Advances in Science, Technology & Innovation
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Vincenzo Naddeo · Kwang-Ho Choo ·
Mohamed Ksibi *Editors*

# Water-Energy-Nexus in the Ecological Transition

## Natural-Based Solutions, Advanced Technologies and Best Practices for Environmental Sustainability

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Vincenzo Naddeo • Kwang-Ho Choo •
Mohamed Ksibi
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# Water-Energy-Nexus in the Ecological Transition

## Natural-Based Solutions, Advanced Technologies and Best Practices for Environmental Sustainability

Springer

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# Preface

The Water-Energy Nexus is one of the most important and priority issues to be resolved for both current and next generations. Water and energy underpin economic and social development. Water is needed for each stage of energy production, and energy is crucial for the provision and treatment of water. In the energy community, much of the attention has centred on the impact of water availability on the different processes of the energy sector and the energy sector's impact on water quality and quantity. This interdependency has significant implications for both energy and water security. With both water and energy needs set to increase, it has become ever more important to understand the linkages between the two, to anticipate future stress points and to implement policies, technologies and practices that soundly address the associated risks.

The findings show that there are ways to mitigate risks. Policies and technologies are already studied and proposed by scholars and technicians for sustainable development. However, a clear vision of both state of the art and all possible solutions is needed for decision-makers to assess the possible trade-offs and different scenarios. A successful action will require a strong, coordinated focus across different branches and levels of government and collaboration between policy-makers, researchers, industry and consumers.

This volume will include papers that broadly address recent and novel developments in technology and in the solutions that could be proposed to help ease chokepoints and reduce demand in both sectors, meaning that water does not have to be a limiting factor for the energy sector and a rise in water demand does not have to be accompanied by an equal rise in energy demand. This volume will provide an opportunity for knowledge exchange to advance our understanding of the current state of Water-Energy systems and their nexuses that will lead to guiding and developing sustainable and resilient systems. The scope of the volume is extended to the relative environmental, management and economic aspects related to the Water-Energy systems.

In detail, this volume includes selected contributions presented during the III edition of the international conference on WaterEnergyNEXUS, which was held in December 2020. This edition of the conference was organized by the University of Sfax (Tunisia), in cooperation with the Sanitary Environmental Engineering Division (SEED) of the University of Salerno (Italy), the Advanced Institute of Water Industry at Kyungpook National University (Korea) and The Energy and Resources Institute, TERI (India)). The first edition of WaterEnergyNEXUS was organized in Korea in 2017 during the Asian International Water Week, one of the more pertinent and significant meetings in Asia for scientists and professionals working in the field of water use and sustainability. The second edition was organized in Salerno (Italy) in 2018. The third WaterEnergyNEXUS conference provided an international digital platform where key topics on water management were discussed by participants with the presentation of nature-based solutions, advanced technologies and best practices by a panel of experts invited as plenary and keynote speakers. Another objective of the third edition of the WaterEnergyNEXUS conference is to enhance cooperation, integration and sustainable development in the Euro-Mediterranean region on the critical links between Water and Energy.

The WaterEnergyNEXUS series of conferences are supported by the UNESCO World Water Association Programme (WWAP) and the International Water Association (IWA). It also enjoys the patronage of several international scientific societies, associations and organizations and has established a publishing partnership with Springer Nature.

This volume gives an overview of current research focusing on emerging Water-Energy Nexus issues and challenges and their potential applications to a variety of environmental problems that are impacting the Euro-Mediterranean zone and surrounding regions. A selection of novel and alternative solutions applied worldwide will also be presented. The volume contains carefully refereed contributions selected from the conference. Topics covered include (1) Nexus framework and governance, (2) environmental solutions for the sustainable development of the water sector, (3) future clean energy technologies and systems underwater constraints, (4) environmental engineering and management and (5) implementation and best practices.

Intended for researchers in environmental engineering, environmental science, chemistry and civil engineering, this volume is also an invaluable guide for industry professionals working in both the water and energy sectors.

Fisciano, Italy Vincenzo Naddeo
Daegu, Korea (Republic of) Kwang-Ho Choo
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# Contents

# About the Editors

**Prof. Vincenzo Naddeo** is Full Professor at Department of Civil Engineering of the University of Salerno (Italy) and Director of the Sanitary Environmental Engineering Division (SEED), where he drives research and academic activities in the Environmental Engineering fields. He serves as Affiliate Professor at both the Department of Civil and Environmental Engineering of the University of Washington (Seattle, WA, USA) and at the Department of Water Resources and Environmental Engineering of the Tamkang University (New Taipei City, Taiwan).

