Environmental Valuation as an Economic Solution for Environmental Sustainability

Ewan W. Fennema

Campus Fryslân, Leeuwarden (Netherlands)

Bachelor's Thesis - Global Responsibility and Leadership

Dr A. (Arianna) Rotulo

06/06/2025

Acknowledgements

I would like to express my gratitude to Dr. Arianna Rotulo for her invaluable supervision and support throughout the writing of this thesis. I am also thankful to Calvin Grad for his thoughtful feedback and guidance at several key milestones during this project.

Abstract

While environmental degradation and unsustainable resource use continue to worsen, this thesis examines whether environmental valuation can serve as an economic solution for environmental sustainability. Using a systematic literature review guided by the PRISMA-EcoEvo framework, the study evaluates how tools such as shadow pricing, carbon credits, biodiversity offsets, and ecosystem valuation can contribute to environmental sustainability. The findings indicate that environmental valuation can enhance policy efficiency by internalizing externalities, promoting conservation incentives, and guiding resource allocation. Shadow pricing, in particular, proved to be the most effective tool in aligning economic decisions with environmental goals. However, limitations such as methodological inconsistencies, ethical concerns about monetizing nature, and the effectiveness of methods limit their reliability. For instance, carbon offsetting and biodiversity credits often lack credibility and produce delayed or insufficient ecological benefits. While environmental valuation does not fully capture the intrinsic value of nature, it remains an influential tool for integrating sustainability into economic and policy frameworks. Ultimately, the study concludes that environmental valuation, despite its limitations, can be considered an economic solution for achieving environmental sustainability.

Keywords

Environmental valuation, Environmental sustainability, Shadow pricing, Biodiversity offsets, Carbon credits, Ecosystem valuation, Natural resources, Environmental economics, Sustainable development, Environmental decision-making

Table of contents

Introduction

According to the United Nations, global natural resource consumption is expected to rise 60% by 2060, which has severe consequences for biodiversity loss, water stress, air pollution, and climate change (World Economic Forum, 2024). The World Economic Forum's Global Risk Report (2024) identified 'Disrupted supply chains for critical goods and resources' as the top risk in the world. This evidence demonstrates the need for recognizing the value of nature, as it is "crucial in fostering healthy and resilient ecosystems, essential for ensuring the long-term well-being of the ever-growing global population" (AccountingInsights Team, 2024). For example, ecosystem services like water purification and carbon sequestration are valued at $125 trillion per year but remain excluded from policy decisions (Costanza et al., 2014). "It is imperative to understand and acknowledge the true worth of natural assets, not only for the present but also for future generations" (AccountingInsights Team, 2024).

Natural resources are finite, as they depend on the Earth's capability to renew them. For instance, forests can regenerate and provide harvestable products, while natural resources like oil are non-renewable (EEA, n.d.). Currently, humans are exploiting natural resources beyond their regenerative capacities (EEA, n.d.). Global material extraction grew from 27 billion tons in 1970 to 92 billion tons in 2017, exceeding the biocapacity by 75% (UNEP, 2019). The overexploitation of natural resources leads to the degradation of ecosystems, resulting in a loss of biodiversity and the collapse of essential ecosystem services (Lampert, 2019). For example, there has been a 68% decline in global wildlife populations since the 1970s (WWF, 2020). These consequences could be irreversible, affecting availability and access to clean water, air, and fertile soil (Lampert, 2019). Furthermore, exploitation of natural resources such as deforestation reduces carbon sequestration capacity and increases the amount of greenhouse gases in the atmosphere (OECD, 2022). This will further heat the climate and can result in multiple tipping points, for example, in the melting of the polar regions, where sea ice, which plays an important role in regulating our climate, has declined by 13% per decade since 1979 (OECD, 2022; NOAA, 2022).

The Economics of Ecosystems and Biodiversity for National and International Policy Makers (TEEB) released a statement that is aimed at pushing governments to adopt better accounting systems to measure the true value of natural resources and take into consideration this value when making governmental decisions (WWF, 2009). Traditionally, governments and corporations frequently neglected the value of natural resources and environmental degradation in their cost-benefit analyses, resulting in market failures such as the overexploitation of natural resources (Pearce & Turner, 1991). Additionally, accounting and reporting of the true value of natural resources were rare, as institutions often did not consider the ecological risks in investment decisions (Heal, 2001). Ecosystem services, which provide natural resources, such as water purification, carbon sequestration, and soil fertility, were often treated as free goods and separate from economic decision making (Costanza et al., 1997).

