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Contents

Executive Summary

This research systematically identifies, examines and compares two primary methodologies for the social discount rate (SDR) calculation: the social rate of time preference (SRTP) and the social opportunity cost (SOC). The SRTP, grounded in the Ramsey formula, emerges as an advantageous approach for assessing infrastructure with a long useful life. Indeed, its effective integration of economic and societal indicators contributes to more reliable long-term estimations by governmental bodies. However, challenges in SRTP implementation exist, primarily due to a lack of consensus on input values, leading to potential inconsistencies in practical applications. In contrast, the SOC methodology faces drawbacks; it lacks a well-defined estimation protocol and fails to account for consumption displacement, which hampers its recommendation within guidelines. Particular concerns about the applicability of SOC arise from the several differences between public and private sectors, undermining its reliability.

This research enriches the understanding of the SDR, enhancing clarity about its estimations and providing valuable insights for practitioners and policymakers. By presenting the advantages and disadvantages of each method, it can facilitate the improvement of current methods or the development of new frameworks. Ultimately, this research fosters more informed decision-making and strategic practice within the realm of SDR computation.

1 Introduction

In the realm of projects, it is possible to distinguish two broad categories. On the one hand, there are projects triggered by the opportunity to generate revenue, maximise profits, or enhance market competitiveness (Williamson, 1988). These projects are typically funded and executed by private institutions, as the driving force is the pursuit of financial gains and profitability. An example of such projects can be the construction of a hotel or the coding of a new videogame. On the other hand, there are "social" projects with the primary goal of social, environmental, technological, or humanitarian outcomes (Hwang et al., 2011) without prioritising financial gains. These projects (e.g., building a new hospital, a new train station or a new university) are usually implemented by public institutions and evaluated through a cost-benefit analysis, as their focus extends beyond financial metrics (Engel et al., 2010). In the middle, there are all these projects that, even if justified by an economic return, are regarded as social infrastructure that are necessary for a country to function and are, therefore, of public interest. Water, electricity or Information and Communication Technologies (ICT) infrastructure are typical examples. Nuclear power plants, producing electricity, fulfil an essential social need and can therefore be considered a form of social project. Indeed, nuclear power plant investments could be assessed using a social discount rate to ensure intergenerational equity, sustainability, and proper consideration of risks and externalities. It aligns with policy goals (e.g., net-zero) and facilitates holistic decision-making for long-term societal welfare.

A pivotal factor influencing the assessments of social projects is the social discount rate (SDR) (Krahn and Gafni, 1993; Florio, 2006). The SDR is the "*interest rate applied to benefits and costs that are expected to occur in the future in order to convert them into a present value* (Broughel, 2020). It measures "t*he rate at which a society would be willing to trade present for future consumption*" (Lopez, 2008). In other words, it represents "*the opportunity cost of resource use over time*" (Castillo and Zhangallimbay, 2021). Therefore, the SDR is the rate employed to include the social perspective in weighing future benefits and costs against present ones (Groom et al., 2022). In other words, the SDR compares consumption behaviours of today with potential consumption behaviours of tomorrow and aligns with principles of the System of Provision approach (SoP) in holistically assessing systemic impacts at societal level (Fine and Leopold, 1993). With respect to the traditional Financial Discount Rate (FDR) used in the discounted cash flow analyses, the SDR considers broader social implications, as it takes into account the preferences of society as a whole rather than individual investors (Florio, 2006; Greaves, 2017). The SDR is employed in public decision-making, particularly in areas where the impacts transcend financial considerations (Chapman and Elstein, 1995).

The SDR strongly influences the evaluation of projects, particularly infrastructure with a long-life cycle (as in the case of nuclear power plants). A high SDR could hinder the delivery of necessary projects, while an excessively low SDR could promote unnecessary projects and, therefore lead to an inefficient resource allocation. Furthermore, a relatively high SDR – which gives less significance to future costs and benefits - favours projects with immediate benefits (OECD, 2018). Additionally, the SDR impacts both the initial determination of whether a public project warrants funding and the subsequent evaluation of its performance (Rambaud and Torrecillas, 2006). Hence, the implications of the SDR estimation are remarkable.

Notably, there is no single standardised method for calculating the SDR. In other words, while for "regular discounting" the standard uses a Weighted Average Cost of Capital (WACC), calculated using a standard formula (WACC = Debt/(Debt + Equity) x cost of Debt x (1-tax rate) + Equity/(Debt + Equity) x cost of Equity[1]), there is not a single standard approach to calculate the SDR.

The literature presents several methods to calculate the SDR. This document provides a critical overview of the main methods to calculate the SDR. In particular, the aim of this document is two-fold. First, it aims to provide an overview of the main methods to calculate the SDR, examining the main characteristics (e.g., inputs, theoretical approach) and the advantages and disadvantages of each method. Second, this document provides a pilot application of each main method in the nuclear sector. The rest of the document is structured as follows. Section 2 details the methodology adopted. Section 3 presents and discusses the findings, showing a pilot application for each method. Section 4 concludes the document.

[1] The Weighted Average Cost of Capital (WACC) is a financial metric that represents the average rate of return a company needs to generate to satisfy all its investors, including both debt and equity holders. It is calculated by weighting the cost of each type of capital (debt and equity) by its respective proportion in the company's capital structure. The "debt-related" part of the formula (after tax) represents the cost incurring from borrowing funds through debt instruments like bonds or loans. Since interest on debt is typically tax-deductible, the formula then multiplies this result by (1 - tax rate) to adjust for the tax shield on interest payments. The "equity-related" part of the formula is represented by the return required by equity investors to compensate them for the risk of owning shares in the company. The formula calculates the proportion of the company's capital structure represented by equity (Equity / (Debt + Equity)). This proportion is multiplied by the cost of equity.

2 The role of Social Discount Rate in Cost-Benefit Analysis

Cost-benefit analysis (CBA) is a fundamental tool used in economics and decision-making processes to evaluate the feasibility and desirability of a particular investment (European Commission, 2014). It involves systematically comparing the costs incurred with the benefits gained from a proposed project, policy, or investment. The essence of CBA lies in its ability to provide a structured framework for assessing the trade-offs inherent in any decision. On the one hand, costs encompass all expenditures associated with implementing the decision, including both monetary outlays and opportunity costs, which represent the value of the next best alternative forgone. On the other hand, benefits encapsulate all positive outcomes or gains resulting from the decision, whether tangible or intangible, such as increased revenue, improved public health, or enhanced quality of life (Koopmans and Mouter, 2020). The analysis typically involves quantifying costs and benefits in monetary terms to facilitate comparability and decision-making. CBA represents a vital tool for policymakers, businesses, and individuals alike, aiding in the identification of optimal choices that maximize societal welfare or individual utility (Vickerman, 2007).

