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ADDRESSING UNCERTAINTY IN COST-BENEFIT ANALYSIS OF INTERGENERATIONAL INVESTMENTS – INSIGHTS FROM POLAND'S FRAMEWORK

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Purpose: The study identifies key shortcomings in how uncertainty is incorporated into Cost-Benefit Analysis (CBA) for intergenerational investments in Poland and puts forward recommendations for improving the regulatory project evaluation framework.
Design/methodology/approach: The paper draws the Polish framework limitations and improvement recommendations by critically reviewing relevant literature, including empirical studies, the CBA regulatory framework in Poland, and internationally recognized best practices, particularly from the US and UK.
Findings: The current evaluation framework in Poland lacks sufficient empirical grounding and relies heavily on EU CBA guidelines, which inadequately address intergenerational uncertainty. National guidelines should specifically recognize the limitations of standard risk assessment methods for intergenerational issues, recommend approaches such as real options analysis, define normative principles that reflect intergenerational ethical concerns, and adopt declining discount rates to better account for long-term uncertainty.
Research limitations/implications: The study primarily focused on the Polish framework, particularly concerning good practices in the US and UK evaluation guidelines. Including perspectives from additional countries—both in terms of regulatory contexts and case study–based research—would deepen understanding of intergenerational equity and uncertainty role in project evaluation.
Practical implications: The findings provide practical guidance for decision-making on intergenerational investments in areas such as climate change and nuclear energy, benefiting policymakers and investors.
Social implications: Adopting the recommendation would improve the quality of investment decisions and the efficiency of public spending, contributing to greater social welfare for both current and future generations.
Originality/value: Intergenerational uncertainty has not yet been addressed in Poland's CBA regulatory framework. This paper offers recommendations with the potential to advance the research and policy-making in sectors like climate change and nuclear energy, central to achieving the EU's climate neutrality goals.
Keywords: intergenerational investment, cost-benefit analysis, uncertainty, Poland.
Category of the paper: conceptual paper, viewpoint.

1. Introduction

Poland, one of Europe's most coal-dependent countries, faces a transition challenge to meet climate goals. Despite commitments drawn in Poland's Energy Policy 2040 (Polityka Energetyczna Polski Do Roku 2040, 2021), the country struggles with a project implementation due to climate-resilient infrastructure gap, reliance on coal, and lack of readiness for large-scale renewable or nuclear alternatives (Mrozowska et al., 2021). Substantial investments are needed, particularly to tackle climate change, as to date, climate change mitigation efforts are limited (Kundzewicz, Matczak, 2012). Transitioning from coal to cleaner sources faces a substantial challenge as well, particularly regarding nuclear energy infrastructure (Gierszewski et al., 2021).

Such investments require particular attention in their evaluation, as their life span exceeds that of the currently living generation. These projects can be defined as intergenerational investments, with impacts extending beyond a single generation (30-40 years) (Foltyn-Zarychta, 2018). These investments typically fall into the category of public projects, as a large part of their effects – such as reducing greenhouse gas emissions – have public good characteristics and therefore are not traded efficiently on markets. Relying solely on financial evaluation based on market prices can therefore lead to suboptimal decisions in terms of social welfare maximization. This calls for expanding financial appraisal into economic appraisal, specifically cost-benefit analysis (CBA), where shadow prices are used instead of market prices for estimating the true value of benefits and costs for society (Boardman et al., 2018; Dasgupta, Pearce, 1972; Zerbe, Bellas, 2006).

However, the long-time frame combined with environmental impacts creates a substantial level of uncertainty that must be addressed during the evaluation of such projects (Hartzell-Nichols, 2012; Pindyck, 2000). Moreover, ethical concerns arise, as the recipients of the investment's future impacts are unable to participate in the decision-making process. (Piacquadio, 2020; Randall, 2020; Taebi, 2012).