Simultaneously, the WWF outlines that investing in the conservation, management, and restoration of ecosystems will provide a larger economic return than the unchecked use of natural resources would bring (WWF, 2009). This is not always obvious, as economists do not assign market prices to natural resources (U.S. Department of Agriculture, 2025). According to the United Nations Environmental Programme (2022), understanding and accounting for a wide range of nature's value is needed in policy decisions to address the biodiversity crisis and achieve sustainable development goals. This is essential, as currently, natural resources are being extracted faster than they can regenerate, with estimates indicating that humanity is using 1.75 Earths' worth of natural resources annually (Wackernagel et al., 2017).

This is partly because 73% of consumers across all countries in the European Union indicate that a product's environmental impact is important for them, but fail to act sustainably (Elmor et al., 2024). Environmental sustainability often does not even enter a consumer's mind during their decision-making process, even if they claim to care about sustainability (Elmor et al., 2024). This is because a product's attributes, such as price and quality, overshadow environmental concerns (Elmor et al., 2024). Another aspect that plays a role in consumers' decisions is that the effects of environmental degradation are not direct (Varutti, 2023). According to Varutti (2023), we often do not grieve environmental degradation and ecological loss because we have difficulty perceiving the gradual environmental changes.

In addition to consumers, businesses tend to overlook sustainability as well, which is partially due to the fact that some natural resources, such as clean air, are non-excludable and non-rivalrous (Hardin, 1968). People use these goods without bearing the direct costs (Elmor et al., 2024). A further explanation for why environmental values and costs are overlooked is the emphasis on immediate returns. Businesses often prioritize short-term profitability over long-term sustainability (Sheetal, 2024). The pursuit of immediate financial gains is crucial for businesses due to shareholder pressure and market competition, even when unsustainable practices result in higher costs over time (Bansal & DesJardine, 2014; Eccles et al., 2014). More sustainable practices ensure resource availability and resilience for future generations, but do not guarantee the immediate profits (WCED, 1987). Alternative economic mechanisms are essential for addressing the limitations of traditional market systems in capturing the full costs and benefits associated with economic activities or policies (Fund, 1988).

The topic of environmental economics emerged around the 1960s, together with the budding environmental movement (Kerr, 2024). The "budding environmental movement" refers to the widespread action around environmental concerns in the 1960s and 1970s (I. Origins of the Environmental Movement · Exhibit · Give Earth A Chance: Environmental Activism in Michigan, n.d.). Beforehand, economic benefit was defined as 'material well-being', which was simply done to justify several environmentally harmful projects (Kerr, 2024). Around the 1970s, economists started to better understand the tradeoffs of development projects, including the environmental costs (Kerr, 2024).
This initiated the development different theoretical frameworks, for example, the National Environmental Policy Act (NEPA) that came in 1970, which required agencies to asses their environmental impacts on their actions prior to their decisions (US EPA, 2025).

Two years later, in 1972, the Stockholm Conference became the first major international conference on the environment, which resulted in the creation of the United Nations Environment Programme (UNEP) (United Nations, n.d.). This conference started to create "the link between economic growth, the pollution of the air, water, and oceans, and the well-being of people around the world"

(United Nations, n.d.). In 1987, the Brundtland report was published, introducing the term ‘sustainable development’ (Kono, 2014). “The idea of sustainable development emphasized lifting those at the base of the economic pyramid to higher standards of living. Simultaneously, it prompted decoupling environmental degradation and economic prosperity” (Kono, 2014). Following up on this event, in 1992, the United Nations Conference on Environment and Development (UNCED) was held in Rio de Janeiro. This conference established the UNFCCC (United Nations Framework Convention on Climate Change), as well as the Rio Declaration and Agenda 21 (United Nations, n.d.). Agenda 21 is a non-binding action plan for sustainable development focusing on many different dimensions, including economic dimensions and management of resources for development (United Nations, n.d.). The Rio Declaration includes 27 guiding principles for sustainable development, including the ‘polluter pays principle’, where those responsible for environmental damage are assigned responsibility for it (United Nations, n.d.). And the UNFCCC, which is a treaty aimed at stabilizing greenhouse gas concentrations (United Nations, n.d.).

An important achievement for environmental sustainability happened in 1997, when the Kyoto Protocol was launched. The Kyoto Protocol became the first international treaty to set legally binding emission reduction targets for developing countries (UNFCCC, n.d.). The Kyoto protocol also introduced the concept of emissions trading, with carbon credits and offsets. Article 12 of the Kyoto Protocol established the CDM, which allows industrialized countries to implement emission-reduction projects in developing countries in exchange for certified emission reduction credits (CER), to achieve their Kyoto targets (UNFCC, n.d.). Additionally, Article 17 in the Kyoto Protocol allows countries with a surplus in emission allowances to sell these emission permits to countries that exceed emission targets, creating a carbon market (UNFCC, n.d.).

