Discounting for Economic Analysis of Long-Lived and Short-Lived Water Resource Investments

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Abstract. With reference to the Cost-Benefit Analysis (CBA) of water resource projects, this paper intends to show the effects of discounting cash flows on the evaluation results. These are projects that commonly involve the use of unique and irreplaceable natural sites, often with potentially irreversible consequences and considerable effects on the community. Therefore, in the analyses it is of absolute importance to give the right "weight" to costs and benefits progressively more distant in time. In other words, the Social Discount Rate (SDR) must be chosen correctly. In this way, decision-makers can orientate themselves towards investment choices aimed at safeguarding the proper management of water resources.

This research proposes a discounting approach that distinguishes between long-lived and short-lived water projects. Specifically: (i) a constant and dual discounting approach for interventions with a useful life of 30 years or more; (ii) a declining dual discounting approach for investment decisions with very long lifespan. The main novelty is the introduction in the logical-mathematical structure of the SDR of the environmental quality, expressed as a function of the Water Resource Index.

An application compares the CBA results obtained both using the discount rates proposed here and the constant discount rates suggested by the European Commission. The substantial differences obtained show the importance of the defined model on the whole process of allocation of resources to water projects.

Keywords: Cost-benefit analysis · Dual discounting · Economic evaluation · Water projects

1 Introduction

Balancing consumption with supply is a key challenge for effective water management worldwide. The rapid population growth of recent decades will result in a 40% shortfall between projected demand and available water supply by 2030. In addition, feeding 9 billion people by 2050 will require a 60% increase in agricultural production – which today consumes 70% of resources – and a 15% increase in water withdrawals. In addition, estimates indicate that 40% of the world's population lives in water-scarce areas and

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about ¼ of the world's GDP is exposed to this challenge [1]. The Global Risk Perception Survey, conducted among 900 experts recognised by the World Economic Forum, found that water crises will generate the largest level of social impact over the next 10 years [2]. In other words, water scarcity, hydrological uncertainty and extreme weather events are seen as threats to wealth and global stability.

Water management issues are increasingly becoming a priority political issue at international level. The United Nations recognises water management as the core of sustainable development. In fact, the United Nations Sustainable Development Goal (SDG) 6 on water and sanitation - adopted as part of the 2030 Agenda - provides the blueprint for ensuring availability and sustainable management of water and sanitation for all. According to the third United Nations World Water Development Report (UN WWAP, 2009), both economic development and security are put at risk by poor water management [3]. The UN WWAP (2014) also pointed out that the water-energy nexus is playing an increasingly crucial role. So, concern about a global energy crisis is now matched by worry about a looming global water crisis [4].

Promoting water security in a scenario of increasing water demand but decreasing water supply requires investment in the development and careful management of natural and man-made infrastructure. Governmental instruments such as legal and regulatory frameworks, water pricing and incentives are required to better allocate, manage and conserve water resources [5–7].

Therefore, there is a clear need to characterise new methodologies able to guide the policymakers towards more sustainable investment choices in the water sector. In this respect, environmental discounting is a potentially relevant research area for water resources management. While the importance of the Social Discount Rate (SDR) for the assessment of problems with environmental effects has been widely acknowledged, the choice of SDR is rarely discussed when policy objectives must be translated into actions and intervention strategies [8–10]. In other words, it is underestimated that the outcome of a Cost-Benefit Analysis (CBA) is markedly influenced by the value of the discount rate used in the assessment.

The aim of the paper is to suggest the Social Discount Rate (SDR) to be used in the water resource investment analyses, distinguishing between long-lived and short-lived water projects. This can be done by first analysing the emerging discounting approaches (Sect. 2). Then, by defining an innovative model for estimating discount rates for water investments (Sect. 3). Finally, showing how discount rates estimated with the proposed model can guide decision-making towards investment choices aimed at preserving the sustainable water management of water resources.

2 Literature Review

Discounting is a mathematical procedure used to make costs and benefits that occur at different instants in time economically comparable. Dasgupta points out that there are many reasons for discounting [11]. The first is that individuals expect their level of consumption to increase over time and that, consequently, the marginal utility of consumption tends to decrease. Because of this expectation, individuals are willing to give up a unit of consumption today only if they can get a higher reward in the future. The second explanation is that individuals are generally "impatient" or "myopic" because of the risk of not being alive in the future and, for this reason, always tend to attach greater weight to current consumption.

