IMPROVED DEVELOPMENT AND MANAGEMENT OF WATER RESOURCES IN REGULATED RIVER SYSTEMS

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The CEDREN EcoManage project was finalized in December 2015 and the main objective of the project was the improved development and management of energy and water resources. Three main axes of management parameters were studied; 1) Energy indicators, 2) Water consumption in the hydropower sector and 3) the off-set options for ecosystem services. The first axis on energy indicators dealt with developing a consistent energy indicator framework which allows for reliable comparisons and benchmarking between technologies. This activity included calculation of Energy Payback Ratio, Net Energy Ratio and Cumulative Energy Demand values for different electricity generation technologies. The second axis dealt with developing a methodology for the assessment of water consumption in hydropower plants, allowing comparison with other enabling electricity production technologies by different water footprint methods. The final axis dealt with the demonstration of the applicability of the Ecosystem Services in identifying the full social costs of hydropower development and designing instruments to internalize these costs in hydropower developers and customers decision-making. Key research findings for each of the axes are shown, with emphasis on implementation of the tools and concepts into the decision making processes for stakeholders in both industry and governmental management. Examples of methods and tools used in the study are presented, showing the potential improvements in decision making. Finally a new project proposal is presented as a continuation of the EcoManage project.

1 INTRODUCTION

The main objective of CEDREN EcoManage was to further develop decision support tools and concepts for relevant stakeholders (i.e. the hydropower industry, national water management authorities). The overall target of the project was to provide a selection of tools, not necessarily directly connected, but related to different (or similar) aspects of sustainable energy and water resource management. Three concepts were chosen: 1) Energy indicators, 2) Water consumption in the hydropower sector, and 3) the off-set options for ecosystem services.

2 ENERGY INDICATORS

2.1 Introduction and methods

Referring to life-cycle assessments (LCA) as a tool to assess environmental impacts of products or services, energy indicators are a central part in most LCA investigations. Energy input and output is an important parameter in LCA. As global targets to expand the development and implementation of renewable energy into the grid to replace fossil based electricity production are currently being introduced, sound and relevant comparison of the actual energy demand of each of the energy production technologies must be conducted. The results from EcoManage give a basis for using the most adequate energy indicator, dependent on the need of future case studies, also discussing system boundaries as a potential source of incoherence. In the EcoManage project three selected energy indicators were selected for review and validation in relation to use in hydropower sustainability assessment [1]. The two main indicators were Cumulative Energy Demand (CED) and Energy Payback Ratio (EPR). The study aimed to improve the basis for comparing electricity production (i.e. hydropower, wind power, and electricity from biomass, coal and gas). For EPR and CED respectively, the following cases were investigated: hydropower (16/14), wind power (10), biomass (6), coal and natural gas (6).

2.2 Results

Table 1: Description of parameters used in the energy indicators studied in EcoManage

Category	Short	Details
Energy use for production of energy infrastructures	A	Primary energy required for building the infrastructure
Energy use for delivery of fuel source and internal energy use at the generation plant	B	Primary energy required for extraction, processing and transport of fuel
Extracted energy	Q	Can in some cases be characterized as embedded energy in the extracted fuel
Final energy product	W	Delivered final energy product

EPR = Energy payback ratio = W / (A+B) (for parameter description, see Table 1). EPR is the total final energy product generated during a system's normal lifespan, divided by the supporting primary energy required to build, maintain and supply the system. Embedded energy in fuels is not included. CED = Cumulative energy demand = (A+B+Q) / W. CED involves all primary energy required to build, maintain and supply the system, including embedded energy in fuels, divided by the final energy product generated during a system lifespan. Calculations of EPR for all involved cases rank hydropower as having the best performance (50-500 kWh/kWh), then wind power (3-30 kWh/kWh). The thermal power generation technologies (biomass, natural gas, coal) ranks lower with EPR values ranging from 1 through 6 kWh/kWh. Calculation of CED for all involved cases gave the same relative results as for EPR, hydropower ranking best, and coal ranking lowest.