The prevailing practice of public project evaluation in Poland relies heavily on EU guidelines. However, both the general risk assessment procedure and the intergenerational perspective regarding – particularly climate change and energy sectoral characteristics – appear to be insufficiently addressed, both concerning regulations and guidelines, and empirical research studies devoted to Poland. Although EU CBA guidelines (European Commission, 2021; European Commission, 2015) offer some tools for dealing with uncertainty in project appraisal procedures, such as sensitivity analysis or expected Net Present Value (NPV), these approaches are vulnerable to several limitations specific to intergenerational investments.

This limited empirical evidence, coupled with a weak country-specific regulatory framework, creates a pivotal research gap, with potentially crucial practical and social implications, as Poland faces substantial investment needs regarding intergenerational investments.

At the same time, recent advances in some of the countries leading in CBA frameworks developments, such as the US and the UK, have increasingly recognized the importance of intergenerational risk and uncertainty in climate and energy project appraisals. In the US, the Environmental Protection Agency's (EPA) guidelines address the issues of environmental justice and intergenerational transfers, including social discount rate recommendations (EPA, 2024). The UK's HM Treasury Green Book introduces declining discount rates and explicit treatment of uncertainty to better reflect intergenerational equity (HM Treasury, 2022).

Thus, the paper aims to answer the following question: What are the main shortcomings in incorporating uncertainty into CBA for intergenerational investments in Poland? The purpose of the study is to propose recommendations for improving the regulatory evaluation framework.

The novelty of the research stems from investigating the uncertainty in the intergenerational context in Poland's CBA framework, which – to the best of author's knowledge – was not addressed distinctively in the capital budgeting literature in Poland so far. The results, particularly the recommendations addressing the deficiencies of the existing framework, hold significance for the research and policy-making in sectors such as climate change and nuclear energy, central to achieving the EU's climate neutrality goals.

The methods of investigation in the paper employ a critical review of relevant literature, including CBA empirical studies for Poland, and the Polish regulatory framework consisting of CBA's guidelines for project evaluation and legal acts addressing CBA. A comparative analysis of country developments and internationally recognized best practices from the US and UK is performed concerning intergenerational uncertainty's economic and ethical dimensions to generalize findings into policy recommendations.

The paper begins by introducing various concepts of uncertainty in project evaluation, then moves on to discuss the key uncertainty issues related to intergenerational investments. Next, a critical analysis of how the CBA framework in Poland addresses uncertainty is presented, followed by suggestions for methodological improvements based on international experiences. The paper concludes with a summary of the main findings and the study's limitations.

2. Uncertainty in project evaluation

Risk and uncertainty are complex issues. For project evaluation, both concepts need careful clarification. In economics, the concept of risk is separated from uncertainty. Risk can be defined as randomness with knowable probabilities, while uncertainty – as randomness with unknown probabilities (Knight, 1921).

Riesch highlights three dimensions of uncertainty (Riesch, 2013):

- location – where the uncertainty is located: the parameters, outcomes, probabilities, the model, or input data,
- level – the level of uncertainty, ranging from classically defined risk with known states and probabilities to total ignorance,
- nature – the source of uncertainty, subdivided into epistemic and ontological. Epistemic uncertainty refers to systematic uncertainty, where some facts could theoretically be known but remain uncertain due to, for example, a lack of precision in data observations. Ontological uncertainty, on the other hand, refers to a state of insufficient knowledge, often described as "unknown unknowns".

Spash distinguishes between weak and strong uncertainty. The former is further divided into weak objective uncertainty, which aligns with the concept of risk in economics, and weak subjective uncertainty, where only outcomes are known and probabilities are assessed based on human preferences. Strong uncertainty includes partial ignorance, where outcomes are unknown, and "indeterminacy," where outcomes are unpredictable (Spash, 2020).

Distinguishing between the known and unknown future, Stirling proposes dividing both facets of uncertainty – outcomes and probabilities – into "problematic" and "unproblematic" categories, based on the level of knowledge. When both areas are unproblematic, a decision-maker faces a situation of risk. When probabilities are known but outcomes are not, the situation is described as "ambiguity". Conversely, when outcomes are known but probabilities are problematic, the situation is characterized by "uncertainty". Finally, "ignorance" arises when there is poor knowledge of both outcomes and probabilities (Stirling, 2007).