It follows that, to choose between alternative projects, it is necessary to estimate the current value of the future flow of net benefits that the different investment alternative generates [12–14]. Discounting is therefore a mathematically step of the Cost-Benefit Analysis (CBA) needed to compare the Cash-Flows of a proposed investment project [15–17].

The choice of the Social Discount Rate is a crucial step in CBA, as small variations in it significantly influence the outcome of the evaluation. This is particularly true for projects with environmental impacts, which tend to occur over long-time intervals [18]. Like forestry, fisheries and climate change applications, water resource investments represent decisions that generate intergenerational effects. In addition, water resource investments commonly involve the use of irreplaceable natural sites, often with potentially irreversible consequences [19]. Choosing the right discount rate can lead to more sustainable project choices. In this regard, the literature is almost unanimous in excluding the use of exponential discount procedures. In fact, the use of constant discount rates underestimates the environmental effects that occur in a period distant from that of the evaluation.

According to Emmerling *et al.* [8], the climate targets of the Paris Agreement (2015) can only be achieved by using lower discount rates than those suggested by governments, such as the one proposed by Stern [20]. van den Bijgaart *et al.* [21] and van der Ploeg and Rezai [22] show that the discount rate is a crucial determinant of the Social Cost of Carbon.

In the case of projects with long-term effects, other scholars believe that time-declining rates should be used to give greater weight to events that are progressively more distant in time [23, 24].

According to a recent branch of the literature, the discounting of environmental components should instead take place at a different and lower "environmental" rate than the "economic" one, the latter being useful to evaluate strictly financial cash flows [25, 26].

Finally, other scholars estimate specific rates for environmental categories and services. Just to mention a few, Vazquez-Lavín *et al.* [27] propose a declining discount rate for eco-system services, with particular attention to projects aimed at preserving biodiversity in marine protected areas in Chile. Muñoz-Torrecillas *et al.* [28] evaluate a SDR to be applied in US afforestation project appraisal.

In practice, while the European Commission recommends the use of exponential discounting also for long-term valuations [29], France and the UK have decided to use time-declining discount rates. The UK Green Book proposes a decreasing sequence of rates for projects with impacts over more than 30 years [30]. In France, the discount rate has been increased from 8% to 4%, suggesting a decreasing discount rate down to 2% for very long-term assessments [31].

The aim of this research is to define a new approach for the estimation of SDR to be used in the analysis of water resource investments, distinguishing between long-lived and short-lived projects. To give the right weight to the environmental effects, a dual discounting model is proposed, which allows to evaluate a different economic discount rate than the one useful for the environmental components.

3 The Social Discount Rate for Water Resource Investments

Water is fast becoming a scarce resource in almost every country in the world. This scarcity makes water both a social and an economic good used for multiple purposes.

Therefore, it is essential to assess the sustainability of Water Supply Projects (WPs) so that planners, policy makers, water companies and consumers are aware of the true economic cost of scarce water resources and the appropriate levels of tariff needed to financially sustain it [32].

In this perspective, the choice of the Social Discount Rate becomes essential to correctly assess the economic performance of water projects. Thus, we define: (i) a constant dual discounting approach for water projects, whose useful life is at most 30 years (Sect. 3.1); (ii) a declining dual discounting approach for investment decisions with very long lifespan (Sect. 3.2).

3.1 A Discounting Approach for Short-Lived Water Projects

In the case of water projects with a useful life of thirty years or more, it is considered coherent to give the right weight to the financial and extra-financial effects of the investment using a constant and dual discounting approach. In fact, for short-lived water projects, the contraction of the present value of cash flows over time can be considered acceptable. However, as the environmental effects are not negligible, it is necessary to discount them at a lower rate than the economic rate.

In order to estimate a double discount rate, i.e. an economic one for the strictly financial terms, and an environmental one for the extra-financial effects, the environmental quality is introduced in the logical-mathematical structure of the Social Discount Rate. This can be done by assuming that: (i) any improvement in environmental quality will matter more to future generations than to current ones, as the environment tends to deteriorate over time; (ii) the utility of society $U(c_{1t}, c_{2t})$ is a function of both consumption c_{1t} and environmental quality c_{2t}, where the availability of the two goods varies over time; (iii) the utility or “happiness” function $U(c_{1t}, c_{2t})$ is of the Cobb-Douglas type, increasing and concave; (iv) environmental quality and consumption are two mutually substitutable goods; (v) environmental quality increases less quickly than consumption [24].