The output of CBA typically consists of a comprehensive report or presentation detailing the findings and conclusions derived from the analysis. This output generally includes:

1. Cost-Benefit Ratio: A quantitative measure comparing the total present value of benefits to the total present value of costs, indicating the efficiency of the project or policy.
2. Net Present Value (NPV): The difference between the present value of benefits and the present value of costs, providing a monetary measure of the project's profitability.
3. Sensitivity Analysis: Examination of how changes in key assumptions or variables affect the results, helping to assess the robustness of the analysis.
4. Recommendations: Based on the analysis, recommendations may be provided regarding the viability or desirability of the project or policy.
5. Qualitative Analysis: Additional qualitative insights may be offered, such as non-monetary impacts, distributional effects, and risk considerations.

To generate these outputs, the CBA involves two primary tasks crucial for decision-making: firstly, the identification and monetization of costs and benefits, and secondly, the selection of an appropriate discount rate, specifically the discount rate or social discount rate, to discount future cash flows (Simonelli, 2013). Identification and monetization entail categorizing and quantifying all relevant costs and benefits associated with a proposed action or policy. The discount rate choice is imperative as it reflects the opportunity cost of capital and adjusts future cash flows to their present value, ensuring comparability and facilitating informed decision-making amidst uncertainty and intertemporal considerations. The choice of the discount rate is crucial for the assessment of financial and economic indicators and, more generally, to assess any present value of investment assessment (Zhuang et al., 2007).

The present value is a financial concept used to determine the current worth of future cash flows, investments, or liabilities by discounting them back to their current value. It acknowledges the time value of money, which states that a euro received today is worth more than a euro received in the future due to its potential earning capacity. Present value calculations involve applying a discount rate, typically reflecting the cost of capital or the rate of return on alternative investments, to adjust future cash flows to their equivalent value in today's terms (Graham and Harvey, 2001). Present value analysis aids in decision-making, investment appraisal, and financial planning.

$$PV = \frac{C}{(1+i)^n} \qquad (1)$$

- PV represents the present value
- C represents the cash flow
- i represents the discount rate
- n represents the number of years between today and the year in which the cash flow will occur

This formula clearly illustrates the relevant role of the discount rate, substituted with an SDR in the case of social-oriented investments as aforementioned. For instance, a positive cash flow of 100€ occurring 40 years from now has a present value of 67€ considering a discount rate of 1%, a present value of 14€ considering a discount rate of 5% and a present value of 2€ considering a discount rate of 10%. Therefore, the selection of an appropriate FDR or SDR has a huge impact on the computation of the present value, especially for cash flows occurring on a long-time horizon. As aforementioned, with respect to the traditional FDR, the SDR considers broader social implications (Florio, 2006; Greaves, 2017). In particular, the SDR is employed in public decision-making, particularly in areas where the impacts overcome mere financial considerations encompassing broader societal implications (Chapman and Elstein, 1995).

For this reason, considering a proper SDR, well representing the social cost of capital, is key in the evaluation of infrastructure such as nuclear power plants (NPPs), since they are characterized by high negative cash flows in the short term (i.e., planning, design and construction) and by positive cash flows in the long term (i.e., operations), with the exception of decommissioning.

3 Method

The methodology adopted is a systematic literature review (SLR), following the PRISMA approach (Moher et al., 2015) and previous SLRs in the energy sector (Mignacca et al., 2020; Mignacca and Locatelli, 2020). In order to collect the scientific documents about the SDR, we implemented the following query in Scopus: *"social discount rate*"* (applied to title, abstract, and keywords) in May 2023. We extracted the documents from Scopus due to the scientific merit of the indexed literature. We did not select a timeframe; therefore, it is 1969-2023. Excluding one non-English document, we retrieved 435 documents from the Scopus database. After the initial collection, we filtered according to two criteria:

1) A careful reading of the title and abstract of each document to exclude documents not related to the aim of this study. In particular, we excluded the documents not related to the use of the SDR in the assessment of projects and the documents discussing the SDR without focusing on its calculation method. In this first filtering phase, we excluded 277 documents, leaving 158 documents.
2) A careful reading of the introduction and conclusion of the remaining 158 documents. Applying the same exclusion criteria of Step 1, we excluded 103 documents, leaving 55 documents to be analysed.

In the final sample, 48 out of 55 are "Articles", 2 are "Conference papers", and 5 are "Reviews".