He is Editor of the Water Environmental Research (Wiley) and Associate Editor of Case Studies in Chemical and Environmental Engineering (Elsevier), *Euro-Mediterranean Journal for Environmental Integration* (Springer), Scientific Report (Nature Portfolio) and of the Earth, Frontiers for Young Minds (Frontiers). He is Special Issues Editor and Social Media Editor for *Journal of Hazardous Materials* (Elsevier), *Journal of Hazardous Materials Letters* (Elsevier) and *Journal of Hazardous Materials Advances* (Elsevier). He presently serves on the editorial board of several ISI journals including Science of Total Environment (Elsevier), Desalination (Elsevier), PeerJ (Life, Bio, Environment and Health Sciences), Frontiers in Bioengineering and Biotechnology, Water (MDPI) and Bioengineered (Taylor & Francis). Dr. Naddeo is also actively involved in a variety of scientific organizations, funding agencies, and European networks. He holds seven patents, four on innovative technologies for the advanced treatment of water or wastewater, two on the next generation of electronic nose (e.Nose) and one patent on an innovative photo-bioreactor for the sequestration of $CO_2$. Prof. Naddeo serves the editorial board of several ISI journals, and he is (co-) Author of over 200 refereed publications in ISI journals, congress proceedings and book volumes.

**Prof. Kwang-Ho Choo** received his Ph.D. degree from Seoul National University, Korea, in 1996 and since then has been working on membrane science and technology for water and wastewater, pursuing innovative solutions for sustainable water production and reuse. His recent research interests include membrane electro-oxidizers and quorum quenching membrane bioreactors. He is currently keen to find synergistic options for Water-Energy Nexus issues, using membranes in conjunction with physicochemical/biological strategies, such as iron oxide adsorption, photocatalysis, electrocatalysis and microbial quorum quenching. He has been actively involved in academic societies, such as International Water Association, Korean Society of Environmental Engineers, Membrane Society of Korea and Korean Institute of Chemical Engineers, as Active Board/Editorial Member.

**Prof. Mohamed Ksibi** completed his Ph.D. in 1993 in Applied Chemistry at the University of Poitiers, France. He also gained the Habilitation (HDR) in Chemistry from the University of Sfax, Tunisia, in 2003. He was appointed as Full Professor of Chemistry in 2009 at the Higher Institute of Biotechnology of Sfax (ISBS). His areas of research interest include removal and toxicology assessment of persistent organic pollutants in the environment (water and sediment/soil). He has supervised ten theses to completion and examined a further five Ph.D.s. He has also supervised 15 M.Sc. theses. He has co-published about 55 papers, 8 chapters and co-edited a book (2 volumes): Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions. He is Co-editor-in-Chief of the *Euro-Mediterranean Journal of Environmental Integration* (h-index 24). He had been Institute's Deputy Director of the ISBS from August 2011 until December 2017, and he served as Director of the Department of Biotechnology and Health at ISBS from May 2008 until May 2011. He has also been Chairman for the 1st in 2017 and the 2nd in 2019 of the Euro-Mediterranean Conference for Environmental Integration (https://www.emcei.net).

# Nexus Framework and Governance: Economic Evaluations for Investment Projects in the Water and Energy Sectors

# Investments in the Water and Energy Sectors. Cost–Benefit Analysis and Multi-criteria Assessments to Support the Decision-Making Processes

Antonio Nesticò

**Abstract**

Any investment in the water and energy sectors has to deal not only with technological issues but also with financial aspects—related to the ability of the project to generate adequate profitability in the relevant market—and to forecast the environmental, social, and cultural effects. In this perspective, the literature provides methodological approaches and evaluation tools. The main references are the cost–benefit analysis (CBA) and multi-criteria techniques. The CBA makes it possible to make judgments about the cost effectiveness of the interventions. The results are expressed in quantitative terms, using the well-known indicators net present value, internal rate of return, benefit–cost ratio, and payback period. Studies allow translating a series of extra-financial effects of investment into monetary terms and considering its risk components and to implement sophisticated models to discount the corresponding cash flows. Instead, the multi-criteria techniques evaluate the multiple effects of an intervention through different value scales, both quantitative and qualitative. Thus, it is possible to obtain a 'profile' of the project effects, looking at its ability in increasing the community well-being. The paper is intended to provide an overview of decision support models. It also aimed to compare the different approaches, propose new evaluation schemes according to the specificities of the water and energy sectors, and represent research perspectives. This was achieved taking into account the essential community and international guidelines on the water resources and energy transition management.

**Keywords**

Water and energy sectors • Economic evaluation • Cost–benefit analysis • Multi-criteria techniques

## 1 Introduction

Water scarcity and energy security are well-recognized worldwide challenges and considered as key components in the United Nations Sustainable Development Goals (Lee et al. 2018). If water plays a key role in energy supply, primarily for thermal power plant cooling and hydropower generation, a significant amount of energy is at the same time required to extract, treat, and distribute freshwater resources (Lee et al. 2017). Therefore, knowing the water–energy interdependencies is fundamental to be able to promote the sustainable and integrated planning of water and energy infrastructure systems.