2.3 Discussion and conclusion

The main driver for differentiating the use of energy indicators is system boundaries. The difference between EPR and CED is related to including primary energy lost by conversion in CED. Even though the ranking in both cases give hydropower and wind power the best performance, focusing on the internal comparison between hydropower projects may give different results dependent on which energy indicator that is used. As the main stakeholder of the EcoManage project is the hydropower industry, the results should be considered when developing new and sustainable hydropower projects nationally and internationally, with the targets of increased renewable electricity production share in the global energy mix as a backdrop.

3 WATER CONSUMPTION

3.1 Introduction and methods

The SRREN-report [2] compared water consumption for different energy technologies. Regarding hydropower, it distinguished between the water consumption in run-of-river hydropower plants and hydropower plants with storage capacity in upstream reservoirs. The latter was indicated to have large water losses, mainly due to evaporation from reservoir surfaces. This conclusion was based on a small dataset which showed large variations (high range), not separating between net and gross losses and the difference in climatic conditions between the associated regions. Another conclusion in the SRREN-report was the lack of a global assessment of lifecycle water consumption of reservoirs. The EcoManage work package on water consumption documented several methodical problems with using gross evaporation calculation [3]. Also discussed was system boundaries when calculating water consumption, the allocation of water consumption in multi-purpose reservoirs (used for more than hydropower), and the benefits of reservoirs to water availability in water scarce areas.

3.2 Results

Based on a global review of gross water consumption and evaporation estimates in relation to hydropower production, results showed a spatial segregation between different climate zones, ranging from an average of 14 m^3/MWh in polar and alpine climates to 1658 m^3/MWh in arid and semiarid climates, using the Köppen-Geiger classification method for climatic regions [4]. Also in the same study is the ratio of net vs gross water consumption estimates for a selection of hydropower plants showing that the net water consumption (taking into account the situation prior to damming) is approximately 60 % or less.

3.3 Discussion and conclusion

Regarding system boundaries, the preliminary gross water consumption calculations does not take into account the more complex hydropower systems where several large water bodies exists and supply a range of downstream hydropower plants, and may be supplied by neighboring water sheds. It is also argued that water consumption can vary from month to month even with limited change in evaporation rates. This might be due to decreasing power production (discharge through downstream turbines), and not a reduction in the total water losses due to reduced surface areas. The conclusions are that spatial system boundaries are not always the one reservoir itself and its immediate hydropower plant, and that evaporated water might return upstream into the same catchment. On a temporal scale annual values might be biased due to the connection between seasonal variation in power production, evaporation from reservoirs and total water loss. Globally, 25 % of reservoirs with a dam higher than 15 m are multi-purpose reservoirs [5]. 3775 out of 8689 reservoirs used for hydropower production are also used for other purposes. In water-scarce areas less the 0.1 % of large reservoirs is used exclusively for hydropower production. Other purposes might be water supply for irrigation, domestic and industrial supply, and flood protection. Based on this, a more detailed approach to water consumption calculation is needed to address the water loss issue when comparing both different energy production technologies and different hydropower projects, also taking into account multi-purpose use of reservoirs.