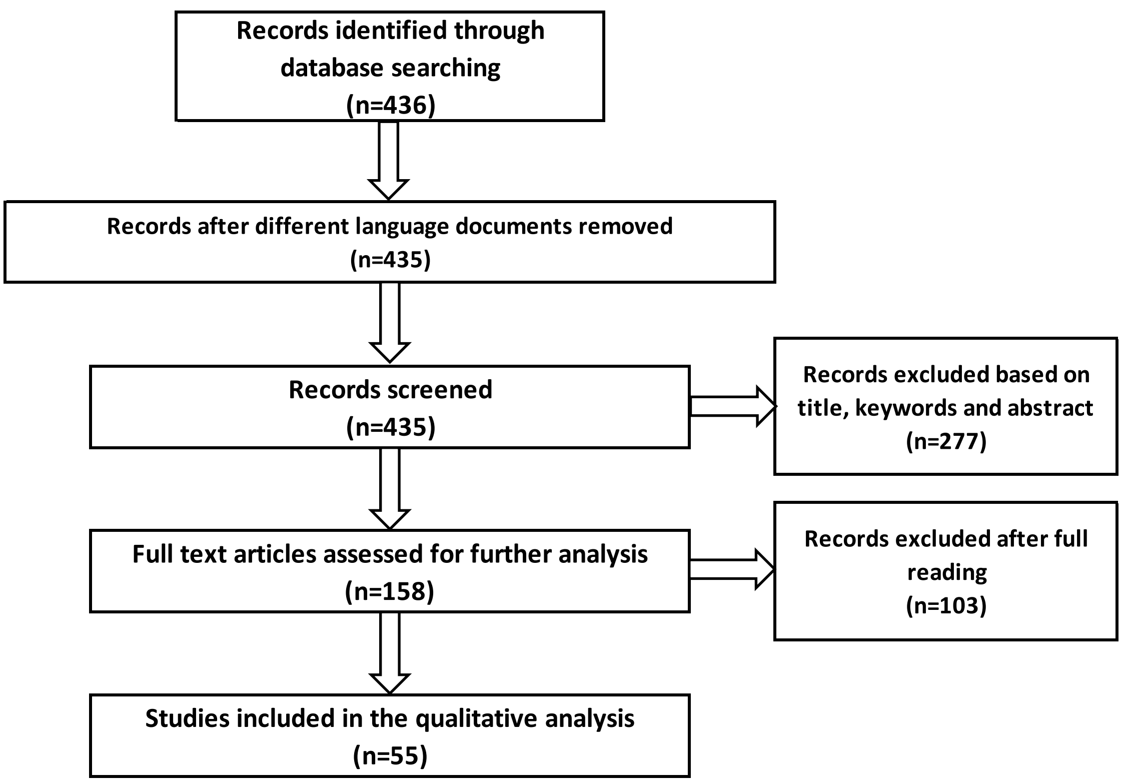

Figure 1: PRISMA methodology with personal adjustments

In our investigation, we performed an inductive and qualitative thematic analysis on the conclusive set of 55 documents. Thematic analysis is a well-established and versatile technique widely utilised in qualitative research (Braun and Clarke, 2006). This approach entails identifying, organising, and interpreting themes and codes within a dataset (Levac et al., 2010).

Out of the initial 55 documents (detailed in annexes), 5 of them, categorised as "Reviews" have been excluded from the analysis. Those documents were, however, read carefully and used to inform the research.

From the thematic analysis, we identified 31 codes grouped into seven themes, as shown in Table 1 (detailed in annexes)

Table 1 Structure of the thematic analysis

Themes	Codes	Themes	Codes
Methods	Social Rate of Time preference	Temporal Horizon	Before 2000
	Social Opportunity Cost		2000-2010
	Weighted Average approach		2010-2023
	Shadow Price of Capital	Advantages	Analytical Framework
Inputs	Utility Discount Rate		Long term consideration
	Elasticity of marginal utility of consumption		Complete analysis
	Growth Rate of per capital consumption		Country structure consideration
	Opportunity cost of capital	Disadvantages	Implementation difficulties
	Weights		Partial consideration
	SPC factor		Public/Private sector differences
Outputs	Single Value		Project specificity
	Range		Long term uncertainty
	No estimation		
Area of adoption	USA		
	Europe		
	UK		
	Australia		
	Asia		
	Latin America		

4 Findings and discussions

The analysis of the scientific documents led to the identification of 13 methods to calculate the SDR: Equity discount rate (Scarborough, 2011), Fisher effect SDR (Freeman et al., 2015), Fuzzy SDR (Dompere, 1993), Gamma discounting (Weitzman, 2001), Hazard Rate SDR (Rambaud & Torrecillas, 2005), Inequality SDR (Emmerling et al., 2017), Marginal cost of funds (Liu, 2003), Minimax regret discounting (Iverson, 2013), Risk-adjusted SDR (Cherbonnier & Gollier, 2022), Social rate of time preference (Ramsey, 1928; Sen, 1961; Kay, 1972), Shadow price of capital (Lind, 1982; Bradford, 1975), Social opportunity cost (Mishan, 1967; Baumol, 1974), Weighted average approach (Harberger, 1972; Edwards, 1986). The most relevant methods (i.e., the most frequently discussed in the scientific literature and empirical documents) are the social rate of time preference (SRTP) and the social opportunity cost (SOC). Therefore, in line with the aim of this document, this section first summarises their key characteristics (e.g., inputs, theoretical approach, advantages, and disadvantages) and then provides a pilot application in the energy sector for both methods.

4.1 Social rate of time preference

The SRTP represents the rate at which society is willing to delay a unit of current consumption in exchange for future ones (Marini and Scaramozzino, 2000). The SRTP method considers that policymakers assess public investments aiming to enhance the overall value of societal well-being. Given that the well-being of a society is related to consumption behaviours, the SDR (i.e., the SRTP in this case) should represent the societal preferences towards immediate and future consumption patterns (Kay, 1972). The discussion surrounding the role of the SDR and its computation through SRTP methodologies resulted aligned with some open debates around the System of Provision approach (SoP) (Fine and Leopold, 1993), introduced in Deliverable 3.1 and adopted in Deliverable 3.2. The SoP, in fact, investigates how consumption patterns and behaviours are influenced by the surrounding environment (Fine, 1994). In particular, the SoP underlines how horizontal factors characterising individual choice (e.g., gender, income, status), should be investigated in relation to the vertical structure that provides certain goods or services (e.g., who produces, distributes and consumes) (Bayliss and Fine, 2020). Identifying consumption behaviours as representative of societal well-being highlights the necessity of further investigating the causes of such behaviours to gain a more holistic understanding of value creation dynamics.

Coming back to the SRTP method, its computation results from the sum of two components:

$$SRTP = \delta + \eta g \qquad (2)$$

where δ is the utility discount rate, η is the elasticity of marginal utility of consumption, and *g* is the annual rate of per capita consumption growth. This section details key information about these parameters.

- The utility discount rate (δ)

The utility discount rate reflects a preference for welfare in the present over the future (i.e., impatience) (Nesticò & Maselli, 2020). There is no consensus on the estimation of the utility discount rate (Tabi, 2013). Table 2 shows several estimations – from 0 to 1.5% - that emerged from the literature review and the related theoretical basis.

Table 2: Estimations of the utility discount rate

δ	Theoretical basis	Sources
0%	Ethical concerns and impartiality of time	Ramsey (1928), Pigou (1932)
1.2%	Average annual probability of death	Kula (1984)
1.3%	Impatience is 0.3% and risk of total destruction of a society is 1%	Scott (1989)
1.1%	Average annual probability of death	Pearce & Ulph (1995)
1%	Impatience calculated with observed savings behaviour	Arrow (1995)
1-1.5%	Catastrophic risk	Evans & Sezer (2004)
1%	Average annual probability of death	Evans (2006)
0.1%	Probability of human race extinction	Stern (2006)

Ramsey (1928) and Pigou (1932) suggested that the welfare of society today and in the future should be equivalent, implying that discounting costs and benefits is not needed. Arrow (1995) suggested a 1% utility discount rate as the result of observed savings behaviour. Kula (1984), Pearce & Ulph (1995), and Evans (2006) estimated δ based on the average annual probability of death and considering the impatience (or myopia) equals zero. Kula (1984) justified this choice, arguing that considering myopia implies introducing irrationality in the decision-making process. Moreover, Scott (1989) used the risk of total destruction of a society, Evans & Sezer (2004) used the catastrophic risk (measure also adopted by HM Treasury (2022) in UK), and Stern (2006) used the probability of human race extinction. On this matter, the European Commission (2014) proxies this value to the ratio between the annual total deaths and the total population. To conclude, there is not a standard method to estimate the utility discount rate.