On the other hand, the design of water and energy infrastructure requires addressing not only technological issues but also a wide variety of economic, social, and environmental conditions. This makes it difficult to decide which technologies to invest in and in what priority order to rank them. The optimal combination of technologies and level of investments is difficult to determine without appropriate analysis methods and tools (Parkinson et al. 2018). In this perspective, study models and algorithms that balance multiple issues—financial and non-financial—can be an essential support to decision-making, allowing planners to move toward more sustainable design solutions. The cost–benefit analysis (CBA) and multi-criteria decision-making (MCDM) methods are essential references. These techniques allow researchers to, respectively, express a quantitative judgment on the economic performance of an investment and evaluate the multiple effects of an intervention based on a set of criteria.

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This paper aimed to compare different methods of decision support in order to propose new evaluation schemes according to the specificities of water and energy infrastructure systems.

The remainder of this work is structured as follows. Section 2 focused on decision support methods, such as CBA and MCDM approaches. In Sect. 3, a critical examination of different approaches useful to solve decisional problems in the energy and water sectors was developed. The last section reported on the conclusions and research perspectives.

## 2 Cost–Benefit Analysis and Multi-criteria Decision-Making

Nowadays, the economic evaluation tools have given answers to new questions, certainly strategic in relation to the achievement of both of the objectives of an economic policy and those of sustainable development of a country. The reference is to CBA and MCDM approaches. These are essential techniques in the resource allocation processes, also in relation to recent national and EU regulations.

The CBA results in the optimization of a single evaluation criterion. The MCDM, however, evaluates the multiple effects of a project, recognizing its multidimensionality. More specifically, the CBA is traditionally used to express an opinion on the economic performance of an investment and to choose from among alternative projects. In summary, the CBA consists of forecasting the costs and benefits that the project generates during the analysis period and the subsequent discounting of cash flows (CFs) and then estimating performance indicators, net present value (NPV), internal rate of return (IRR), benefit–cost ratio, and payback period.

The MCDM techniques allow for comparisons of different design solutions based on multiple criteria (financial, social, cultural, and environmental), which can be expressed through quantitative or qualitative indicators. In other words, the MCDM rationalizes the selection process optimizing a multi-criteria vector, weighted according to the priorities of the decision-maker. By implementing mathematical algorithms structured on specific parameters, the MCDM enables to order the problem solutions, even in the case when no alternative is able to simultaneously maximize all the evaluation criteria. The final combination of alternatives and criteria defines an evaluation matrix—also called impact matrix—in which each row represents the profile of a project, while each column expresses the different projects abilities to achieve the same goal.

## 3 The Economic Analysis of Projects in the Water and Energy Sectors: Critical Issues

Critical issues of the CBA of projects in the water and energy sectors deal with:

1. The estimation of environmental externalities. These externalities often constitute considerable contributions, but they are not always expressed in monetary terms (Dolores et al. 2020);
2. The assessment of investment risk, with particular reference to key variables of the project such as, the greater availability of drinking water provided, the superior reliability of water supply services, the better quality of surface water bodies, the likelihood of flooding, etc. In such circumstances, the difficulty of deterministically expressing CFs leads the analyst to evaluate economic performance indicators in probabilistic terms;
3. The estimate of the discount rate to be used in the analysis, also in function of the extension of the analysis period. In fact, the interventions in question are often characterized by very high initial costs, while the benefits are expressed for decades. Therefore, conventional discounting, based on the use of constant discount rates, causes a marked and sometimes unacceptable reduction in the current cash flow values for future generations, thus underestimating the environmental and social effects of the investment (Macchiaroli et al. 2019; Nesticò and Maselli 2020, 2018). To overcome this problem, one possibility is to use a dual discount rate with a structure that declines over time: a first rate for the discounting of strictly financial cash flows; a second rate, with a lower value, for the evaluation of environmental externalities. It follows that the net present value can be estimated according to (1).

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{F_t}{(1+r_c)^t} + \sum_{t=0}^{n} \frac{E_t}{(1+r_q)^t} \quad (1)$$

where $F_t$ indicates the annual economic cash flows; $E_t$ expresses the annual environmental benefits net of costs; $r_c$ is the economic SDR; $r_q$ is the environmental discount rate, lower than $r_c$.