Fusari interprets "true" or "radical uncertainty" as a form of uncertainty that cannot be represented by probability distributions. It results from the limits of human knowledge and is therefore an expression of human ignorance. Radical uncertainty may be reduced through the acquisition of information; on the other hand, it is also stimulated by social change and innovation. The author further explains that uncertainty reflects the degree of ignorance, as it is not driven by people's expectations, but rather by the instability and/or illusory nature of those expectations. (Fusari, 2013). Alchian states that "uncertainty arises from at least two sources: imperfect foresight and human inability to solve complex problems containing a host of variables even when an optimum is definable" (Alchian, 1950). This form of ignorance—referred to as "unknown unknowns"—is also defined as radical uncertainty. In the economics literature, it is discussed in the context of the impossibility of foreseeing the outcomes of scientific and technological developments, as well as long-term, intergenerational investments such as those related to climate change or nuclear energy.

Finally, some researchers highlight the ethical dimension of uncertainty, which—although often implicitly included in evaluation processes—should be addressed explicitly and separately. Taebi et al. argue that, in addition to scientific and technical uncertainties, normative uncertainties also play a pivotal role in risk-related decision-making. They define normative uncertainties as situations in which all available options are, to some extent, morally indefensible (Taebi et al., 2020).

3. Uncertainty in intergenerational time frame – economics and ethics perspective

Referring to the distinction between weak and strong uncertainty, as well as to its location, level, and nature, intergenerational investments inevitably tend toward the highest levels of ontological uncertainty. Numerous sources in the literature emphasize the particularly high levels of uncertainty associated with long-term investments. Hartzell-Nichols points out that, given the temporal scale alone, uncertainty is almost always present (Hartzell-Nichols, 2012). This issue is especially prominent in discussions on climate change and nuclear energy investments, due to their extremely long life cycles and the substantial risks they pose to future generations.

In case of climate change, the impacts of greenhouse gas (GHG) emissions will extend to many generations (and multiple locations globally), inflicting long-term risks like flooding, high temperature, and other weather extremes. IPCC defines it as burdened with deep or severe uncertainty (IPCC, 2014). Barro argues that uncertainty is central to the analysis of climate change (Barro, 2015). Technological developments, including innovations, ecosystem response, future prices of fossil fuels, occurrence of extreme events such as cyclones, sea-level rise and droughts all create substantial sources of uncertainty (Fleurbaey et al., 2019; Jansen, Bakker, 2006).

Gardiner, in the context of climate change, distinguishes between scientific uncertainty and the uncertainty rooted in economic models used for long-term projections. He emphasizes that scientific models – used to predict global warming, CO_2 emissions, and related phenomena - often assign probabilities, which frames the situation as one of risk and shifts the focus toward a quantitative perspective. In contrast, economic models frequently fail to meet the strict requirements necessary for the meaningful assignment of probabilities (Gardiner, 2004).

Nuclear energy investments also involve extremely long time horizons and are associated with high levels of uncertainty. Nuclear waste remains hazardous for hundreds of years, posing serious health risks due to potential radiation contamination (Kermisch, Taebi, 2017; Medvecky, 2012). In some disposal methods, the waste remains radiotoxic for several thousand years. This raises questions about long-term safety and future uncertainties – such as the potential need to recover radioactive material for its residual energy value – which are particularly relevant when deciding between permanently sealed and open repositories (Taebi, Kloosterman, 2008).

Finally, what further complicates the analysis is that, when the time frame becomes multi-generational, decision-makers face incorporating ethical considerations regarding future generations when dealing with uncertainty (Friederich, Boudry, 2022). Numerous studies argue that a utilitarian-consequentialist perspective is too narrow to adequately address intergenerational ethics (Fleurbaey et al., 2019; Taebi et al., 2020). The stochastic nature of future outcomes may be addressed through various approaches—for example, by expecting less sacrifice from "hard-luck" generations and proportionally more from more "fortunate" ones (Randall, 2020).