In 2005, the Millennium Ecosystem Assessment formalized ecosystem services and their valuation. The United Nations conducted research with over 1300 experts from 95 countries and concluded that human activities have transformed and harmed ecosystems, leading to significant biodiversity loss (Millennium Ecosystem Assessment, 2005). Furthermore, the research concluded that the valuation of these ecosystems serves multiple purposes, such as assessing their contributions, understanding incentives to manage ecosystems, and evaluating alternatives (Millennium Ecosystem Assessment, 2005).

The Economics of Ecosystems and Biodiversity Initiative (TEEB) was introduced in 2008. It was launched by the United Nations Environment Programme (UNEP) and was aimed at highlighting the economic benefits of biodiversity and the costs of biodiversity loss and ecosystem degradation (TEEB, n.d.). It focused on assigning an economic value to ecosystems so that this could be assessed during decision-making (TEEB, n.d.). One year later, in 2009, the Copenhagen Climate summit (COP 15), a non-binding accord, agreed on having to limit the global average temperature increase to no more than 2°C (Center for Climate and Energy Solutions, 2017). It became non-binding because developed countries did not agree on restrictive emissions reduction targets, as well as developing countries insisting on their rights for economic development (Center for Climate and Energy Solutions, 2017). Another major event of economic valuation happened in 2012, when the SEEA was created to present the relationship between the environment and economics (SEEA, n.d.). This system allows countries to measure the contribution of natural resources to the economy and the impact of their economic activities on the environment (SEEA, n.d.)

The Paris agreement in 2015 became the legally binding international treaty on climate change, adopted by 196 countries to limit average global warming to 2°C (The Paris Agreement | UNFCCC, n.d.). The countries involved agreed on national commitments to reduce greenhouse gas emissions, through, for example, Article 6.4, carbon crediting mechanisms, and social costs of carbon (SCC), calculating the economic cost of emitting one additional ton of C02 (Glanemann et al., 2020; Lawton, 2025). SSC calculations, as well as discount rates and long-term cost-benefit frameworks, were legitimized in the Stern review in 2006 (Stern, 2006).

These international frameworks lay the foundation for environmental economics and sustainability and their relevance in the global world (Global Environment Outlook 6, n.d.). They uphold the importance and provide the necessary information and sense of urgency to achieve environmental sustainability. Environmental valuation tools such as shadow pricing, ecosystem service valuation, biodiversity offsets, and carbon credits are instrumental in converting environmental impacts into economic terms (Rossi & Fujii-Rajani, 2024; Brander et al., 2024)

This paper will explore the implementation of these environmental valuation tools and will see whether they contribute as a solution for environmental sustainability. The research question for this paper is: Can environmental valuation be considered an economic solution for achieving environmental sustainability?

Ultimately, this research contributes to the broader discussion on sustainable economic policy by evaluating whether environmental valuation can enhance environmental decision-making and regulatory frameworks.

Literature review

Environmental valuation is “the process of putting monetary values on environmental goods and services”, which is often difficult as many natural resources do not have observed market prices (Dixon, n.d.). According to the United Nations Environmental Programme report (2022), many countries fail to assess the value of their natural resources. As a result, these countries resort to clear-cutting forests (10 million hectares per year, which is equivalent to 27 soccer fields per minute), driving 80% of terrestrial biodiversity decline (FAO & UNEP, 2022; WWF, 2022), as well as overfishing their seas (90% of global fish stocks are overexploited, causing a 39% marine biodiversity loss since 1970) (IPBES, 2019). These examples illustrate the consequences of not valuing natural resources adequately. This behaviour is destroying habitats and placing species and biodiversity at serious risk (WWF, 2009).

Environmental goods or natural resources are materials or substances that occur in nature. Examples include forests of trees, sunlight, as well as fossil fuels and minerals (Miller & Spoolman, 2016). They are used by humans for economic gain, survival, and development (Miller & Spoolman, 2016). This covers the extrinsic value of the environment: “the value it has based on its relationship with or benefits it provides to something external to itself, often humans” (White, 2013). The intrinsic value of the environment refers to “the inherent worth of nature, separate from its usefulness or economic benefits to humans” (US EPA, n.d.). Environmental valuation is often discussed from an anthropocentric perspective, meaning that only the extrinsic value is considered for human well-being (Rea & Munns, 2017). Accordingly, most environmental valuation tools, such as ecosystem service valuation and cost-benefit analysis, are based on the extrinsic value of the environment and its natural resources (Rea & Munns, 2017).