If we assume that consumption and environmental quality are correlated according to a deterministic function such as $c_{2t} = f\ (c_{1t})$, then two discount rate functions are obtained:

i. deriving $U(c_{1t}, c_{2t})$ compared to consumption c_{1t}, we obtain the equation describing the “economic” discount rate r_{ECt}:

$$r_{ECt} = \delta + \left[\gamma_1 + \rho(\gamma_2 - 1)\right] \cdot \left[g_1 - 0.5(1 + \gamma_1 \rho(\gamma_2 - 1)\right] \cdot \sigma_{11} \tag{1}$$

ii. deriving instead $U(c_{1t}, c_{2t})$ with respect to environmental quality c_{2t} we obtain the equation describing the “ecologic” discount rate r_{ENt}:

$$r_{ENt} = \delta + \left[(\rho \cdot (\gamma_2 + \gamma_1 - 1)\right] \cdot \left[g_1 - 0.5(\rho\gamma_2 + \gamma_1)\right] \cdot \sigma_{11} \tag{2}$$

Where:

- δ is the rate of time preference;
- γ_1 the risk aversion parameter of income inequality;
- γ_2 the degree of environmental risk aversion;
- g_1 the growth rate of consumption;
- ρ the elasticity of environmental quality to changes in the growth rate of consumption g_1;
- σ_{11} the uncertainty of the consumption growth rate in terms of the mean square deviation of the variable.

Main novelty of this research concerns the modelling of the ρ parameter, which makes it possible to assess how environmental quality changes as consumption varies. Specifically, environmental quality is expressed as a function of the "Water and Sanitation" index, which makes up the Environmental Performance Index (EPI). This composite index makes it possible to establish how close countries are to achieving the UN's 2015 Sustainable Development Goals [33].

Consider c_1 equal to a country's GDP per capita and c_2 its environmental index. The correlation between the two parameters gives the value ρ:

$$c_1 = x + \rho \cdot c_2 + \varepsilon \tag{3}$$

In (3) x is the intercept of the line on the axis y, ρ is the inclination of the line and ε the statistical error of the regression.

Table 1 summarises the formulas for estimating the economic, social, and environmental parameters of (1) and (2).

3.2 A Discounting Approach for Long-Lived Water Projects

In the case of water projects with intergenerational impacts a dual and declining discounting approach is defined. This means that we estimates two discount rates, economic and environmental, both with a declining structure over time. In this way, greater weight is given to environmental costs and benefits progressively more distant.

The idea is to characterize a stochastic model, in which the growth rate of the consumption g_1 of (1) and (2) is modelled as an uncertain variable. This is a crucial parameter for the evaluation. In fact, since $q_t = f\ (c_t)$, from g_1 depends on both the value of the economic discount rate r_c and the value of the environmental discount rate r_q. The growth rate of consumption g_1 is an uncertain parameter, so it is modelled as a stochastic variable. This means that from the trend analysis of g_1, we first estimate a probability function to be associated with the parameter itself. Then, from the probability function thus obtained, implementing the Monte Carlo simulation, a set of possible values is obtained to associate with the rate g_1 and, consequently, with the unknow value of r_{EC} and r_{EN}.

Table 2 summarises the rationale and practical steps of the model.

Table 1. Methods for estimating the parameters of (1) and (2).

Parameter	Formula
$\delta =$ the rate of time preference	$\delta = l + r$ $l =$ average mortality rate of a country $r =$ pure time preference rate, $0\% < r < 0.5\%$
$\gamma_1 =$ the risk aversion parameter of income inequality	$\gamma_1 = \frac{\log(1-t)}{\log\left(1-\frac{T}{Y}\right)}$ $t =$ marginal tax rate; $T/Y =$ average tax rate
$g_1 =$ the growth rate of consumption	g_1 is approximated to the average growth rate of a country's GDP per capita
$\gamma_2 =$ the degree of environmental risk aversion	$\gamma^* = \frac{\gamma_2 - 1}{\gamma_1 + \gamma_2 - 2}$ $\gamma^* =$ expenditure on environmental quality ($10\% < \gamma^* < 50\%$)
$\sigma_{11} =$ uncertainty of the consumption growth rate	mean square deviation of the variable g_1
$\rho =$ elasticity of environmental quality to changes in the growth rate of consumption g_1	$c_1 = x + \rho \cdot c_2 + \varepsilon$ $x =$ intercept of the line on the axis y; $\rho =$ inclination of the line; ε the statistical error

Table 2. Operational phases of the discounting model for long-lived water projects.