The extant literature focuses heavily on equity and justice, given that future beneficiaries are not yet present and cannot participate in current decision-making. The standard approach to intergenerational risk draws on Harsanyi's (1955) sum of expected utilities in which generations are treated analogously to individuals (Fleurbaey et al., 2019; Harsanyi, 1955). However, as (Piacquadio, 2020) argues, this model is ill-suited to long-term risks, as it treats generations anonymously, even though each generation may be affected differently – thus raising questions of intergenerational equity.

Moreover, the non-identity problem arises: any decision made today may influence who will be born in the future and in what number, meaning that the decision will ultimately affect different individuals than would have existed had the decision not been made (Gardiner, 2006). As Hartzell-Nichols further points out, even if these future individuals are adversely affected, they arguably cannot blame the decision-makers, since the decision itself was a necessary condition for their existence and identity (Hartzell-Nichols, 2012).

For intergenerational investments - particularly where environmental changes are involved – uncertainty is often defined in relation to the potential harm that may be inflicted on the environment in the future. Hartzell-Nichols notes that risks "are generally understood as threats or possibilities of harm, though colloquially the term is sometimes applied to both negative and positive possibilities". She further emphasizes that harm is "a relatively specific moral concept which requires that a person have suffered serious interference with one or more interests that are particularly important to human well-being, and which for that reason are appropriately designated as fundamental" (Hartzell-Nichols, 2012).

The ethical doubts are also raised concerning valuation. Fleurbaey et al. argue while some impacts may be relatively easy to monetize, assigning monetary value to factors such as human health, mortality risk, or the extinction of species is far more ethically complex (Fleurbaey et al., 2019). It is also important to add that valuing non-market impacts experienced by unborn generations suffers from an inherent flaw arising from a lack of knowledge about future people's preferences.

To summarize, in the context of long-term, intergenerational investments, the most appropriate term to describe the prevailing conditions is radical uncertainty. This is due to the lack of information about factors such as ecosystem responses (including the location, extent, and severity of potential threats) and the preferences of future generations. While certain cases may involve more conventional forms of uncertainty or even quantifiable risk, these remain relatively limited in number.

4. Uncertainty in Cost-Benefit Analysis – Poland's framework

The results of the critical review of relevant CBA literature, such as empirical studies for Poland, and the Polish regulatory framework consisting of CBA's guidelines for project evaluation and legal acts addressing CBA shows that public project evaluation in Poland rests mainly on Cost-Benefit Analysis (CBA) guidelines provided by the European Commission for Cohesion Policy (European Commission, 2008, 2015, 2021).

Separate guidelines have been developed only for the transport sector, although they are still based on the general EU guidelines and aim to facilitate access to EU funding ('Niebieskie Księgi 2021-2027', 2023; CUPT, 2016). In the area of legal regulations, the Regulation of the Minister of Climate and Environment also provides a very general framework for the appraisal procedure of energy investments. It primarily aims to implement the European Directive on energy efficiency and, while it addresses the basic structure of CBA, it does not specify detailed requirements, particularly regarding risk, uncertainty, or intergenerational issues (*Rozporządzenie w sprawie określenia metod...*, 2022). It is worth mentioning that local government units were also required to prepare CBAs for electromobility transport investments starting in 2018, according to the 2018 Act on Electromobility and Alternative Fuels. However, a recent amendment to the Act repealed this obligation (*Ustawa o Elektromobilności i Paliwach Alternatywnych*, 2025).

CBA research for Poland is also limited, including several monographs such as (Becla et al., 2012; Drobniak, 2002; Foltyn-Zarychta, 2008; Ligus, 2009); nonetheless, they address uncertainty in the intergenerational context within a very limited scope, except for (Foltyn-Zarychta, 2018) focusing on ethical components in intergenerational investments evaluation; however discussion devoted to risk is not supported by empirical data. Case study research on CBA in Poland is also scarce. Several papers apply CBA for renewable energy sources investment case studies, but they do not address the risk (Włoch, Lazarek-Janowska, 2024b, 2024a). Kołacińska & Sasin investigate nuclear sources of energy, raising the issue of long-term and substantial decommissioning costs; however, risk considerations are limited (Kołacińska, Sasin, 2016). To some extent, uncertainty is discussed in (Halytsia et al., 2022). The authors take into account sensitivity analysis as well as expert assessment of socio-economic risks related to the managed aquifer recharge system in Poland, using a qualitative approach, though they do not explicitly refer to the long-term dimension. None of the papers mentioned addresses the issue of intergenerational uncertainty considerations.