Linked to the exploitation of natural resources are environmental externalities: “the economic concept of uncompensated environmental effects of production and consumption that affect consumer utility and enterprise cost outside the market mechanism” (ESCWA, n.d.). Usually, private costs of production are lower than the social costs (EEA, n.d.). Social costs are “the full cost, including external costs imposed on society by a given activity" (EEA, n.d.). Negative externalities, like pollution or resource depletion of natural resources, can cause environmental problems, like air and water pollution, biodiversity loss, and ultimately, climate change (IISD (SAVi), 2019). These externalities result in inefficient market outcomes, showcasing the need for government intervention to internalize the external costs (IMF, 2018). This is, for example, done with the Pigouvian tax. A Pigouvian tax is "a tax on market transactions that creates a negative externality, or an additional cost, borne by individuals not directly involved in the transaction" (Tax Foundation, 2024). The Pigouvian tax is a form of environmental valuation and decreases the supply of the activity producing the negative externality (CFI, 2023).

Net present value (NPV) in environmental valuation is a financial metric used to determine the economic value of a project (Global Footprint Network, 2020). NPV "adds up revenue and expenditures over a period of time and discounts those cash flows by the cost of money (an interest rate)" (Global Footprint Network, 2020). It is a way to compare the benefits and the cost of a project, most of the time in monetary terms, over its entire lifespan (Global Footprint Network, 2020). NPV is used to determine whether a project is worth executing, by adding the environmental externalities as a cost, a project outcome can significantly change (Inter-American Development Bank, 2018).

In addition to including environmental externalities in NPV calculations, sustainability accounting refers to "incorporating social, environmental, and economic dimensions into analyzing organizational actions" (Ozili, 2021). The aim of sustainability accounting is for companies to take accountability for their resource use, considering the impact of their business on the social, environmental, and economic dimensions, while focusing on making profits (Ozili, 2021). Both NPV and sustainability accounting require environmental valuation for their assessment.

Other important terms regarding environmental valuation and environmental externalities are: The polluter pays principle (PPP), No Net Loss (NNL), and Greenwashing. The polluter pays principle is the environmental policy concept that "those who produce pollution should bear the costs of managing it to prevent damage to human health or the environment" (OECD, 2025). Moreover, No Net Loss is a conservation principle that aims to balance biodiversity losses caused by development with equivalent biodiversity gains elsewhere, so that the total biodiversity value remains the same or improves (Forest Trends, 2017). This leads to concerns for greenwashing, which is given a false or misleading impression of how environmentally friendly a company's products, services, or overall operations are (Delmas & Burbano, 2011)

There are different methods to assign an economic value to environmental aspects (De Bruyn et al., 2010). This paper will discuss the effectiveness of Shadow pricing, Biodiversity offsets, Carbon credits and costs, and Ecosystem valuation. The focus on specifically these four environmental valuation methods stems from their prevalence in policy and market-based mechanisms (Millennium Ecosystem Assessment, n.d.; CE Delft, 2023; OECD, 2016; OECD, 2024).

Shadow pricing

Shadow pricing refers to "assigning a monetary value to an item, commodity, or service that is not ordinarily bought and sold in any marketplace" (Corporate Finance Institute, 2024). An example related to natural resources specifically is the estimated shadow price of a 1% improvement in biodiversity, valued at £45 million (Meier et al., 2024).

Accordingly, shadow pricing is specifically beneficial for sustainability as it "adds a hypothetical surcharge to the price of projects that involve the creation of carbon emissions" (Diviv Group, n.d.). This allows people to see the true costs of an investment or decision that involves emissions. Emissions of carbon are the main driver of climate change and have increased by more than 40% since pre-industrial times (US EPA, 2025). Several companies have adopted carbon pricing mechanisms under which shadow pricing and use shadow pricing to manage their environmental impact (Balch, 2024).