The evaluation of the investment project in the water and energy sectors can be solved through the different approach of multi-criteria techniques. Here, several often-controversial aspects need to be faced such as

a. The identification of the objectives to be achieved, from which the characterization of the logical scheme of evaluation follows;
b. The definition of criteria, sub-criteria, and related indicators, based on the specific objectives of the study, for instance, for interventions relating to water resource management. Lee et al. identify four quantifiable performance criteria to measure attainment of these practices, including technical, economic, and environmental criteria (Lee et al. 2018). The selected attributes were water supply potential, energy efficiency, economic feasibility, and climate stability. Siksnelyte-Butkiene et al. identify 17 economic, 13 social, nine technological, and seven environmental criteria to evaluate three categories of energy systems (Siksnelyte-Butkiene et al. 2020);
c. The choice of the most appropriate multi-criteria technique to solve the specific decision-making problem. This choice depends on the characteristics of the case study, in terms of the analysis objectives, reference territory, intervention specificity, and available information quality to the analyst. In this regard, Ren et al. used linear programming, as well as analytical hierarchy process (AHP) and preference ranking organization method for enriching evaluation (PROMETHEE) multi-criteria methods to evaluate which energy production technology is the most optimal for a household (Ren et al. 2009). Chung and Lee use AHP for the prioritization of water management interventions (Chung and Lee 2009). Kim et al. resort to the fuzzy TOPSIS method for wastewater projects (Kim et al. 2013). Fontana and Morais implement the PROMETHEE method for segmentation network projects in the water sector (Fontana and Morais 2017).

Figure 1 summarizes the main critical points of the economic analysis applied to investment projects in the energy and water sectors.

## 4 Conclusion

Recent political concerns about environmental sustainability led to encourage investments aimed at reducing the consumption of primary resources, including integrated planning of water and energy infrastructure systems. In this regard, the European Union has ambitious decarbonization and energy transition goals, which could be very difficult to achieve if the European water system becomes too stressed, since decarbonization relies on water-demanding energy technologies such as biofuels, carbon capture, or nuclear power. The issues related to water and energy infrastructure systems not only have to involve different actors from all levels of government and civil society organizations, but they also need to ensure technological standards, financial feasibility, and social and environmental sustainability. Therefore, specific methodological approaches and evaluation tools must be defined to support decision-making.

An overview of the main evaluation approaches, synthetically referable to the cost–benefit analysis and multi-criteria decision-making, allows highlighting peculiarities and limitations with specific reference to the water and energy sectors. For the CBA, this study highlighted the criticality in the monetary estimation of environmental externalities, as well as in the investment risk analysis and in the estimation of the discount rate. With reference to MCDM methods, open questions are still related to: the definition of the panel of assessment indicators; the attribution of the relative weights; the choice of the most appropriate technique to solve the specific decision-making problem.

Thus, the outlined framework was intended to represent some research perspectives, with the aim of making the allocation processes of both public and private resources more effective.

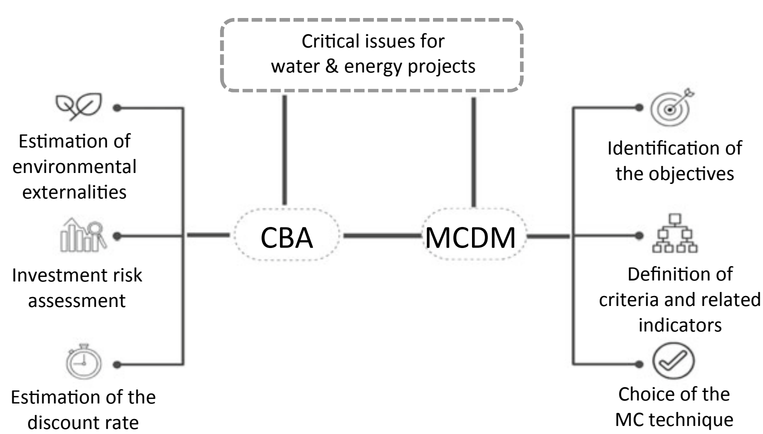


**Fig. 1** Critical issues of the economic analysis for energy and water projects

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# Sustainability and Energy Efficiency in Twentieth-Century Italian Built Heritage

Laura Gabrielli and Aurora Greta Ruggeri

**Abstract**

This research dealt with the urban underutilization of a specific part of the twentieth-century architectural heritage in Italy, i.e., the War Wounded Houses. These buildings, widespread throughout the nation, are mostly abandoned or in a state of neglect. They are also technologically obsolete, and their energy refurbishment seems to be highly unavoidable to promote a new use for these premises. This paper analyzed and suggested a strategic approach to increase sustainability in the building sector in terms of landscape (re-)use and energy efficiency interventions. Acting on the twentieth-century Italian cultural heritage is an opportunity to revitalize urban settings through the cooperation between the theories of architectural conservation, energy retrofit procedures, and financial analyses. The proposed approach, applied to one pilot case study, involves a life cycle costing and a cost-optimal method, used to evaluate and compare different possible energy retrofit scenarios, balancing initial and running costs until the optimal level of intervention is identified. The procedure allows finding the design solution that combines their best energy efficiency targets with costs reduction goals over an extended analysis period. The model also aims at being a repeatable approach for similar cases, where buildings, not appropriately used in their urban context, can be a strategic element in renewal and sustainability processes.