Therefore, taking into account the limited number of Poland-tailored guidelines and regulations, as well as the scarce practical evidence on CBA – particularly within the scope of long-term, intergenerational projects – it can be assumed that the general practice for project evaluation in Poland follows EU Cohesion Policy guidelines (European Commission, 2015, 2021; CUPT, 2016).

Analyzing the guidelines, two major limitations regarding the inclusion of uncertainty in project appraisal can be identified. The first weakness concerns the procedures for addressing risk and uncertainty, particularly the quantitative and qualitative approaches to risk assessment. The second significant flaw stems from the previously mentioned scarcity of country-specific regulations and guidance on the evaluation of intergenerational investments, such as those related to climate change or energy. Relying solely on the EU's main guideline, the *Vademecum*, leaves decision-makers insufficiently informed.

Regarding the risk assessment procedure, it is worth noting that although the current guidelines (European Commision, 2021) do not explicitly discuss risk assessment – or other aspects such as demand forecasting or legal considerations – these elements remain important for project appraisal. The authors of the guidelines assumed these aspects could be addressed within the broader project preparation framework, and the *Vademecum* refers readers to relevant supplementary guidance documents.

Therefore, for a standard risk assessment procedure, readers may refer, for example, to previous guidelines (European Commision, 2021; Florio, 2014). This approach is recommended for strategic projects, while smaller projects undergo a simplified CBA, in which only major risks are identified and briefly described.

In the case of large projects, risk assessment consists of several phases:

- sensitivity analysis – identifying key parameters that could significantly alter the project's outcome (e.g., turning a positive NPV into a negative one),
- qualitative risk analysis – identifying adverse events the investment may face, along with a description of their causes, effects, and levels of probabilities,
- probabilistic risk analysis – assessing the probability distribution of the project's FRR or NPV using techniques such as scenario analysis or the Monte Carlo method,
- risk prevention and mitigation – defining a risk management plan for project implementation, including measures to mitigate and prevent key risks.

The assessment procedure—regarding the intergenerational dimension of uncertainty—may be considered partly sufficient, given the recommendation to apply both quantitative and qualitative approaches. It must be emphasized, however, that all of the above methods operate under the concept of weak uncertainty, relying on probability distributions in the assessment.

The main advantage of such approaches is that they provide clear decision-making information, such as the expected NPV based on alternative scenarios. Sensitivity analysis, as well as qualitative analysis supported by risk prevention and mitigation strategies, offer a description of key factors that can significantly influence the effectiveness of the project.

However, in situations where a project is subject to strong uncertainty, these conventional approaches are largely inadequate

One of the key limitations in appropriately capturing uncertainty in CBA is the strong tendency to rely on monetary measures and quantification. Even in cases where strong uncertainty is undoubtedly present—such as greenhouse gas (GHG) impacts on global climate change—there remains a prevailing inclination to model probability distributions of impacts to enable the application of quantitative methods. For instance, probability distributions for uncertain inputs can be modeled to generate a probability distribution of the outcome, such as the net present value (NPV) (Krutilla, Graham, 2023).

