
	preservation of the morphometric variability of riverbanks	ratio of impoundment to free flowing section	km/km
		length of remaining riverbanks	km
		length of water-bank line at low flows	km
		length of water-bank line at mean discharge	km
		shallows water zones at low flows	ha
		shallows water zones at mean discharge	ha
		gravel banks at low flows	ha
		gravel banks at mean discharge	ha
		connectivity between main river and oxbows	number
		rate of degradation of the river bed	ordinal
	improvement of water quality	saprobic scale	ordinal
		change in groundwater quality	ordinal
	preservation of the groundwater system	length of impervious dams	km
		area with changes in the mean groundwater table (>0.5m)	km²
		area with groundwater dynamics (0.5-1.0m)	km²
		area with groundwater dynamics (>1.0m)	km²

IDENTIFICATION OF GOALS

Hydropower

A governmental agreement which was achieved in Pertisau, 1987 underlined once more the importance of hydropower utilization downstream of Vienna but simultaneously asked for planning steps to establish a national park in the flood plain area of Danube and March.

Goals related to power generation and energy management are included in the energy reports issued regularly by the Ministery of Trade, Commerce and Industries. The principles of governmental energy and environmental policies include the following set of guidelines:

- reduction of primary energy consumption
- increased utilization of renewable resources, especially of hydropower
- minimization of environmental impacts related to power generation and consumption.

Navigation

The Danube section from Braila (170 km) to Kehlheim, FRG (2414.7 km) is classified as category IV according to the European waterways standards (Fekete, 1990). This requires for unimpounded sections a minimun depth of 1,85-2,50 m and a width of 40-180 m for navigation. In impounded sections the minimal prescribed depth is 3.5 m. For the respective Austrian stretch of the Danube the recommendations of the Danube commission include a minimum depth of 2,10 m downstream of Vienna to the border of the CSFR and a width of 150 m. During low flow periods several fords with a depth of 2 m and less restrict economical navigation and frequent dredging works are required to maintain the waterway. Thus, it is an important goal to guarantee at least the minimal requirements for navigation throughout the year.

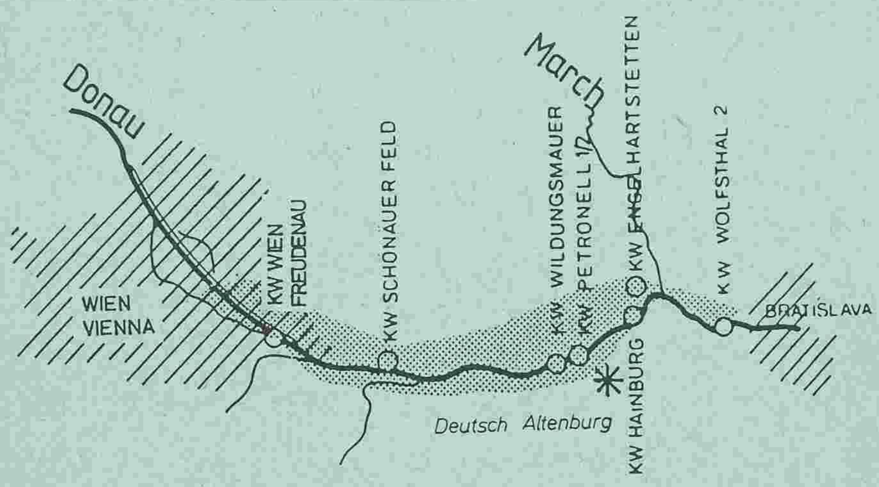

Fig. 2 Alternative plans for hydropower utilization

Drinking Water Supply

One of the goals of the regional water management is the protection of the extended alluvial aquifers bordering the Danube. This resource partly serves the Viennese drinking water supply and also of some villages in the vicinity of the Danube. In this context the emphasis is also on the protections of a medicinal spring which is supplied from a karstic aquifer closely located to the Danube.