**Keywords**

Life cycle costing • Cost-optimal approach • Energy efficiency • Restoration of urban built heritage • Landscape reuse

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## 1 Introduction

The purpose of this paper was to provide a strategy with a multidisciplinary approach applied to the restoration and recovery of a specific part of the twentieth-century built heritage, namely the War Wounded Houses, which are widespread architectures throughout the whole Italian territory. However, they are nowadays facing a critical situation as they are underused or semi-abandoned.

Historically, War Wounded Houses were memorials to celebrate the soldiers and their sacrifice. Besides, they were works of public interest since they were specifically meant to assist war invalids (Fabbri et al. 2018). Today, War Wounded Houses no longer serve their original purpose of war invalid assistance and remain mainly uninhabited. Their presence throughout Italy raises the pressing and controversial question of their reuse.

## 2 Settings and Approach

This research proposed to analyze a case study to provide a replicable model for the preliminary assessment of the economic feasibility in the restoration process. The Cuneo War Wounded House is taken as an exemplary case study (Ruggeri et al. 2020) (Fig. 1).

The owners of the Cuneo House, i.e., the ANMIG Association (Associazione Nazionale Mutilati e Invalidi di Guerra), are struggling to cover the costs of the building, as it presents extremely high operations and maintenance costs. At the same time, renting a few of its rooms does not guarantee sufficient income.

Therefore, it is necessary to create an economic plan to restore and maintain the building overtime properly. This study aimed to strengthen the required integration between restoration and feasibility analysis in the historical building sector, as it is an urban problem that needs to be undertaken if self-sustainability can be guaranteed.



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**Fig. 1** Cuneo War Wounded House

## 3 Method and Results

The case study considered here proposes to convert the Cuneo War Wounded House into a new venue for a music school affiliated with the Conservatory of Cuneo. The ANMIG Association, according to the proposed project, would still retain the ownership and the right of use of the property. However, it would, at the same time, rent part of the building to the Conservatory for its music school. The new function was chosen following a detailed analysis of the supply and demand of the Real Estate market in Cuneo. The purpose of the research was to identify the most appropriate and respectful use for the historical building that would also guarantee a continuative income. In addition, this procedure aimed at providing the ANMIG Association with revenues from rental.

To ensure the economic feasibility for the whole renovation process and the revenues, it is fundamental to act upon reducing the operating costs, renovating the building energy efficiency. Specifically, the aim was to reduce winter heating costs, as they have been identified as the highest running cost. For this reason, some energy improvement options have been suggested. They are compatible with the principles of restoration and aim to maximize the thermal performance of the casing, minimizing heat dispersion. This study offers an alternative scenario analysis with growing performance. Five different actions were introduced: (1) window efficiency improvement; (2) insulation of internal slabs; (3) application of thermal plaster on external walls; (4) insulation of external slabs; and (5) concert hall false ceiling. Five alternative scenarios were proposed: As the energy performance grows, so does the intervention cost. Scenario 1 consists of the application of action 1 alone. Scenario 2 is the sum of actions 1 and 2, while scenario 3 is the sum of actions 1, 2, and 3. Scenario 4 is the sum of actions from 1 to 4, and finally, scenario 5 is the sum of all the proposed actions. The aim was to identify the retrofit scenario that is the most advantageous, applying both the life cycle cost (LCC), calculated as the sum of initial costs (or intervention costs) plus operation and maintenance costs, and the analysis of three economic indicators: discounted payback period (DPB), break-even point (BEP), and net savings (NS) (Remer and Nieto 1995). The LCC analysis allows identifying the scenario that presents the optimum balance between initial costs and running costs, also taking into account the achieved energy performance (Fig. 2).

The considered economic indicators were used as a support in the decision-making process of the investors/developers, who assess the operation according to their preference (Table 1). The case study was also examined through the cost-optimal approach (Wang et al. 2014), combining the economic aspect with the achieved energy performance level.