Step 1	Estimation of the constant parameters of (1) and (2)
Step 2	Estimation of the probability distribution of the consumption growth rate g_1 and, consequently, of the "economic" and "environmental" discount rates r_{EC} and r_{EN} implementing Monte Carlo analysis
Step 3	Estimate of "economic" and "environmental" certain-equivalent discount factors $E_{EC}(P_t)$ e $E_{EN}(P_t)$ $E_{EC}(P_t) = E_{EC}[\exp(-\sum_{i=1}^{m} p_{1i} \cdot r_{1i}) \cdot t] \cdot E_{EN}(P_t) = E_{EN}[\exp(-\sum_{i=1}^{m} p_{2i} \cdot r_{2i}) \cdot t]$ $r_{1i} = i$-th economic discount rate (from r_{EC} of step 2) $p_{1i} =$ probability of the i-th value of the economic rate r_1 occurring probability $r_{2i} = i$-th economic discount rate (from r_{EN} of step 2) $p_{1i} =$ probability of the i-th value of the economic rate r_2 occurring probability $t =$ time variable $m =$ number of intervals in which the functions of r_{EC} and r_{EN} are discretized
Step 4	Estimating the declining "economic" discount rate $\tilde{r}_{ECt}$ and the declining "environmental" discount rate $\tilde{r}_{ENt}$ $\frac{E_{EC}(P_t)}{E_{EC}(P_t+1)} - 1 = \tilde{r}_{ECt}$ $\frac{E_{EN}(P_t)}{E_{EN}(P_t+1)} - 1 = \tilde{r}_{ENt}$

4 Estimation of Social Discount Rate for Water Projects in Italy

The approaches defined in Sect. 3 are implemented to estimate:

i. constant economic and environmental discount rates to be used for short-lived water projects in Italy (Sect. 4.1);
ii. declining economic and environmental discount rates for long-lived water projects in Italy (Sect. 4.2).

4.1 Estimation of r_{EC} and r_{EN} for Short-Lived Water Projects

The implementation of the approach described in Sect. 3.1 returns the results summarised in Table 3. The economic, social, and environmental parameters of formulas (1) and (2) were estimated using the methods shown in Table 1.

Figure 1 returns the regression analysis result delivered by (3), in which $\rho = 0.61$.

Table 3. Estimation of the r_{EC} and r_{EN} for short-lived water projects.

Parameter	Value	Source
l = average mortality rate of a country	1.00%	*World Bank*, time frame 1991–2020
r = pure time preference rate	0.30%	Evans and Kula [34]
δ = time preference rate	1.30%	–
γ_1 = risk aversion parameter of income inequality	1.34	Organization for Economic Cooperation and Development Countries (OECD)
g_1 = consumption growth rate	1.22%	World Bank, time frame 1980–2019
γ_2 = degree of environmental risk aversion	1.15	$\gamma^* = 30\%$ [35, 36]
σ_{11} = uncertainty of the consumption growth rate	0.03%	–
ρ = elasticity of environmental quality to changes in the growth rate of consumption	0.61	–
r_{EC}	3.0%	–
r_{EN}	2.4%	–

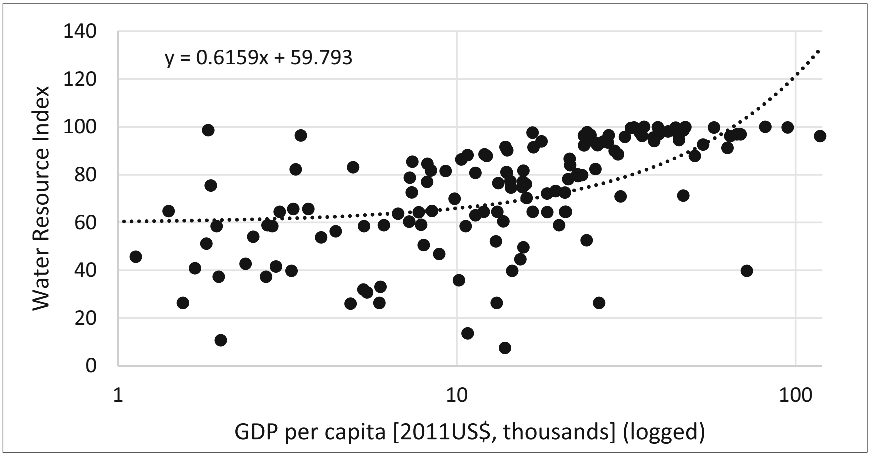

Fig. 1. Relationship between Water Resource Index and GDP per capita.