Environmental preservation

In 1978 and 1979 major areas of the flood plain forests were legally protected by the respective provinces. Because of the unique ecological characteristics of this area planning activities were initiated in the last years to delimit a natural preserve worthy of becoming a national park.

Recently, an institutional framework has been elaborated as was declared in an governmental agreement. Obviously, the preservation of the flood plain forests and of the riparian wetlands by establishing a national park constitutes an important objective for this region.

DESCRIPTION OF ALTERNATIVES

A project named hydropower station Freudenau has been elaborated by the Donaukraft (1989 a). This scheme is located in Vienna and its implementation is planned within the next five years. Therefore, in this paper only the stretch downstream is considered and a time horizon of twenty-five years in assumed.

Various hydropower alternatives have been elaborated in the last six years (Kaniak, 1986; Donaukraft, 1984, 1989 a,b; Regio, 1989).

The level of elaboration varies among the alternatives from a general plan to a detailed engineering plan. The alternatives are characterized (Table 2) by their location and their capacity. Additionally, every alternative is split into a pure economical alternative and a "soft alternative" including secondary measures for the compensation of hydrological impacts caused by the hydropower scheme.

The status quo is considered by alternative I which itself is split up into two subalternatives. The first excludes any hydropower utilization downstream of Vienna, while (1 a) additionally substitutes the nonutilized hydropower by energy import.

The runoff river schemes upstream of Vienna trap the sediments of the Danube, especially the coarse material. As a consequence degradation downstream the last power station is observed. The mean annual degredation of the river bed has been estimated to 1,5-2,5 cm/a (Kresser, 1984) and measures have to be taken to coop with this process. Several measures including artifical armoring of the river bed and addition of coarse grained bed material to decrease the degradation process were analyzed (Ogris, 1989; Zottl, 1988; Bernhart, 1988). Due to the assumed time horizon none of these measures is considered in this paper.

Table 3. – List of hydropower alternatives.

No of Alternative	2 Hainburg	3 Schönauer Feld Petronell 1 Wolfsthal 2	4 Petronell 2 Wolfsthal 2	5 Wildungsmauer Wolfsthal 2	6 Engelh. stetten
Location (km)	1883	1906 1890 1873	 1890 1873	1892.5 1873	1883.0
No of power stations	1	3	2	2	1
Installed capacity (MW)	360	247	327	327	352
Annual power generation (GWh)	2075	1700	1990	1920	2035
Investment costs (Mrd.öS)	11.4	24.9	15.9	15.6	12.2

IDENTIFICATION OF COMPROMISE SOLUTIONS

Based on the analysis in the previous chapters a set of subgoals specifying the general tasks more precisely has been defined. In Table 3 each goal is expressed by a set of criteria and measures (Nachtnebel *et al.* 1990). The impacts of each alternative are characterized with respect to the full set of criteria and the corresponding measures. (Table 4). For ranking the alternatives weights expressing the importance of a criterion have to be defined and a common scale for a tradeoff among the criteria has to be established. This second part of the procedure is value dependent and is thus subjected to subjectivity. Various methods have been developed to assist in multicriteria and/or multiobjective decision making (Goicoechea *et al.* 1982; Nachtnebel, 1988). Due to the fact that some of the criteria are expressed in an ordinal scale. The ELECTRE method (Benayoun *et al.*, 1966) has been applied for ranking the alternatives. Without discussing the ELECTRE method in detail it can be summarized that this method is based on a pairwise comparison of alternatives A_i and A_j. A concordance index counts how often – with respect to a certain criterion – A_i is better than A and expresses the preference by the respective sum of weights. A discordance i)dex considers how strong the assumption A_i better than Aj is violated with respect to a certain criterion. Obviously, an alternative should exhibit a high concordance index and a low discordance index to be among the prefered alternatives.