- Elasticity of marginal utility of consumption (η)

The elasticity of the marginal utility of consumption measures how the marginal value of consumption decreases as per capita consumption increases (Moore et al., 2004). The literature presents two models for its calculation.

First, the personal taxation model - proposed by Stern (1977) and Cowell & Gardiner (1999) - which aims to emulate the state tax policies that strive to alleviate disparities in income. In this case, the elasticity of marginal utility of consumption represents the government's aversion to income inequality (Evans, 2005). Indeed, as the income tax structure becomes more progressive, the value of the elasticity tends to increase. In this model, its value can be calculated using the following formula:

$$\eta = \frac{\log(1-t)}{\log\left(1-\left(\frac{T}{Y}\right)\right)} \qquad (3)$$

where t is the marginal rate of tax on income, T is the total tax on income liabilities, and Y is the pre-tax income. The equation suggests that if the marginal and the average tax rates[2] are known, it is feasible to estimate the elasticity for a certain country.

The second approach is based on the demand for food model proposed by Fellner (1967). In this model, the elasticity of marginal utility of consumption is calculated as follows:

$$\eta = \frac{b(1-wb)}{|c|} \qquad (4)$$

where b is the income elasticity for preference-independent goods, c is the compensated price elasticity for preference-independent goods, and w is the budget share for preference-independent goods. The literature highlights several estimations – from 0.48 to 1.89 - of the elasticity of marginal utility of consumption (η), as shown in Table 3.

η	**Model**	**Sources**
1.28	Demand for food model	Percoco (2008)
0.483	Demand for food model	Seçilmiş & Akbulut (2019)
1.56-1.89	Personal taxation model	Kula (1984)
1.28-1.41	Personal taxation model	Cowell & Gardiner (1999)
1.3-1.5	Personal taxation model	Evans & Sezer (2004)
1.1-1.8	Personal taxation model	Evans & Sezer (2005)
1.34	Personal taxation model	Percoco (2008)
1.4	Personal taxation model	Tabi (2013)
1-1.4	Personal taxation model	Seçilmiş & Akbulut (2019)

Table 3: Estimations of the elasticity of marginal utility of consumption (η)

Percoco (2008) and Seçilmiş & Akbulut (2019) utilise both methods. The calculation based on the demand for food model gave a lower value with respect to the one based on the personal taxation model. The different values in table 3 suggest that the results are sensitive to various parameters, such as the level of aggregation of data, the choice of the estimations, the geographical context, and reference time-period. For

[2] The average tax rate is the ratio between T and Y.

instance, the estimations provided by Evans & Sezer (2005) differ according to the EU country considered, covering a range of values where the lower value is 1.1 in Sweden and the upper value is 1.8 in Luxembourg.

- The annual rate of per capita consumption growth (g)

The growth rate of per capita consumption represents the wealth degree of a society (Moore et al., 2020). With a higher *g*, more emphasis is placed on improving the circumstances of the current generation. The documents collected in our SLR calculate *g* as the average growth rate of GDP per capita of the country investigated in a specific time period. In estimating *g*, the main issue is the time period to select. Tabi (2013) examines – in the case of Hungary - how *g* is substantially sensitive to the time period considered in the analysis. Table 4 summarises this analysis.

Table 4: Tabi's (2013) estimations of g

Timeframe	Average GDP growth	Motivations
1991-2009	1.33%	Time period from the transition until the estimation
1998-2007	3.78%	"Booming" of the economy
1998-2009	2.65%	Including the effect of the financial crisis
2000-2006	4.01%	Time period according to EU guide

Therefore, the value of the growth rate can drastically impact the SDR estimation. It is worth highlighting that the average GDP growth over the last decade ranges between 2% and 3% (World Bank, 2024).

An alternative approach to estimate *g*, used by Moore et al. (2020), is the adoption of a regression model. They estimated the historical average growth rate by calculating the natural logarithm of real per capita consumption and then regressing the variable on a linear time trend.

4.1.1 Advantages

The SRTP stands out for its inherent theoretical simplicity (Groom et al., 2022), yet it is based on a rigorous theoretical approach (Nesticò & Maselli, 2019). A key advantage of the SRTP is its alignment with the country's specific structure, favouring an alignment with the application context. On the advantages of the the SRTP, Nesticò & Maselli (2020, p. 4) state: *"the [SRTP] is to be preferred as it is not based solely on financial information deriving from the market, but on demographic and socio-economic indicators that are more representative of the territory. Furthermore, the implementation of the Ramsey formula requires non-complex availability data, indispensable for the measurement of the parameters"*. Another advantage of the SRTP is its comprehensive treatment of long-term considerations. On this matter, Groom et al. (2005, p. 5) pointed out: *"Ramsey interpreted equation as the maximand of an infinitely lived representative agent acting as a trustee for current and future generations in choosing consumption and saving […]. Although there has been criticism of this approach, there is at least some agreement that this abstraction represents a convenient framework for long-term analysis"*. An extension of the Ramsey formular that considers the potential long-term impact of the project is conducted by Gollier (2013):

$$SDR = \delta + \eta g - 0.5\eta(\eta + 1)t\sigma_t^2 \qquad (5)$$

where σ_t^2 is the variance of the per-period logarithmic consumption growth between time 0 and t, which is normally distributed. Through this factor that diminishes the initial value of the SDR, Equation 4 effectively captures the uncertainty about the future. This results in a lower SDR, which value more the future costs and benefits.