**Fig. 2** Cost-optimal analysis on five energy retrofit scenarios

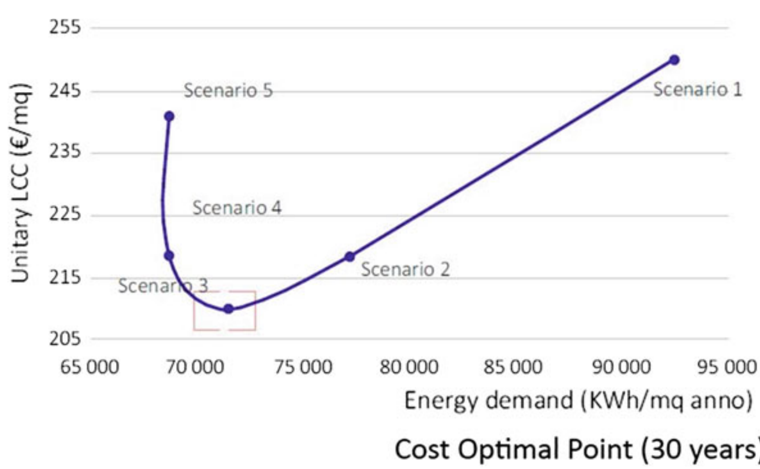

**Table 1** Model parameters and results

| | Energy demand (kWh/sqm/year) | Energy consumption (€/year) | Annual savings (€/year) | Initial costs (€) | Net savings (€) 30 years | LCC (€/sqm) |
|---|---|---|---|---|---|---|
| Scenario As is | 172.625 | 10.303 | 0 | 0 | 0 | 0 |
| Scenario 1 | 92.605 | 5.837 | 4.466 | 19.121 | 95.603 | 250 |
| Scenario 2 | 77.246 | 4.501 | 5.802 | 35.419 | 110.549 | 218 |
| Scenario 3 | 71.543 | 3.798 | 6.505 | 50.597 | 111.815 | 210 |
| Scenario 4 | 68.731 | 3.727 | 6.575 | 59.788 | 104.269 | 219 |
| Scenario 5 | 68.725 | 3.713 | 6.589 | 78.264 | 86.121 | 241 |

## 4 Conclusion

The objective of this paper was the joint analysis of a restoration and energy efficiency improvement process and the economic feasibility assessment of the suggested interventions. The energy measures studied according to several scenarios were analyzed following a general approach in the energy sector, namely the life cycle cost (LCC) approach. The LCC can be used with other economic indicators, such as the DPB, the NS, and the BEP. Along with these indicators, and according to the European Directives, using the five different scenarios made it possible to analyze alternative solutions and give new life to the building, from both an energy and economic point of view.

The chosen approach has led to identifying the best energy efficiency improvement scenario to renovate the building and reduce its running costs. This action turns the use of the building into a profitable project, suitable to host a new function. It is a new stimulation for its urban setting that could trigger a virtuous cycle of regeneration. This study proves that the interaction between restoration, urban stimulation, and economic analysis is essential. It offers a way to allow stakeholders to manage and preserve the existing urban heritage. A model for planned conservation was suggested, using the LCC approach. This model is replicable on other similar architectures and could be a support for the decision-making process. The used method allows controlling costs over the whole useful life of the property and the distribution over time of the involved monetary amounts. In this study, it was possible to combine restoration and energy efficiency improvements, linking conservation to the need of obtaining proper incomes from the use of the building.

Future research developments could introduce a sensitivity analysis in the model to test if changing the initial input data (time–cost of money, energy price, consumption parameters) would also change the final result and compromise the assessment of the restoration project.

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# Long-Term Effects Evaluation for Investments in the Energy and Water Sectors

Gabriella Maselli and Antonio Nesticò

**Abstract**

The rapid economic and demographic growth of recent decades, together with the rising living standards and the unplanned urbanization process, have caused a disproportionate use of water and energy resources. This requires methodologies to support the decision-making processes capable of establishing sustainable actions and strategies. Therefore, in the Cost–Benefit Analysis (CBA) of investment projects, it is of increasing interest to also consider the extra-financial effects that are generated. For such effects, conventional discount procedures are often inadequate, especially when intergenerational environmental effects need to be assessed. This paper proposed a model that differently discounts the economic effects and environmental impacts that projects in the water and energy sectors determine. The model outlines a declining structure for both of the economic discount rate and the environmental discount rate. The main novelty of the model lies in the introduction of environmental quality into the logical-mathematical estimation scheme. Environmental quality is expressed according to the indicators that contribute to the Environmental Performance Index (EPI). The use of dual and declining discounting procedures makes it possible to give greater weight to environmental externalities, orienting guiding the decision-maker towards more sustainable investment choices.

**Keywords**

Energy and water investments • Economic evaluation of projects • Social discounting • Environmental indicators

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## 1 Introduction

The disproportionate use of water and energy resources in recent decades has led to considering the water and energy sectors as a single system of scarce resources. It follows that any intervention related to one of the two sectors inevitably affects the other (Chang et al. 2016; Macchiaroli et al. 2019).