However, it is important to emphasize that the process of deriving such distributions is often prone to imprecision. The CBA guidelines (European Commision, 2015) suggest that probability distributions may be based on various sources, such as experimental data, analogous cases (both of which may be unavailable under strong uncertainty), or expert opinions. The guidelines further state that, in cases of doubt, a triangular distribution may be applied and can provide "an important improvement in the understanding of the project's strengths and weaknesses as compared with the base case". Still, when strong uncertainty surrounds long-term scenarios, this approach may lead to significant oversimplification. Jansen and Bakker (2006), for example, found that when applying triangular distributions to estimate climate change externalities, the resulting uncertainty was greater than the estimated value of the externality itself (Jansen, Bakker, 2006). In addition to these methodological concerns, quantitative risk assessment may be particularly problematic in the Polish context. Even in the transportation sector – where guidelines are relatively well developed – recommendations often favor a qualitative approach due to the lack of national databases that would enable robust quantitative risk analyses for infrastructure projects.

While qualitative risk assessment partly addresses the problem of radical uncertainty, it still reflects the CBA's inherent tendency to quantify all information. In qualitative assessments, risk matrices typically estimate the level of probability using a dual description: a qualitative label (e.g., *very unlikely*) and a corresponding quantitative range (e.g., 0-10% probability). Additionally, this approach relies on expert judgment. While expert input can serve as a valuable mechanism for obtaining insights in the face of limited knowledge, it must be emphasized that – even when structured – these estimates are ultimately based on opinion rather than empirical evidence (Cooke, 2013; Kunreuther et al., 2014).

Regarding the second major shortcoming—addressing intergenerational issues—the *Vademecum* refers to topics such as climate change and energy in a limited manner. It briefly discusses climate risk assessment, suggesting that significant risks should be managed and reduced to an acceptable level through adaptation measures or by deferring implementation. However, it does not explicitly reference general guiding principles—such as the precautionary principle—which could further support decisions to adopt more extensive adaptation actions, postpone, or even abandon the investment.

Additionally, although the *Vademecum* refers to the flexibility of delaying investments, it fails to mention explicitly the real options approach, which could help decision-makers explore alternative approaches to dealing with uncertainty. Furthermore, the document does not address the concept of irreversibility – one of the crucial dimensions of long-term investments. Irreversibility can pertain to both social and environmental domains. In the social context, it refers to situations where an investment turns out to be suboptimal (i.e., a better project should have been selected), but disinvestment is not feasible, leading to sunk costs and reduced social welfare. In the environmental context, irreversibility involves the permanent loss or degradation of environmental goods, such as biodiversity. Neither the current CBA guidelines nor earlier versions acknowledge this issue.

Moreover, the guidelines lack normative principles for long-term decision-making. Given that CBA is grounded in a utilitarian framework based on an additive social welfare function, incorporating alternative ethical perspectives – such as deontological approaches – could significantly enhance the ethical quality of decisions under extreme long-term uncertainty (Taebi et al., 2020). However, the *Vademecum* narrows the discussion of intergenerational equity to the issue of long-term discounting. While it recommends applying declining social discount rates for projects with long-term impacts, it fails to provide specific values. It is also worth noting that Poland still lacks official, country-specific guidelines for both intragenerational and intergenerational discounting, although relevant research exists (Buła, Foltyn-Zarychta, 2023; Catalano, Pancotti, 2022; Florio, Sirtori, 2013). For instance, Buła, Foltyn-Zarychta propose rates that decline from approximately 4.06% (for time horizons up to 30 years) to 0.67% (for horizons longer than 300 years).

Finally, the issue of uncertainty in the valuation of non-market impacts receives insufficient attention in the guidelines. It is mentioned only briefly in the waste management section, despite being relevant to many other sectors – such as energy. In current practice, air pollutants and greenhouse gas (GHG) emissions are often monetized not only in CBAs but also in cost-effectiveness analyses used for comparing project alternatives (European Commission, 2021). However, as noted by Cygler & Dubel and Jones et al., the valuation of environmental impacts remains highly uncertain, even for short-term projects (Cygler, Dubel, 2022; Jones et al., 2014). For intergenerational investments, these challenges are even greater, as impacts may unfold over extremely long time horizons. In such cases, valuation becomes difficult not only because of uncertainty surrounding the efficient price of public goods but also due to the fundamental lack of knowledge of the preferences of future generations.