Shadow pricing could offer an approach to integrate environmental considerations in economic decision-making by assigning monetary values to non-market goods and natural capital/resources, such as clean air, water, and biodiversity (AccountingInsights Team, 2024). This allows for the internalization of environmental externalities, ensuring that the true costs and benefits of environmental impacts are reflected in economic analyses. For example, companies like Microsoft and Swiss Re have implemented an internal carbon pricing mechanism to account for their environmental impacts (Balch, 2024). Microsoft charges its business units a 15-100/metric ton internal carbon fee, which is used to fund sustainability projects (Microsoft, 2024). While Swiss Re charges a $100 metric ton shadow price to all business decisions, which the company uses to step away from high-carbon assets (Swiss Re, 2023)

On the other hand, shadow pricing is often still dependent on assuming perfect markets, leading to inaccurate shadow price estimates (Hernández-Solano et al., 2023). Perfect markets, as defined in economic theory, require conditions such as perfect competition, complete information, homogeneous goods, and no externalities, assumptions that rarely hold in reality (Hernández-Solano et al., 2023). Since shadow pricing frequently relies on these idealized market conditions, estimates may fail to reflect true social opportunity costs in the case of market imperfections (Boardman et al., 2018).

Due to the absence of a universal model for shadow pricing, a global implementation of the method remains complicated; "There is no consensus on the 'correct' shadow price of carbon... Disparities in methodologies across jurisdictions complicate global coordination." (World Bank 2020). Moreover, a significant challenge lies in accurately determining these prices due to the complexity of ecological systems and the lack of standardized valuation methods (Brander et al., 2024). Inconsistencies undermine the reliability of shadow pricing in guiding sustainability practices (Brander et al., 2024).

Biodiversity offsets

Biodiversity offsets are "measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development" (BBOP, 2012). These offsets are implemented after a project and aim to achieve a "no net loss" or "net gain" in biodiversity (IUCN, 2014).

As of 2023, more than 100 countries have incorporated biodiversity offsetting principles into national policy, legal frameworks, or practice, with the majority of the biodiversity offsetting being initiated by Australia, Canada, the United States, Colombia, and South Africa (OECD, 2023). For example, the U.S. Wetlands Mitigation Banking system, mandated under the Clean Water Act, requires developers to offset environmental damage by purchasing credits from a mitigation bank that restores or preserves wetlands (EPA, 2023). There are multiple types of biodiversity offsets, such as habitat creation or restoration, protection or management, and biodiversity banking (credits are bought and sold on a market) (Ledec et al., 2016).

Biodiversity offsets are quantified using “biodiversity metrics” that take into account habitat area, condition, species richness, and ecological function (UK DEFRA, 2024). Tools like the Biodiversity Metric 4.0 in the UK provide a way to measure ecological loss (Heydon et al., 2023). However, Biodiversity offsets often fail to fully compensate for ecological losses, as many studies lack a comprehensive assessment of both biodiversity losses and gains (Josefsson et al., 2021). In practice, most evaluations did not measure the biodiversity losses caused by development projects, leading to a continued net loss of biodiversity (Josefsson et al., 2021).

The biodiversity credit market has made transactions up to 1.85 million US$, and projections suggest that demand for biodiversity credits could reach 2 billion US$ by 2030 and 69 billion US$ by 2050 (Pollination Group, 2024; Khatri et al., 2023). In Europe, the EU No Net Loss Initiative has encouraged member states to integrate offset mechanisms into spatial planning, particularly for large-scale infrastructure and energy projects (European Commission, 2025).

Adding to that, the International Finance Corporation (IFC) Performance Standard 6 requires biodiversity offsets when critical habitat is affected by private-sector projects it funds (IFC, 2019).

The efforts made by the European Commission and International Finance Corporation aim to achieve a common goal: “The goal of biodiversity offsets is to achieve no net loss, or preferably a net gain, of biodiversity on the ground with respect to species composition, habitat structure and ecosystem services, including livelihood aspects."(UNEP/CBD/COP/9/INF/29, 2008).

Biodiversity offset guidelines have also been adopted in other parts of the world. For example, South Africa’s Department of Forestry, Fisheries, and the Environment (DFFE) published their National Biodiversity offset guidelines under section 24J of the National Environmental Management Act (NEMA) (Webber Wentzel, 2023). This guideline standardized biodiversity offset practices in South Africa

(Webber Wentzel, 2023). Another global partnership that developed biodiversity offset practices is the 'Business and Biodiversity Offsets Programme (BBOP) (BBOP, 2012). The BBOP is an international collaboration initiated in 2004 that includes 40 organizations, including companies, governments, financial institutions, and NGO's (BBOP, 2009). The collaboration led to the implementation of projects in countries such as Madagascar, Australia, New Zealand, and the United States, with many other countries expressing interest (BBOP, 2009).

Despite these efforts, implementation and regulation of biodiversity offsets vary greatly by jurisdiction, affecting the standardization and transparency of biodiversity offset outcomes (OECD, 2023).