4 ECOSYSTEM SERVICES

4.1 Introduction and methods

Hydropower concessions in Norway are often approved individually for river sections, limiting the scope for optimal use of the hydrological system for power and environmental standards for Hydropower operations. Off-setting the biodiversity impacts of river regulation from hydropower at one site with off-site measures in other rivers holds the promise of getting more power out of the hydrological system with no net loss of biodiversity. In salmon bearing rivers, environmental flow rules in the concessions are often set based on a ‘single criteria’ approach focusing on salmon habitat conditions. The study looked at the salmon bearing Mandal River, Norway and first asked what cost-effect gains could be made for power and salmon if concession requirements were evaluated across two river reaches – the Laudal and Bjelland reaches together – instead of one reach at a time, effectively using the biodiversity offset to obtain more power per salmon equivalent. We also looked at how this cost-effectiveness could be further enhanced by physical habitat restoration measures at the Laudal site. The study then considered whether the conclusions from the cost-effectiveness analysis of offsetting, was changed by taking a multi-criteria approach [6] including ecosystem services affected, focusing on river landscape aesthetics and recreational salmon fishing. The study required integration of a series of models, including hydropower production, river hydraulics, wetted area, salmon smolt productivity, mesohabitat classification and photosimulation of river aesthetics. We test the use of Bayesian belief network (BBN) as a meta-modeling tool to integrate model simulations as a series of conditional probability distributions [7]. BBNs make it possible to conduct integrated assessments of uncertainty across the model chain, which is essential considering hydrological variability

4.2 Results

The cost-effectiveness analysis shows that the smolt-to-power loss ratio is much higher for the Bjelland than Laudal reach indicating that biodiversity offsetting measures could be undertaken in the Laudal reach to compensate for higher power production in the Bjelland reach [8]. Increasing salmon spawning habitat by removing a number of weirs and putting out spawning gravel would enhance the effectiveness of an off-setting scheme. The operator Agder Energi is using the results of the habitat restoration part of the study to justify relaxing minimum flow requirements in the Laudal concession. Habitat restoration modeling combining hydraulics and IBSalmon simulation models show that physical habitat restoration is in fact more effective than increasing environmental flow per unit of power loss. Nevertheless, habitat remediation through weir removal also affects riverscape aesthetics, in that larger calm water surfaces are converted to rapids in a number of places adjacent to landowner residences. Photosimulations showed significant visual effects. The mesohabitat classification showed that weir removal also provided a number of additional sites for recreational fishing. Conclusions regarding the cost-effectiveness of offsetting are modified by these ecosystem service considerations, depending on the weight assigned to ecosystem services versus smolt productivity and hydropower loss. Landscape aesthetics affect relatively few residents for longer periods whereas new recreational fishing opportunities affect a potentially larger number of users during a few weeks in the fishing season. The importance of these effects is uncertain given diversity of perceptions of river aesthetics across users. However, integrated uncertainty analysis using an MCDA in a Bayesian belief network shows weighting of aesthetic impacts is unlikely to change the overall conclusions about cost-effectiveness of biodiversity offsetting in the Laudal stretch. In fact, potential gains in hydropower make it possible to consider direct compensation measures to riparian landowners affected by the loss of weirs.

4.3 Discussion and conclusion

The biodiversity offsetting problem between two river reaches studied here is exploratory, and not at present on the table for concession revisions. In fact, the present concession requirements in the Laudal stretch alone are considered too strict, given the findings from the IBSalmon modeling. Before considering offsetting offsite, onsite habitat restoration actions are more cost-effective, and also easier to propose as part of the procedures established for individual concession reviews by Norwegian energy and environmental authorities. Our hypothesis is that given uncertainty about river ecosystem function, authorities set environmental flow regulations using a ‘safe minimum standards’ approach with a considerable risk buffer. Our modeling shows that this lack of ecosystem functional knowledge can be costly. The wider biodiversity offsetting literature also demonstrates that more detailed ecosystem function modeling can reduce the need for so called large ‘risk ratios’. The cost-effectiveness of offsetting is constrained by a number of other conditions. Potential power gains from reducing environmental flows are limited by existing turbine capacity. It is important to note that off-setting opportunities in the Mandal River have only become possible thanks to decadal trends of reduced acid rain, which increasingly boosts the effect of any salmon habitat measures.

5 SUMMARY

The EcoManage project has evaluated, tested and through case studies implemented three concepts acting as relevant tools for decision-making processes for stakeholders in regulated water sheds, aiming at both the planning stage and the operational stage. All scientific groups involved have contributed to a better understanding of the concepts on a national and international level, through several publications and participation in conferences and forums with other scientists, stakeholders, politicians, regulatory authorities, NGO's and land owners/sports fishermen.

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