For these projects, the benefits last for many decades, while the mitigation costs are essentially concentrated in the first years of the works' life. Therefore, in the *ex-ante* economic evaluations of investments in the water and energy sectors, it is of crucial importance to correctly evaluate the extra-financial impacts that the project generates in the long term (Maselli and Nesticò 2021; Dolores et al. 2020). However, conventional discounting, which uses constant social discount rates (SDRs), is increasingly inadequate, as they lead to excessively contracting the current value of intergenerational environmental costs and benefits (Ruhl 2015; Overton et al. 2015). In other terms, the traditional discounting procedures are based on exponential functions of the $e^{-SDR \cdot t}$ type. It is clear that as the time horizon increases, the present value of future cash flows decreases.

Thus, the objective of the paper was to define a model for estimating a dual declining discount rate: (a) an economic discount rate and (b) an environmental discount rate. The main novelty of the model lies the introduction of environmental quality in the logical-mathematical estimate scheme. Environmental quality is expressed as a function of the "Water Resources" and "Climate & Energy" environmental indices, which combine—together with other indicators—to form the Environmental Performance Index (EPI). This index is defined and estimated by the Center for International Earth Science Information Network (Columbia University) and the Center for Environmental Law and Policy (Yale University), and it ranks 180 countries on the basis of 24 key performance indicators and allows this to measure the progress of countries towards achieving the 2015 United Nations Sustainable Development Goals.



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Finally, on the basis of the proposed methodology, an empirical estimate of the declining discount rates (environmental and economic) to be used in the Cost–Benefit Analysis of projects in the water-energy sector for Italy was carried out.

## 2 Materials and Methods

According to some scholars, one possibility to give greater weight to cash flows over time is to resort to declining discount rates (DDRs), instead of constant discount rates (Cropper et al. 2014; Freeman et al. 2015). According to other authors, however, environmental effects should be discounted differently and separately from economic impacts (Viscusi et al. 2008; Nesticò and Maselli 2021, 2020). This means that a discount rate $r_c$ should be adopted for the discounting of strictly financial cash flows that is different and higher than the discount rate $r_q$ for the evaluation of environmental externalities. Gollier hypothesizes that the inter-temporal social welfare function is the sum of the utilities $U$ deriving from both consumption $c_t$ and environmental quality $q_t$ (Gollier 2010). By deriving $U(c_t, q_t)$ with respect to consumption $c_t$ and with respect to environmental quality $q_t$, we obtain the equations that describes the discount rate $r_c$ and the discount rate $r_q$:

$$r_c = \rho + [\eta_1 + \delta \cdot (\eta_2 - 1)] \cdot [g_1 - 0.5 \cdot (1 + \eta_1 + \delta \cdot (\eta_2 - 1)] \cdot \sigma_{11} \quad (1)$$

$$r_q = \rho + [(\delta \cdot \eta_2 + \eta_1 - 1] \cdot [g_1 - 0.5 \cdot (\delta \cdot \eta_2 + \eta_1)] \cdot \sigma_{11} \quad (2)$$

With reference to (1) and (2): $\rho$ is the time preference rate; $\eta_1$ the parameter of aversion to the risk of income inequality; $\eta_2$ the degree of aversion to environmental risk; $g_1$ the consumption growth rate; $\sigma_{11}$ the consumption growth rate uncertainty in terms of mean square deviation of the variable; $\delta$ is the environmental quality elasticity to changes in the consumption growth rate $g_1$. Gollier explains the hypotheses underlying formulas (1) and (2) and the estimation of the terms necessary to estimate $r_c$ and $r_q$ (Gollier 2010, 2012).

In the outlined framework, we intend to define a model for estimating the economic and ecological discount rate to be used in evaluating those investments that use energy and water resources according to an integrated approach. Since, such projects often unfold their long-term effects, it is believed that the joint use of declining discounting and dual discounting can guide the analyst towards the selection of more sustainable investment alternatives. Therefore, the proposed model intends to estimate the $r_c$ and $r_q$ rates of formulas (1) and (2), defining a structure declining in time for both.

There are two main novelties of the model. The first is related to the environmental quality expressed as a function of the "Water Resources" and "Climate & Energy" indices. These two environmental indices combine to form the Environmental Performance Index (EPI) (Wendling et al. 2018).

The value of $\delta$ depends on the environmental quality, i.e. the elasticity of environmental quality to changes in the growth rate of consumption $g_1$. Consider c equal to the per capita GDP of a country and $q_1$ the relative Water Resources index. The value $\delta_1$ is derived from the correlation between the two parameters, which represents the inclination of the line:

$$c_1 = x_1 + \delta_1 \cdot q_1 + \varepsilon_1 \quad (3)$$

where $x_1$ is the intercept of the line on the $y$ axis and $\varepsilon_1$ is the statistical error of the regression.