Carbon credits/costs

Carbon pricing mechanisms, including carbon taxes and emissions trading systems (ETS), are tools for reducing greenhouse gas emissions by assigning a monetary value to carbon emissions (Samuel, 2025). As of 2023, there are 75 carbon pricing methods implemented globally, covering approximately 24% of global greenhouse gas emissions (Twidale, 2024). The carbon pricing mechanism generated $104 billion in revenues in 2023, with around half of the funds being allocated to climate and nature-related programs (World Bank Group, 2024).

Still, global carbon price coverage does not meet the Paris Agreement's goals (World Bank Group, 2024). "Currently, less than 1% of global greenhouse gas emissions are covered by a direct carbon price at or above the range recommended by the High-level Commission on carbon prices to limit temperature rise to well below 2ºC" (World Bank Group, 2024). The recommended carbon price by the High-level Commission is $63–$127 per ton of CO_2 by 2030, adjusted for inflation (World Bank Group, 2024). As of 2022, 15% of the 8402 companies that share their climate data with CDP report using internal carbon pricing, with prices ranging from 0.01 to $3,556 per ton of CO2 (World Bank 2023).

Often, making environmentally sustainable decisions is difficult (Solomon, 2024). This is one of the reasons companies refer to carbon offsetting rather than internalizing the costs of externalities, leading to inefficient environmental outcomes (Pazos, 2024). Notably, carbon offsetting is different from shadow pricing carbon, as carbon offsetting refers to compensating for emissions, while shadow pricing internalizes the costs of carbon in a financial decision (Stern, N., 2007). “Businesses and governments look to meet their climate targets, many turning to carbon offsets. That is, they are paying someone else to reduce or avoid putting greenhouse gases into the atmosphere, so they do not have to.” (Johnston-Leek, 2024).

Many climate offset projects have failed to reflect their true environmental value; for example, 90% of rainforest carbon offsets are said to be worthless (Johnston-Leek, 2024) A report from the Science Based Targets Initiative (2024) highlighted that carbon credits or carbon offsetting are often ineffective in delivering genuine emissions reductions and delay meaningful changes to the operational process, hindering the transition to net-zero emissions.

Furthermore, many carbon crediting projects overstate their climate impact. A meta-analysis published in Nature Communications evaluated 2346 projects and found that less than 16% of carbon offsets corresponded to genuine emissions reduction (Crook, 2024; Taaffe, 2024).

Ecosystem valuation

Ecosystem valuation is the process of assigning economic value to the benefits provided by ecosystems, known as ecosystem services (Wang et al., 2013). Ecosystem services can be categorized into four primary types: Provisioning services, regulating services, cultural services, and supporting services (Millennium Ecosystem Assessment, 2005). Provisioning services refer to ecosystem services that provide natural resources such as food, water, and genetic resources (Millennium Ecosystem Assessment, 2005). Regulating services refer to benefits that are derived from the regulation of ecosystem processes, such as climate regulation, disease control, and water purification (Millennium Ecosystem Assessment, 2005). Cultural services refer to non-material benefits gained from ecosystems in spiritual enrichment, cognitive development, and reflection (Millennium Ecosystem Assessment, 2005). Finally, supporting services refer to services necessary for the production of all other ecosystem services, such as soil formation, photosynthesis, and nutrient cycling (Millennium Ecosystem Assessment, 2005). All of these ecosystem services are vital for human well-being and economic development (Pearce, 2024).

The United Nations Environment Programme's (UNEP) Project for Ecosystem Services (ProEcoServ) was a four-year initiative aimed at integrating the economic value of ecosystems into national policies and development planning. The project was implemented in Chile, South Africa, Trinidad and Tobago, and Viet Nam, where it assessed various ecosystem services, including water provision, soil retention, shoreline protection, carbon sequestration, and pollination (United Nations Environment Programme, n.d.). The findings revealed that these ecosystem services contributed around one billion dollars annually to the economies of the participating countries. For example, in Trinidad and Tobago, soil retention services in the Northern Range forests were valued at up to $622 million per year, and in South Africa's Eden District, ecosystem-based disaster risk management approaches led to savings of approximately $166 million (United Nations Environment Programme, n.d.).

Many ecosystem services, especially cultural and non-market ones, are difficult to quantify, often leading to undervaluation (Pascual et al., 2017). Additionally, a lack of ecological data makes ecosystem valuations less reliable (Ninan & Inoue, 2013). Finally, ethical arguments also arise when assigning a monetary value to ecosystems, stating that it ignores the intrinsic worth of ecosystems (McCauley, 2006).