4.2 Estimation of r_{ECt} and r_{ENt} for Long-Lived Water Projects

To estimate time-declining discount rates r_{ECt} and r_{ENt} for long-lived water projects in Italy, the steps described in Table 2 are followed.

Step 1. For the estimation of the constant parameters, δ, γ_1, γ_2, σ_{11} e ρ, reference is made to the values in Table 3.

Step 2. At this point, it is essential to obtain the probability distribution that best describes the historical series of g_1. From this, by implementing the Monte Carlo technique, it is possible to forecast all the values that the rates r_{EC} and r_{EN} can have.

Figure 2 illustrates the probability distribution of g_1 that best approximates the historical data, i.e. the Weibull distribution. Figures 3 and 4 show the probability distributions of r_{EC} and r_{EN}, of which only positive values are considered, since the discount rate has a logical-mathematical meaning only if it is greater than zero.

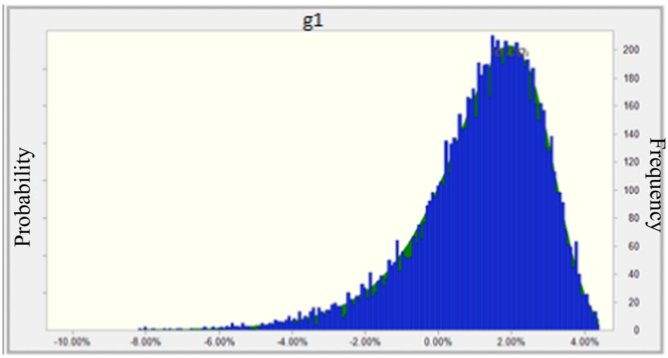

Fig. 2. Probability distribution of g_1.

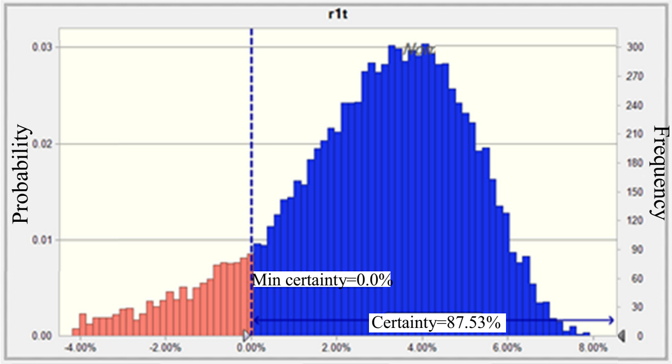

Fig. 3. Probability distribution of r_{EC}.

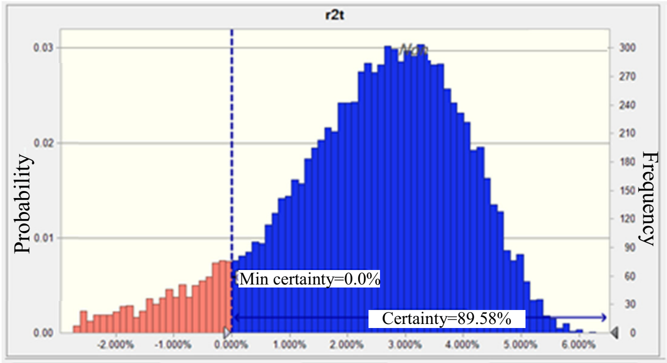

Fig. 4. Probability distribution of r_{EN}.

Step 3. At this stage, using approach of the Expected Net Present Value (ENPV), we move from the uncertain and constant discount rate to the certain but decreasing discount rate with a "certainty equivalent". This requires estimating the economic discount factors $E_{EC}(P_t)$ and ecological $E_{EN}(P_t)$ for each future instant t according to the mathematical formulations shown in Table 2.

Step 4. From the time trend of each of the two discount factors, it is possible to estimate the values of the declining economic discount rate $\tilde{r}_{ECt}$ and the declining environmental discount rate $\tilde{r}_{ENt}$ according to the formulations in Table 2 for step 4.

Figure 5 summarises the results of the elaborations.