5. Directions to improve the uncertainty assessment process for intergenerational public projects in Poland

Considering recommendations for improving how uncertainty is addressed in public project evaluation, the primary direction for progress in Poland is to expand the existing empirical research base beyond the mandatory EU guidelines. Uncertainty can be better incorporated through alternative methods the literature highlights: real options analysis, which captures the value of flexibility by allowing project implementation to be delayed until new information becomes available (Pindyck, 2000); or game theory, which can be employed to operationalize the precautionary principle by minimizing potential adverse outcomes (Kunreuther et al., 2014). Alternative approaches recommended for dealing with radical uncertainty may also employ Robust-Decision Making, which engages stakeholders and iteratively identifies new strategies that perform well across many scenarios and allow to prioritize flexibility and resilience over precision, which is particularly helpful for cases where we expect to gain knowledge over the investment life-time (Dittrich et al., 2016; Robust Decision Making, 2025) or scenario planning, a semi-quantitative approach that develops plausible scenarios and investigates what impact would they have via stakeholders assessment (Alizadeh et al., 2016; Amer et al., 2013).

Other useful frameworks include sets of guiding principles – such as the precautionary principle itself, minimax and maximin rules, and the safe minimum standard principle (Krutilla, Graham, 2023; Turner, 2007). A meta-analysis of evidence-based studies would provide a critical foundation for further development, serving both as a learning tool and a valuable data source – for instance, to support benefit transfer methods used in non-market valuation of project impacts (Krutilla, Graham, 2023). Given the current scarcity of case-study–based CBA research in Poland, expanding this empirical base would enhance uncertainty-related methods not only for intergenerational investments but also for broader CBA applications.

Independently of broader methodological advancements, a range of country-specific regulations, guidelines, and reports should be developed to support decision-makers in the evaluation and project selection processes.

With respect to international guidelines for project appraisal, several methodological recommendations can be drawn from the experiences of other countries – particularly the United Kingdom and the United States – which have advanced the use of Cost-Benefit Analysis to support decision-making in environmental and climate-related domains.

The UK's *Green Book* (HM Treasury, 2022) introduces several approaches that are also present in earlier EU guidelines (European Commission, 2015), such as sensitivity analysis, scenario analysis, and the Monte Carlo simulation. As alternatives to standard risk assessment, the *Green Book* further recommends the use of decision trees and real options analysis. However, it places stronger emphasis on qualitative and intergenerational aspects as well as on the issue of irreversibility compared to the EU guidance. Notably, the UK Treasury provides supplementary guidance on intergenerational wealth transfers and social discounting. This includes a recommended declining schedule for the Social Discount Rate over time and specific advice on accounting for the impacts of climate change. The guidance highlights the use of real options analysis in situations involving potentially irreversible impacts, stressing the option value of sequential decision-making and the role of increasing information over time. In addressing the qualitative challenges of uncertainty assessment, the *Green Book* explicitly references the precautionary principle as a good practice for risk mitigation. This includes the possibility of abandoning a project – even in cases where knowledge about its effects and associated probabilities is limited.

The U.S. guidelines prepared by the Environmental Protection Agency (EPA, 2024) – considered among the most appropriate for evaluating intergenerational investments for the US - recommend several methods to address uncertainty. These include sensitivity analysis, especially concerning key assumptions, and probabilistic approaches such as Monte Carlo analysis, which help account for analytical uncertainty and variability. However, the guidelines also highlight the limitations of such methods, particularly the frequent lack of sufficient data to characterize probability distributions reliably. When decision-makers face incomplete information, the guidelines suggest alternative tools, including break-even analysis, which is especially useful when a single key parameter is unknown. In such cases, the analysis can determine the threshold (or "switch point") of this missing value at which a project remains viable. The guidelines also advocate the use of expert elicitation, noting that uncertainty can be also reflected in the dispersion of expert opinions. In addition, the EPA recommends considering option value as a valuable tool in cases of irreversible decisions and situations where uncertainty may diminish as more information becomes available over time. While the selection of analytical tools does not differ significantly from those in EU guidance, the U.S. guidelines place greater emphasis on addressing uncertainty and knowledge gaps explicitly. Importantly, the EPA guidelines also give greater attention to intergenerational considerations than *Vademecum*. A dedicated section addresses environmental justice, while intergenerational equity is primarily covered in the context of discounting. The guidelines review various approaches to estimating social discount rates for long-term investments, advocating the use of declining discount rates or explicitly incorporating uncertainty in future consumption growth rates – one of key components in social discount rate calculations.