Methodology

Scope and database selection

This study adopts the PRISMA-EcoEvo framework (O'Dea et al., 2021), which structures the data collection process into four key stages: identification, screening, eligibility, and inclusion/exclusion. This approach ensures transparency and replicability in evaluating environmental valuation and its contribution to environmental sustainability. The article selection process is outlined in the PRISMA flow diagram presented in Figure 1.

The systematic literature review examines how environmental valuation and environmental valuation methods function as economic strategies in support of environmental sustainability. Scopus and EBSCO were chosen as the primary databases due to their broad and reliable coverage of both economic and environmental research (Falagas et al., 2008).

Search strategy and identification

The literature search was conducted across two major economic databases: EBSCO and Scopus. To identify relevant publications, the following search string was applied to titles and abstracts: (((shadow pric*) OR (carbon offset) OR (nature credit*) OR (environmental valuation) OR (ecosystem service pricing)) AND ((economic solution) OR (market-based approach) OR (pricing mechanism) OR (cost-benefit analysis)) AND ((sustainability) OR (environmental sustainability) OR (green economy) OR (climate policy)))

No language filters were applied to avoid bias. By using the truncation (*) in the string, a broad range of terms under which 'price', 'pricing', and 'prices' are included. This accounts for every term with an asterisk. The approach ensures the inclusion of papers covering relevant topics regarding environmental valuation and environmental policies.

The research string aligns with the research objectives of examining the effectiveness of environmental valuation and environmental valuation tools. The search terms are grouped into three key blocks, each corresponding to a dimension of this paper.

1. *Environmental valuation tools*

   The first block of terms: "shadow pric*", "carbon offset", "nature credit*", "environmental valuation", and "ecosystem service pricing". Covers a broad range of environmental valuation methods to assign economic value to environmental goods and services.

2. *Economic mechanisms and policy instruments*

   The second block: "economic solution", "market-based approach", "pricing mechanism", and "cost-benefit analysis", covers economic frameworks and tools through which the valuation methods above can be implemented. The inclusion of these terms ensures the search string captures valuation tools used in policy, market contexts, and regulation frameworks.

3. *Environmental sustainability and policy context*

   The third block: "sustainability", "environmental sustainability", "green economy", and "climate policy", covers the broader goal of environmental valuation. These terms make sure that results are scoped to specifically look at environmental sustainability-related fields rather than values in unrelated fields.

Screening and eligibility criteria

The initial database search yielded a total of 964 articles. Scopus returned 364 articles on March 20, 2025, and EBSCO provided 600 articles on March 24, 2025.

For the screening process, books, book chapters, reviews, and other grey literature document types were excluded from the search to concentrate on the more detailed analyses and methodologies commonly found in peer-reviewed articles. After implementing search filters that limited results to academic journals and articles only and excluded publications dated before 2015, 406 articles remained available. The 2015 cutoff was applied to ensure all included research reflected developments from the past decade and reflects policy shifts post-Paris Agreement, providing current perspectives on the topic. The relevance was determined in two stages:

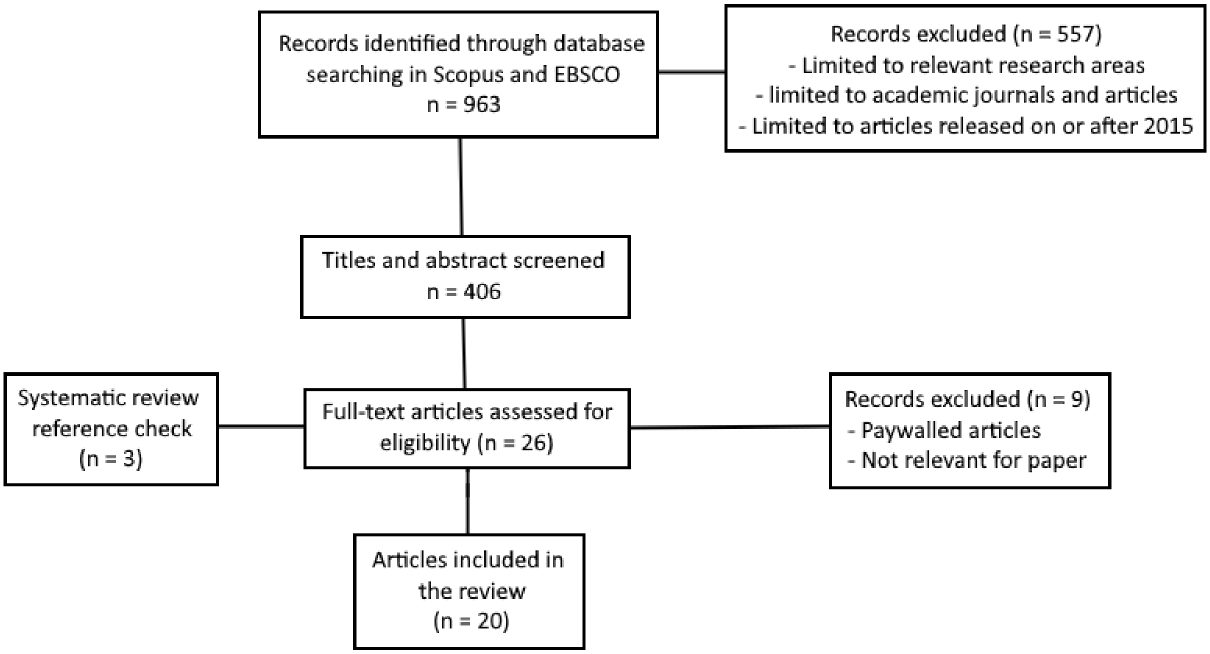
1. Title and abstract screening
2. Full-text assessment to ensure alignment with the research objectives.