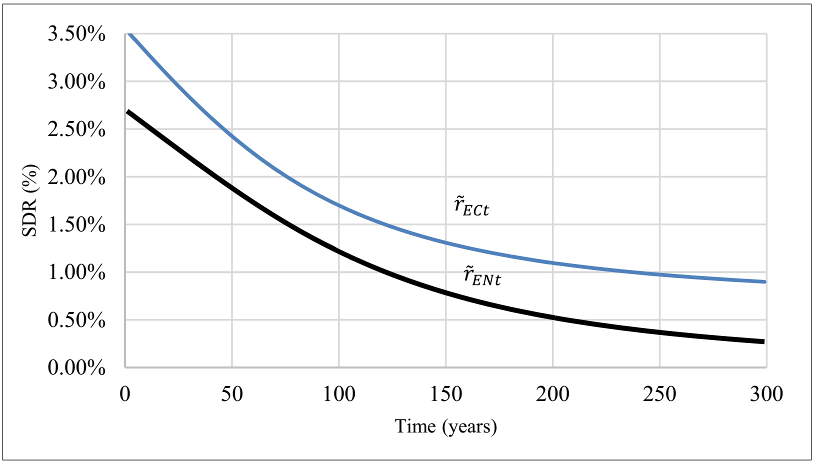

Fig. 5. Function of declining discount rates $\tilde{r}_{ECt}$ and $\tilde{r}_{ENt}$.

5 Discussion and Conclusions

The processing carried out gives the following results.

- For short-lived water projects in Italy: a r_{ECt} discount rate of 3.0% for strictly financial components and a rate of 2.4% to discount environmental effects.
- For long-term water projects: an economic discount rate r_{ECt} that runs from an initial value of 3.5% to a value of about 1% after 300 years; and an environmental discount rate r_{ENt} that goes from a value of 2.7% to a value of 0.3% after 300 years.

The results obtained by implementing the two approaches are consistent with each other. In fact, the average r_{ECt} value for the first 30 years is 3.1%, which corresponds roughly to the 3.0% r_{EC} value obtained by implementing the determination approach. Similarly, the average value of r_{ENt} for the first 30 years is 2.4%, which corresponds to the value estimated for short-lived projects.

The value obtained for the economic discount rate is also in line with the 3.0% discount rate suggested by the European Commission for countries outside the Cohesion Fund [19].

In order to understand how the results obtained may influence the outcome of an economic assessment of a water resources investment, we show how the discount factor $F_S = 1/(1 + r)^t$ varies as time t.

increases in two cases:

1. Using the constant discount rate of 3.0%, suggested by the European Commission;
2. Using a double declining discount rate, with $r_{ECt} < r_{ECt}$.

Figure 6 shows the relationship between discount factor F_D and time t, with $1 < t <$ 100 years.

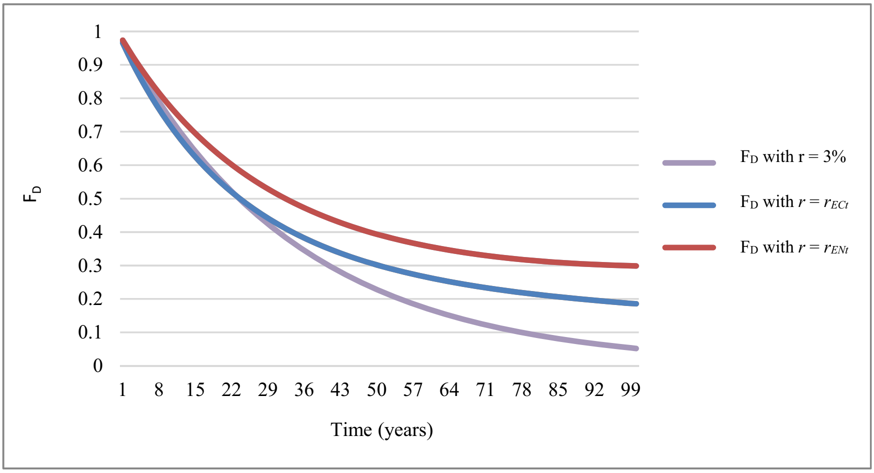

Fig. 6. Relationship between F_{D}–t.

Two main findings emerge from the analysis:

1. For periods of analysis up to thirty years, it can be considered consistent not to use a declining logic. However, using a double discount rate also for short-lived water projects allows to give more weight to environmental effects which are often not negligible already at the beginning of the assessment;
2. For periods of analysis longer than thirty years, the use of a constant discount rate would halve the "weight" of the environmental effects compared to a declining environmental rate. After one hundred years, using a constant SDR would mean not considering at all the environmental damages and benefits that the project is able to generate.

In conclusion, the repercussions that the choice of discount rate can have on the whole decision-making process are extremely important. The study shows that the use of dual and declining discounting approaches specific to water resources investment can guide the analyst towards more sustainable investment choices, both in the short and long term.

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