To summarize, drawing upon international experience – and in addition to developing a stronger body of evidence-based research – Poland could benefit from creating country-specific guidelines that explicitly address the following areas:

- The limitations of standard risk and uncertainty assessment procedures when applied to intergenerational timeframes and sector-specific contexts.
- Theoretical approaches designed to address limited information in long-term evaluations, such as the real options approach or robust-decision making, which can support decision-making under uncertainty.

- Qualitative, prescriptive principles – particularly the precautionary principle – which can help balance the heavily quantitative nature of CBA. Such principles also allow for the inclusion of normative preferences related to intergenerational equity and environmental justice, for example, prioritarianism-based principles, which could be translated into decision rules such as giving priority to projects that help to avoid catastrophic risks to future generations which over other investments.
- Declining discount rates, which reduce the social discount rate over time, thereby increasing the present value of long-term effects. This implicitly promotes more equal treatment of future generations compared to exponential discounting – which is the approach adopted currently. The new approach would be particularly relevant for projects posing significant long-term threats, such as radioactive waste management.

6. Summary

In the context of project evaluation, it is essential to distinguish between risk and uncertainty. When a situation is characterized by a lack of sufficient knowledge – whether descriptive or prescriptive (ethical) – substantial uncertainty arises. This type of uncertainty requires particular attention, especially in decisions involving intergenerational impacts. Projects such as those addressing climate change or nuclear energy are subject to strong uncertainty due to extended timeframes, unpredictable ecosystem responses, and unknown effects on social welfare of future generations. These conditions limit the applicability of quantitative methods, as both outcomes and probabilities are often inadequately and imprecisely defined.

Poland's current framework for evaluating such projects - relying primarily on EU Cost-Benefit Analysis guidelines and lacking a robust base of empirical, case study–driven research – offers predominantly quantitative tools geared toward risk rather than uncertainty evaluation. These tools are insufficient for addressing the deeper complexities of uncertainty. Oversimplification often results from assigning probabilities in contexts of limited knowledge or relying heavily on expert opinion in the absence of empirical data. Additionally, current guidelines pay insufficient attention to issues such as irreversibility, flexibility in the project lifecycle, and ethical concerns related to intergenerational justice.

Drawing on international best practices, particularly from the United States and the United Kingdom, Poland could develop national guidelines that explicitly:

- Acknowledge the limitations of standard risk assessment approaches when applied to intergenerational investments.
- Promote the use of uncertainty-aware methods such as real options.

- Emphasize normative principles that reflect ethical considerations across generations and complement quantitative analysis.
- Adopt declining discount rates to ensure fairer treatment of future generations.

These recommendations offer practical guidance for improving decision-making for intergenerational public investments in high-uncertainty sectors such as climate change mitigation and adaptation and nuclear energy. Implementing such measures could enhance the quality of public investment decisions, increase the efficiency of public spending, and contribute more effectively to maximizing social welfare across generations.

However, the study has its limitations. While this research focused on best practices in the U.S. and U.K., expanding the analysis to include other countries would offer a broader comparative perspective. For instance, France also has adopted a declining discount rate scheme for investment horizons exceeding 30 years (Attema et al., 2018). A systematic review of CBA case studies from multiple countries would help clarify how intergenerational considerations—including equity, uncertainty, irreversibility, and epistemic limitations—are taken into account.

It must also be acknowledged that certain challenges, such as uncertainty over future generations' preferences, are inherently irresolvable. Nonetheless, by drawing on international best practices and expanding the empirical research base, Poland has the opportunity to gradually build a more robust and ethically sound project evaluation framework.

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