4.1.2 Disadvantages

The primary issue is the lack of consensus regarding the value to be adopted for estimating the inputs (Groom et al., 2022). On this matter, Zhuang et al. (2007, p. 22) stated: *"[the] choice of utility discount rate involves normative value judgment, and estimation of the elasticity of marginal utility of consumption is sensitive to data and methodology"*. Furthermore, Nesticò & Maselli (2019, p. 4) pointed out: *"the greatest difficulty in implementing the formula is linked to the estimation of the growth rate of consumption. Several models are proposed for the g forecast, from which it emerges that the SDR value is strongly influenced by the persistence of the shocks in the economic growth process"*. Overall, there is a lack of a common framework that practitioners can adopt to compute the SDR. Another disadvantage of the SRTP method is poor consideration of displacement effects, as highlighted by Zhuang et al. (2007, p. 9): *"a major criticism on using SRTP as the social discount rate is that it is purely a measure of the social opportunity cost in terms of foregone consumption and ignores the fact that public projects could displace or crowd out private sector investment if they cause the market interest rate to rise […]. If additional public investment is made at the cost of displacing private investment, its marginal social opportunity cost should also reflect what the displaced private investment would otherwise bring to the society, which can be measured by the marginal social rate of return on private sector investment (SOC)"*.

4.1.3 Pilot application to the nuclear sector

This section provides a pilot application of the SRTP method to show how this method could be applied to calculate the SDR to be applied in the evaluation of a nuclear power plant project. In this application, we considered a hypothetical case of a nuclear power plant to be built in Italy, with a useful life of 60 years. The first stage is the calculation of the utility discount rate (δ), which we consider as the sum of two elements: the impatience (k) and the mortality rate (l). Following the approach previously adopted by Percoco (2008), we estimated the individuals' impatience as an outcome of the Survey of Households Income and Wealth (SHIW) performed by the Bank of Italy. The survey is based on the question: *"Suppose that you win €5000, payable for certain in a year from now. What is the maximum amount that you are willing to pay to have the €5000 immediately?"*. The majority of the interviewees declared a zero-preference rate; therefore, a 0% rate of impatience (k) is applied in this case. The mortality rates are calculated by the Italian National Institute of Statistics, i.e. Istat[3], allowing to determine a value of l of 0.98-0.99%, and, therefore, a value of δ of about 0.99%. To estimate the elasticity of marginal utility of consumption (η), we considered the value of 1.45, recently suggested by Scasny & Opatrny (2022). The calculation was based on the personal taxation model. Last, the consumption growth rate (g) can be

[3] Data from Demo.istat.it – Tavola di mortalità 2022

estimated using the average growth rate of the GDP per capita of the country. As aforementioned, different time periods might be adopted for its calculation. We used a 60-year period, which is the life of the infrastructure. The average value is approximately 1.94%[4]. Therefore, using the formula $SRTP = \delta + \eta g$, the final value of SDR for Italy would be 3.8%. This would be slightly higher than the 3% suggested by the European Commission guidelines (European Commission, 2014). Notably, using the average growth rate of per capita consumption over the period 2000-2022, the estimation changes to 0.28%, leading to an SDR of 1.4%. This highlights the importance of consistently selecting a standardised timeframe for the growth rate estimation.

The SDR impacts the investment decisions on a hypothetical NPP by discounting the cash flows (both cost and revenues) it generates over the years and assessed during a cost-benefit analysis. Being a long-term infrastructure that generates revenues only after several years from the first cost, a low SDR would benefit the evaluation of NPP investments.

4.2 Social opportunity cost

The social opportunity cost (SOC) is based on the idea that resources within an economy are limited. The government and the private sector contend to have the same pool of financial resources, and public investments may displace private ones (Baumol, 1974). For this reason, public investment should generate at least the same return as private investment. The SOC can be calculated as the marginal pre-tax rate of return on private investments (Schelling, 1995). Remarkably, in the case of a perfectly competitive economy, SOC and SRTP would lead to the same result, as the return to private investment and the consumption rate of interest are equalised. In reality, imperfections in capital markets, consumption or profit taxes, and additional market externalities contribute to the distortion of the economy, leading to different results for the two methods (Nordhaus, 1997). The return on private investments represents the way to measure the opportunity cost of not investing the same resources in the private sector. The literature suggests the use of the marginal pre-tax rate of return on private investments for the SOC estimation. A good proxy is the real pre-tax rate on top-rated corporate bonds (Zhuang et al., 2007). As outlined by Moore et al. (2004), it is considered to be an approximation, as the private investment's rate of return encompasses additional benefits to remunerate investors for risks that are commonly greater than those associated with public sector investments. Additionally, the literature highlights the fact that if the capital for the financing of a public project is partially satisfied by postponing consumers' consumption, the SDR should be lower than the one provided using this input.

4.2.1 Advantages

The literature does not mention specific advantages of the SOC method. However, the Australian Government (2020), which recommends this methodology, defines the method to be less subjective with respect to other methods of calculating the SDR. The rationale behind this advantage lies in the method's dependence on real market data and observations of returns from different investment options. Market data tends to be more objective and less susceptible to individual biases. Additionally, whereas certain alternative approaches may incorporate normative presumptions about society's intergenerational valuations, the SOC primarily centres on delineating actual economic actions and market dynamics.

[4] Data from the World Bank database - data.worldbank.org

4.2.2 Disadvantages

This literature suggests several disadvantages of the SOC method. In particular, it presents several issues regarding its implementation, as also highlighted by the few estimations conducted using the SOC method. A key reason is the lack of an analytical framework (Kossova and Sheluntcova, 2016). Moreover, the SOC method may lead to estimate ranges and not exact values. For instance, Abelson & Dalton (2018) leveraged the SOC method to compute the SDR in the context of Australia, concluding *"that a private project might have a real pre-tax weighted average return of around 6.46 per cent with a range of possible estimates from 4.94 per cent to 8.14 per cent"*. Notably, another key issue is the lack of precision in the inputs employed to gauge the returns within the private sector. On this matter, Moore et al. (2020, p. 5) stated: *"Obtaining a value for the SDR based on observed market returns is problematic because they do not accurately measure the social marginal return to private investment. Private returns include monopoly and informational rents and do not net out negative externalities. Additionally, they are often estimated using the average, rather than marginal, return on investment"*. Additionally, as for the SRTP, a theoretical issue about SOC is the partial consideration of the displacement effect. On this matter, Moore et al. (2004, p. 6) stated: *"the basic motivation is that the opportunity cost of doing a public project is the forgone return on the marginal private project. However, typically some (if not all) costs will displace consumption; thus, this method is generally invalid"*. Another reason for the critique directed at the SOC method lies in its consideration of the rate of return in private investments as an opportunity cost, despite existing disparities between the public and the private sectors. The principal concern revolves around the fact that private investments entail a greater level of risk compared to their public counterparts. Incorporating a risk premium into public investments may lead to an overvaluation of the SDR (Moore et al., 2017). Furthermore, public projects also involve alternative avenues of funding, such as taxes and/or foreign capitals, which are disregarded by the SOC method (Simonelli, 2013). Furthermore, the SOC method disregards the long-term perspective, as stressed by Groom et al. (2005, p. 16)*: "there is uncertainty concerning capital accumulation, the degree of diminishing returns, the state of the environment, the state of international relations, and the level and pace of technological progress"*.