It is evident that the ranking process is dependent on the weights. Assuming equal weights for the three main objectives the alternatives 1, 2 and 3 are dominated by 4, 5 and 6. Further, alternative 5a achieves the best compromise among the objectives. Even in case of increasing the weight for the ecological objective alternative 5a remains among the best until it is finally dominated by alternative la. This holds only if weights greater 0.7 are assigned to the ecological objective and less than 0.3 for the social and the economic objectives. A sensitivity analysis was additionally performed to consider the uncertainty inherent in the figures given in Table 4. It can be summarized that the dominance of the alternatives 5 and 4 is stable within a broad variation of the outcomes of the alternatives.

SUMMARY AND CONCLUSIONS

Several alternatives for utilizing the hydropower potential of the Danube downstream of Vienna have been elaborated. Due to ecological objections no decision has been taken until now. In this paper a methodology has presented to assist in decision making. In the first step a pure impact assessment was performed within an extended framework considering economic, ecological and social tasks. A set of 33 criteria characterized quantitatively – as far as possible – the outcome of each alternative with respect to the goals and the corresponding subgoals.

In a subsequent step aspiration levels and weights were assigned to each criterion to achieve a tradeoff among the objectives. A compromise solution including two hydro-

Table 4. – Alternatives versus criteria array.