Repeating the same procedure for $q_2$, which represents the Climate and Energy index, the elasticity $\delta_2$ is obtained.

Finally, the value of $\delta$ is derived from the average of the values $\delta_1$ and $\delta_2$.

The second novelty refers to the modelling of the consumption growth rate $g_1$ which appears in formulas (1) and (2). The consumption growth rate is an uncertain variable, that is to say, it is modelled as a stochastic variable. This means that from the analysis of the historical trend of $g_1$, a probability function is first estimated to be associated with the parameter itself. Then, by implementing the Monte Carlo analysis, we obtain a series of probable values to be associated with the rate $g_1$ and, consequently, with the unknowns $r_c$ and $r_q$. Finally, the passage from the uncertain and constant discount rate to the certain but decreasing rate with a "certainty-equivalent" requires an estimate first of the certain equivalent economic $E_c(P_t)$ and environmental $E_q(P_t)$ discount factors for each future instant $t$, hence the "certainty-equivalent" economic $r_{ct}$ and environmental $r_{qt}$ discount rates.

Figure 1 illustrates the sequence of operational steps underlying the model.

## 3 Results and Discussion

The proposed model is implemented to estimate the economic DDR and the ecological DDR for Italy, with the aim of discounting financial cash flows and net environmental benefits generated by intergenerational investment projects that jointly use water and energy.

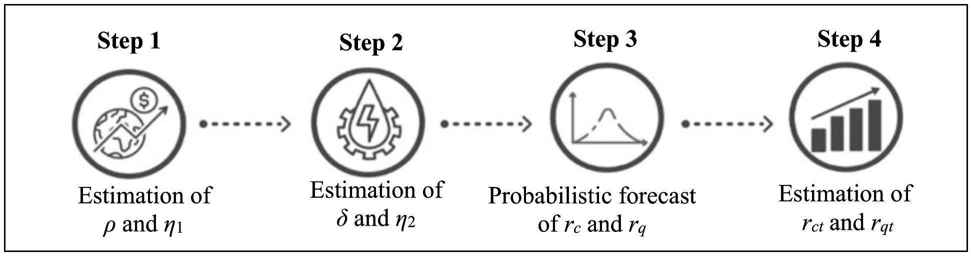


**Fig. 1** Model phases

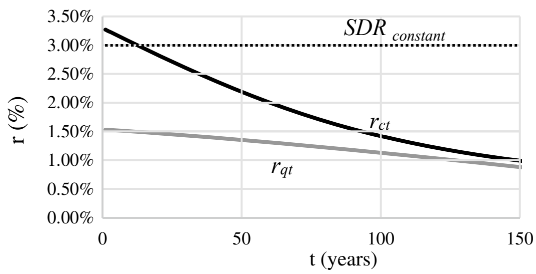


**Fig. 2** Term structure of $r_{ct}$ and $r_{qt}$ for Italy

The following results were revealed from the achieved elaborations:

- the $r_{ct}$ economic discount rate function starts from an initial value of 3.27% to reach the value of 0.99% after 150 years;
- the environmental discount rate $r_{qt}$, on the other hand, assumes markedly lower values than $r_{ct}$, starting from a value of 1.53% to reach 0.88% after 150 years.

It is interesting to note that using the constant discount rate of 3.0% suggested by the European Commission, a Net Present Value (NPV) was estimated to be approximately four times lower than if the estimated economic and environmental discount rates were used. The effect is to progressively underestimate the more distant over time Cash Flows, and to consider strictly financial terms in the same way as the environmental effects.

Figure 2 reports the functions of the economic declining rate and the ecological declining rate as well as the conventional function of the discount rate, which is constant over time.

## 4 Conclusion

The aim of the paper was to characterize a model for estimating the economic DDR and the ecological DDR useful for discounting the financial and extra-financial effects generated by investment projects that jointly use water and energy resources. This can be done by expressing the environmental quality that governs the estimate of the social rate of time preference as a function of the "Water Resources" and "Climate & Energy" environmental indices. A limitation related to the use of these indices is the absence of time series; therefore, the study was conducted only with reference to 2020 data. The implementation of the model in the case of the Italian economy shows how the use of dual and declining discounting makes it possible to attribute greater weight to the environmental effects that are progressively more distant over time than the use of constant discounting. It was said that the higher the discount rate, the lower the present value of the Cash Flows (CFs) over time, as these are discounted with such a function as: $e^{-SDR \cdot t}$. In other words, using constant discount rates over time, CFs are very distant CFs would be underestimated in CBAs, i.e. the analyst would focus on investments with high initial returns, but with greater long-term environmental repercussions. Therefore, the political implications that the implementation of the proposed model can determine on the entire environmental decision-making are relevant.

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