4.2.3 Pilot application to the nuclear sector

In order to provide a pilot application of the SOC method in the aforementioned context of a nuclear power plant built in Italy, we adopted the procedure proposed by Abelson & Dalton (2018), who base their calculation on the Capital Asset Pricing Model (CAPM). In particular, the risk-adjusted return is calculated as:

$$Risk\ Adjusted\ Return = Risk\ Free\ Rate + (Beta * Market\ Risk\ Premium) \quad (6)$$

- The risk-free rate is assumed to be 2.5%, that may be the yield on 10-year government bonds, which can represent a low-risk investment[5].
- The market risk premium is assumed to be 6%[6].

[5] Data from tradingeconomics.com/germany/government-bond-yield
[6] Data from *oecd-nea.org*

- The beta of a prospective investment indicates the extent to which it contributes to the overall risk of a market-representative portfolio; stocks with a beta exceeding one are considered riskier than the market, while those with a beta below one are presumed to mitigate portfolio risk. The beta of the nuclear power plant project is assumed to be 1.2[7], which is reasonable considering the investment risk in NPP.

The result of the calculation, using the Italian context as an illustrative example, is 9.7%. This value would be the SDR based on the SOC methodology. With respect to the SRTP, more assumptions need to be made before the calculation process. Moreover, while the Ramsey formula provides a standardised framework in the estimation of SRTP, in this case there is no general agreement about which might be the right procedure for the calculation. Zhuang et al. (2007), for instance, propose a different approach based on top-rated corporate bonds.

In the evaluation of a hypothetical NPP investment assessment, a higher SDR will tend to prioritize short-term cash flows over long-term ones. Therefore, in evaluating an investment for an NPP, this SDR will tend to give greater importance to negative cash flows generated during the planning, design, and construction phases while diminishing the significance of positive cash flows generated during operations.

[7] Data from pages.stern.nyu.edu

5 Comparison and areas of adoption of SRTP and SOC

The pilot applications in the energy sector to calculate the SDR show how the methods can lead to substantially different results (i.e., SDR = 3.8% adopting the SRTP method and 9.7% adopting the SOC method). The pilot applications also highlight how the SRTP is a more straightforward and accurate method for calculating the SDR. Conversely, the issue with the SOC methods lies in the lack of a well-defined framework for the estimation. We adopted the CAPM as proposed by Abelson & Dalton (2018), which provides a relatively straightforward formula for calculation, but it is not widespread in the literature. In contrast to the SRTP, SOC yields significantly higher output, leading to a more stringent selection of projects for implementation. These two methods – SRTP and SOC – are also often recommended by different countries and supranational entities in the social discounting guidelines. It compiles information regarding both the numerical value and the methodologies utilised in their respective proposals. Table 5 presents the methods endorsed in several areas and the SDR value recommended.

Table 5: Value and methods adopted by guidelines in the SDR estimation

Area	SDR	Method	Sources
UK	3.5%	SRTP	HM Treasury (2022)
USA	3-7%	SRTP and SOC	Office of Management and Budget's (2023)
EU	3-5%	Not defined	European Commission (2014)
ADB	9%	SRTP	Asian Development Bank (2017)
LATAM	12%	SOC	Inter-American Development Bank (2022)

- UK

The HM Treasury (2022) includes an annex dedicated to elucidating the role of the SDR in the context of project appraisal and discounting, offering precise and detailed recommendations. The document advocates for a fixed SDR value of 3.5%, computed through the SRTP method. This value is lower than the estimations that emerged from the literature reviews in studies in the context of UK. Indeed, estimates of 4% and 4.5% are reported by Evans & Sezer (2004) and Groom & Maddison Pr. (2019), respectively. The higher value in the aforementioned studies is primarily attributed to the utilisation of an elasticity of marginal utility of consumption set at 1.5, deviating from the value of 1 employed in the guidelines.

- USA

Two key documents suggesting the SDR value in the USA are Circular A-4 issued by Office of Management and Budget's (OMB) (2023) and Circular A-4 references Circular A-94 (OMB, 2022). While the OMB (2022) proposes a singular value of 7% as an appropriate representation of the opportunity cost of capital, OMB (2023) introduces an additional discount rate of 3%. This new rate is intended to estimate the SRTP.

Furthermore, considering the potential displacement of private investment and private consumption by regulatory projects, the guideline advocates for computing under both SOC and SRTP discount rates. The notable discrepancy between the dual values endorsed by the guidelines gives rise to an imprecise evaluation of the project. This discrepancy's significance is emphasised in the opening section, where a mere 2% fluctuation in the SDR could ascertain the project's eligibility for funding. The substantial variance of 4 percentage points, particularly over an extended period, will inevitably lead to considerable disparities. A more precise estimation, recently put forth by Nesticò & Maselli (2020), proposes a value of 4.7%, obtained via the application of the Ramsey formula. To enhance this approach, they advocate for incorporating a sensitivity analysis to gauge the discount rate's robustness. The suggested value harmonises effectively with the guideline, positioning itself almost midway between the spectrum of the two SDR values recommended in those guidelines. Consequently, an adjustment of approximately +/-2% within the context of the sensitivity analysis emerges as the suitable approach.

- European Union

The European Commission (2014) guidelines propose the following recommendations regarding the SDR: *" the European Commission recommends that for the social discount rate 5 % is used for major projects in Cohesion countries and 3 % for the other Member States. Member States may establish a benchmark for the SDR which is different from 5% or 3 %, on the condition that: i) justification is provided for this reference on the basis of an economic growth forecast and other parameters; ii) their consistent application is ensured across similar projects in the same country, region or sector. The Commission encourages MSs to provide their own benchmarks for the SDR in their guidance documents, possibly at the start of the operational programmes and then to apply it consistently in project appraisal".* The EU guidelines do not endorse any specific method for the suggested 3/5% estimations.