Criteria	Unit	1	1a	2	2a	3	3a	4	4a	5	5a	6	6a	Weigth	Scale	Best	Worst
power generation	GWh	0	2075	2075	2075	1700	1700	1990	1990	1791	1791	2075	2075	20	20	2075	0
investment costs	Mrd ÖS	0.1	22.3	11.4	12.0	24.9	26.1	15.9	16.7	15.6	16.4	12.2	12.8	20.0	20.0	0.1	26.1
operation costs	ordinal	2.0	2.0	3.0	3.0	5.0	5.0	5.0	5.0	5.0	5.0	3.0	3.0	6.0	5.0	1.0	5.0
employment	manyears	0.5	0.5	17.1	18.0	37.5	39.2	23.9	25.1	23.4	24.6	18.3	19.2	15.0	15.0	39.2	0.5
longterm employment	number	30.0	30.0	70.0	70.0	210.0	210.0	140.0	140.0	140.0	140.0	70.0	70.0	10.0	10.0	210.0	30.0
recreation	ordinal	1.0	1.0	4.0	4.0	3.0	3.0	4.0	4.0	4.0	4.0	4.0	4.0	12.0	10.0	1.0	5.0
navigation	days	111.0	111.0	116.0	116.0	11.0	11.0	11.0	11.0	11.0	11.0	116.0	116.0	12.0	15.0	11.0	116.0
medicinal springs	ordinal	2.0	2.0	3.0	3.0	1.0	1.0	1.0	1.0	1.0	1.0	3.0	3.0	5.0	5.0	1.0	5.0
area of constr.site	ha	0.0	0.0	740.0	740.0	660.0	660.0	655.0	655.0	465.0	465.0	496.0	496.0	3.0	10.0	0.0	740.0
initial vegetation	ha	18.2	18.2	0.8	0.8	7.1	7.1	1.4	1.4	3.1	3.1	1.1	1.1	4.0	15.0	18.2	1.1
losses inundated area	%	0.0	0.0	86.4	86.4	25.0	25.0	62.0	62.0	52.0	52.0	87.8	87.8	10.0	20.0	0.0	87.8
floodplain forest	ha	120.2	120.2	18.3	18.3	55.0	55.0	32.5	32.5	38.9	38.9	24.0	24.0	1.0	10.0	120.2	18.3
forest edges	km	33.8	33.8	2.9	2.9	1.6	1.6	12.1	12.1	19.0	19.0	3.4	3.4	1.0	10.0	33.8	2.9
forest galleries	km	16.0	16.0	5.9	0.6	8.7	8.7	7.6	7.6	10.3	10.3	6.4	6.4	1.0	10.0	16.0	5.9
water fowl	ordinal	4.0	4.0	4.0	4.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0	4.0	2.0	10.0	1.0	5.0
faunistic pop.	ordinal	1.0	1.0	5.0	5.0	3.0	3.0	4.0	4.0	4.0	4.0	5.0	5.0	16.0	15.0	1.0	5.0
compatibility n.park	ordinal	1.0	1.0	5.0	5.0	3.0	3.0	4.0	4.0	4.0	4.0	5.0	5.0	6.0	15.0	1.0	5.0
river impoundment	%	1.0	1.0	0.3	0.3	0.2	0.2	0.1	0.1	0.2	0.2	0.3	0.3	8.0	15.0	1.0	0.1
original banks	km	96.0	96.0	23.0	23.0	36.5	36.5	35.5	25.5	40.1	40.1	23.0	23.0	3.0	10.0	96.0	23.0
bank line (1)	km	113.8	113.8	83.7	83.7	81.6	81.6	82.7	82.7	85.0	85.0	83.7	83.7	1.0	10.0	113.8	81.6
bank line (2)	km	100.0	100.0	83.7	83.7	81.6	81.6	82.7	82.7	85.0	85.0	83.7	83.7	1.0	10.0	100.0	81.6
shallow water (1)	ha	165.5	165.5	57.8	57.8	47.0	47.0	39.8	39.8	48.6	48.6	57.8	57.8	3.0	10.0	165.5	39.8
shallow water (2)	ha	166.2	166.2	52.5	52.5	47.0	47.0	39.8	39.8	48.6	48.6	52.5	52.5	3.0	10.0	166.2	39.8
gravel zones (1)	ha	168.1	168.1	1.4	1.4	0.0	0.0	0.0	0.0	12.9	12.9	1.4	1.4	2.0	10.0	168.1	0.0
gravel zones (2)	ha	6.8	6.8	0.0	0.0	0.0	0.0	0.0	0.0	2.1	2.1	0.0	0.0	1.0	10.0	6.8	0.0
connectivity	number	42.0	42.0	11.0	11.0	25.0	25.0	20.0	20.0	23.0	23.0	12.0	12.0	4.0	10.0	42.0	11.0
degradation	ordinal	5.0	5.0	2.0	2.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	7.0	10.0	1.0	5.0
surface w. qualitiy	ordinal	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0	15.0	1.0	5.0
gw.water quality	ordinal	2.0	2.0	5.0	4.0	3.0	2.0	4.0	3.0	3.0	2.0	5.0	4.0	2.0	10.0	1.0	5.0
impervious dams	km	0.0	0.0	57.8	58.8	15.5	15.5	42.5	42.5	31.5	31.5	57.8	57.8	4.0	15.0	0.0	57.8
change in mean gw.level	km^2	65.5	65.5	68.3	6.3	69.5	29.7	67.3	23.5	61.9	20.8	68.3	6.3	4.0	15.0	6.3	69.5
area gw.dynamics (<1.0)	km^2	51.8	51.8	4.1	4.1	14.3	10.1	12.4	9.2	12.4	9.2	4.1	4.1	4.0	15.0	51.8	4.1
area gw.dynamics (>1.0)	km^2	35.9	35.9	4.1	4.1	8.0	8.5	8.7	7.4	8.7	7.4	4.1	4.1	5.0	15.0	35.9	4.1

(1) at low flows, (2) at mean discharge

power scheme downstream of Vienna was identified. This solution exhibited its preference within a broad variation of the weights. In case of a pronounced preference of the ecological objective the alternative without any hydropower utilization became dominant. However, the evaluation procedure, performed in the second step is subjected to subjectivity inherent in any preference structure.

The proposed methodology provides a tool to trade off differently expressed criteria, to aggregate the measures of efficiency and finally to rank the alternatives. Subsequently, a sensitivity analysis was applied with respect to preference values or judgements for each criterion.

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