In contrast to the recommendations provided in the guidelines, practitioners are notably engaged in the process of estimating the SDR. Scholars commonly employ the SRTP approach and the Ramsey formula for these estimations. Evans & Sezer (2005) undertook the calculation of SDR for EU member countries. With the exception of Poland and the Slovak Republic (affected by excessive disequilibrium growth rates in recent periods), the computed values ranged from 2.3% for Denmark to 5.6% for Ireland. While there are discernible variations among EU countries, the discrepancies in SDR values are not excessively pronounced. This could possibly account for the inclusion of the predefined values suggested by the EU guidelines.

- Asia

The "*Guidelines for the Economic Analysis of Projects*" established by the Asian Development Bank (ADB) (2017) recommend using a discount rate set at 9%. However, for specific project categories, it is possible to employ a lower discount rate of 6%. The underlying methodology employed is the SRTP. Existing literature predominantly focuses on estimations rooted solely in the SRTP. The primary parameter diverging between the guidelines and practical estimations is the growth parameter. While ADB (2017) advocate for a value of g=5%, derived from the projected GDP per capita growth for the Asian region during the 2016-2030 timeframe, the estimations in the literature rely on historical growth rates from the period between 1970 and 2004. This leads to a contrast where the guidelines suggest a growth rate of 5%, whereas the alternative approaches of Evans & Sezer (2004) and Zhuang et al. (2007) yield a range between 2% and 4.5%.

- Latin America

The Inter-American Development Bank (2022) proposes the highest discount rate among the discussed guidelines, standing at 12%. This rate aligns with the concept of the opportunity cost of capital and has retained this value since 1998. However, the document does not elaborate on any additional specifics regarding the methodology employed in calculating this rate. The literature proposes diverse methodologies for calculating SDR in Latin America. Among these, the employment of the SRTP is prominent, whereas the SOC is omitted from the estimation process. Notably, Edwards (1986) introduces a value of 9.72%, which is derived as a weighted average of SRTP, SOC and the cost of foreign borrowing. Although this value does not align closely with the suggested rates, it notably demonstrates more proximity compared to the estimations put forth by Moore et al. (2020). In the latter work, they estimate the SDR by employing SRTP for seventeen Latin American countries. The computed average SDR value across these nations is 3.77%. However, there exist substantial deviations from this average, with Paraguay registering the lowest value 2.14% and Chile exhibiting the highest at 5.83%.

6 Conclusions

CBA holds significant relevance in evaluating investments in NPP due to their long-term implications and complex cost-benefit dynamics. NPP involve substantial upfront investments, extended operational lifespans, and diverse socio-economic impacts, necessitating a comprehensive assessment framework. CBA facilitates systematic consideration of both tangible and intangible costs and benefits associated with nuclear energy investments, encompassing construction costs, operational expenses, environmental impacts, energy security, and public health considerations.

The key role played by the SDR in NPP investment analysis is paramount, particularly in addressing the interplay between long-term positive cash flows and short-term negative ones. Nuclear projects typically exhibit a temporal mismatch between significant initial capital outlays and delayed revenue streams, as well as long-term benefits such as emissions reduction and energy security enhancements. The SDR enables the conversion of future cash flows into present values, thereby balancing the importance of short-term costs against long-term benefits. Yet, in the literature, there is no agreement on a single method to compute the SDR.

The systematic literature review conducted revealed 13 distinct methods for computing the SDR. Among these, the most pertinent approaches, extensively deliberated in both academic discourse and empirical studies, are the SRTP and the SOC. These methods stand out for their prominence in scholarly discussions and practical applications concerning the determination of the SDR.

SRTP reflects societal willingness to defer current consumption for future gains. Policymakers use SRTP to assess investments for societal well-being enhancement. The SDR captures societal preferences on present and future consumption. Debates on SDR align with the System of Provision approach, emphasizing influences on consumption patterns and societal well-being.

SOC asserts that resources are finite, with public and private sectors competing for the same pool of funds. Public investments should yield returns akin to private ones. Calculated as the marginal pre-tax rate of return on private investments, SOC aligns with SRTP in a perfectly competitive economy. However, imperfections in capital markets and other externalities lead to divergent results.

The illustrative example regarding the hypothetical assessment of an NPP in Italy showed that the SRTP method to compute the SDR provides more favourable outcomes. In fact, the SRTP provides a value of the SDR more than two times lower than the one computed according to the SOC method, and would provide higher relevance to long-term positive cashflows generated by the NPP. Moreover, the SOC computation requires more assumptions to be made with respect to the SRTP.

7 Annexes

Table 6. List of documents analysed through the thematic analysis

AUTHORS	TITLE
Abelson P.	A Partial Review of Seven Official Guidelines for Cost-Benefit Analysis
Abelson P., Dalton T.	Choosing the Social Discount Rate for Australia
Arrow K.	Intergenerational Equity and the Rate of Discount in Long-Term Social Investment
Baumol W.	On the Social Rate of Discount.
Burgess D. F.	Reconciling alternative views about the appropriate social discount rate
Castillo J. G., Zhangallimbay D.	The social discount rate in the evaluation of investment projects: An application for Ecuador.
Chapman G. B., Elstein A. S.	Valuing the Future: Temporal Discounting of Health and Money.
Cherbonnier F., Gollier C.	Risk-adjusted Social Discount Rates
Cowell F., Gardiner K.	Welfare weights
Dasgupta P.	Discounting climate change
Dompere K. K.	A fuzzy-decision theory of optimal social discount rate: Collective-choice-theoretic
Drupp M. A., Freeman M. C., Groom B., Nesje F.	Discounting disentangled
Edwards S.	Country risk, foreign borrowing, and the social discount rate in an open developing economy
Emmerling J., Groom B., Wettingfeld T.	Discounting and the representative median agent
Evans D.	Uncertainty and social discounting for the very long term
Evans D. J., Sezer H.	Social discount rates for member countries of the European Union
Evans D. J., Sezer H.	Social discount rates for six major countries
Florio M.	Cost-benefit analysis and the European Union Cohesion fund: On the social cost of capital and labour
Freeman M. C., Groom B.	How certain are we about the certainty-equivalent long term social discount rate?
Freeman M. C., Groom B.	Positively gamma discounting: Combining the opinions of experts on the social discount rate
Freeman M. C., Groom B., Panopoulou E., Pantelidis T.	Declining discount rates and the Fisher Effect: Inflated past, discounted future?
Gollier C., Hammitt J. K.	The Long-Run Discount Rate Controversy.
Greaves H.	Discounting for public policy: A survey.

Groom B., Drupp M. A., Free-man M. C., Nesje F.	The Future, Now: A Review of Social Discounting
Groom B., Hepburn C., Koun-douri P., Pearce D.	Declining discount rates: The long and the short of it
Groom B., MaddisonPr D.	New Estimates of the Elasticity of Marginal Utility for the UK
Haacker M., Hallett T. B., Atun R.	On discount rates for economic evaluations in global health
Haveman R. H.	The opportunity cost of displaced private spending and the social dis-count rate
Henderson N., Bateman I.	Empirical and public choice evidence for hyperbolic social discount rates and the implications for intergenerational discounting
Hultkrantz L.	Discounting in economic evaluation of healthcare interventions: what about the risk term?
Iverson T.	Minimax regret discounting
Johansson-Stenman O., Sterner T.	Discounting and relative consumption
Kossova T., Sheluntcova M.	"Evaluating performance of public sector projects in Russia: The choice of a social discount rate"
Krahn M., Gafni A.	Discounting in the economic evaluation of health care interventions
Liu L.	A marginal cost of funds approach to multi-period public project evalua-tion: implications for the social discount rate
Lyon R. M.	Federal discount rate policy, the shadow price of capital, and challenges for reforms.
Marini G., Scaramozzino P.	Social time preference
Mishan E. J.	Criteria for Public Investment: Some Simplifying Suggestions
Moore M. A., Boardman A. E., Vining A. R.	Social Discount Rates for Seventeen Latin American Countries: Theory and Parameter Estimation
Moore M. A., Boardman A. E., Vining A. R., Weimer D. L., Greenberg D. H.	"Just give me a number!" Practical values for the social discount rate
Nesticò A., Maselli G.	A protocol for the estimate of the social rate of time preference: the case studies of Italy and the USA
Nesticò A., Maselli G.	Intergenerational discounting in the economic evaluation of projects
Nocetti D., Jouini E., Napp C.	Properties of the social discount rate in a benthamite framework with het-erogeneous degrees of impatience
Pearce D., Ulph D.	A social discount rate for the United Kingdom
Percoco M.	A social discount rate for Italy
Rabl A.	Discounting of long-term costs: What would future generations prefer us to do?

Rambaud S. C.	A new argument in favor of hyperbolic discounting in very long term project appraisal
Rambaud S. C., Torrecillas M. J. M.	Some considerations on the social discount rate
Scarborough H.	Intergenerational equity and the social discount rate
Scasny M., Opatrny M.	New estimates of the Elasticity of Marginal Utility of Consumption for Europe: Implications for the Social Discount rate.
Seçilmiş E., Akbulut H.	Social discount rates for six transition countries
Simonelli F.	The role of the discount rate in cost-benefit analysis between theory and practice: A comparative survey
Tabi A.	Using the stated preference method for the calculation of social discount rate
Weitzman M. L.	Gamma discounting
Zhuang J., Liang Z., Lin T., DeGuzman F.	Theory and practice in the choice of social discount rate for cost-benefit analysis: A survey

Table 7. Description of codes emerging from the thematic analysis.

Themes	Codes	Description
Methods	Social Rate of Time Preference	Consumption-based approach. It considers the preference of consuming now with respect to saving for consuming in the future.
	Social Opportunity Cost	Investment-based approach. It considers the rate of return on the displaced private investment.
	Weighted Average approach	It consists in a weighted average of the Social Rate of Time Preference and the Social Opportunity Cost.
	Shadow Price of Capital	It converts all the streams of costs and benefits into consumption equivalents.
	Others	It comprehends the other less cited methodologies not considered in the analysis.
Themes	**Codes**	**Description**
Outputs	Single value	The output of the analysis in a singular value to be applied as SDR.
	Range	The output of the analysis is a range of possible values to be applied as SDR.

	No estimation	The analysis, while focusing in a SDR methodology, doesn't estimate the value of the SDR.
Themes	**Codes**	**Description**
Inputs	Utility Discount Rate	It reflects the pure time preference of today with respect to the future of society.
	Elasticity of marginal utility of consumption	It is the absolute value of the rate at which the marginal value of the consumption decreases as per capita consumption increases.
	Growth rate of per capita consumption	It represents the wealth degree of a country.
	Opportunity cost of capital	It measures the best alternative rate of return of a project in the private sector.
	Weights	They measure the weights associated to the parameters used in the Weighted Average approach.
	SPC factor	It is the rate used in the SPC methodology to convert all the costs and benefits into consumption equivalents.
Themes	**Codes**	**Description**
Temporal Horizon	Before 2000	The outputs are linked to this code if they are estimated before year 2000.
	2000-2010	The outputs are linked to this code if they are estimated between 2000 and 2010.
	2010-2023	The outputs are linked to this code if they are estimated between 2010 and 2023.
Themes	**Codes**	**Description**
Area of application	USA	The outputs are linked to this code if they are estimated with data related to USA.
	European Union	The outputs are linked to this code if they are estimated with data related to one of the EU nations.
	UK	The outputs are linked to this code if they are estimated with data related to UK.
	Australia	The outputs are linked to this code if they are estimated with data related to Australia.
	Asia	The outputs are linked to this code if they are estimated with data related to Asia.
	Latin America	The outputs are linked to this code if they are estimated with data related to one of the Latin American nations.

Themes	Codes	Description
Advantages	Analytical framework	The method provides an analytical framwork as a foundation to the analysis.
	Long term consideration	The method considers the long term effect of the project.
	Complete analysis	The method considers that resources come from both the displacement of private invetsments and postponing present consumption.
	Country structure consideration	The method bases the analysis on the configuration of the country.
Themes	**Codes**	**Description**
Disadvantages	Implementation difficulties	The method has difficulties in practical implementation.
	Partial consideration	The method either considers the displacement effect or the postponement of consumption.
	Public/Private sector differences	The method doesn't consider the difference between the public and the private sector.
	Project specific	The project specificity of the methodology creates problems in the estimation.
	Long term uncertainty	The method is not designed to take into account long-term considerations, leading to uncertainty of the result.

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