In and exclusion criteria

The inclusion and exclusion criteria were established to ensure the relevance and quality of the selected literature. Articles were included if they directly discussed environmental valuation concepts such as shadow pricing, carbon offsets or costs, ecosystem valuation, and biodiversity offsets. Additionally, articles were selected if they focused on economic policies or market-based approaches addressing environmental issues, or if they examined sector-specific applications of environmental valuation.

Conversely, articles were excluded if they were summaries or meta-analyses of existing studies, published before 2015, discussed shadow pricing in non-environmental contexts, or constituted grey literature or non-peer-reviewed sources.

After applying all inclusion and exclusion criteria and reviewing the articles, 26 papers were identified as eligible for inclusion in the study. Additionally, 3 more articles were identified and included through a snowballing approach, by reviewing the reference lists of initially selected papers. After further evaluation, 9 papers were excluded, 5 due to paywall restrictions that prevented access to the full text, and 4 due to not being relevant to the research objectives. Articles were considered relevant if they directly engaged with economic valuation tools in the context of environmental sustainability, based on their stated aims and key findings. Only studies that included empirical, theoretical, or applied insights within environmental valuation and sustainability were included. As a result, 20 papers were examined in the final analysis.



(Figure 1, Flow chart)

Theoretical framework

The findings are structured according to the mitigation hierarchy, which includes mitigation, avoidance, and compensation, as outlined in the article by Huber et al.[2]. The analysis begins with a broad discussion of environmental valuation, including its general positive and negative aspects. The analysis then progresses to evaluate specific tools: shadow pricing, ecosystem valuation, biodiversity offsets, and carbon credits, according to their positive and negative implications, again categorizing them as either mitigation or compensation. Due to the lack of data relating to the second pillar, avoidance, the discussion does not cover this category.

Findings

Figure 2 summarizes the positive and negative aspects of environmental valuation. The keywords grouped by each category reflect recurring thematic terms identified through the systematic literature review and represent the authors' synthesis of the findings. The table serves as a conceptual overview to guide further discussion on the implications of environmental valuation.

Aspects of environmental valuation	Category	Keywords
Policy Guidance	Positive	Environmental Valuation, Cost-Benefit Analysis, Policy Design, Economic Efficiency[7, 8, 9, 10, 11, 15, 16, 19, 20]
Pollution Control	Positive	Prevention, Externalities, Cost of Restoration[7]
Impact Awareness & Accountability	Positive	Polluter Pays Principle, Ecosystem Services, Economic Valuation, Environmental Impact Awareness[7, 8, 9, 10, 11, 15, 16, 17]
Inaccurate Valuation	Negative	Complexity, Standardization Issues, Market Assumptions, Valuation Accuracy[3, 5, 6, 11]
Ethical Concerns	Negative	Intrinsic Value, Moral Value, Ethics, Utilitarianism, Market Commodification[3, 5]

(Figure 2, recurring thematic keywords on the pros and cons of environmental valuation)

Environmental valuation

Policy guidance (positive)

Many of the articles report that monetary valuation of environmental impacts serves as a tool for guiding policymakers and regulators by quantifying costs and benefits, thereby supporting informed, timely, and economically efficient decision-making to address environmental challenges[7, 8, 9, 10, 11, 15, 16, 19, 20]

For example, Gourevitch et al.[8] report that "in order to inform decision-making, the value of the clean water must be assessed in terms of the marginal benefits and costs associated with pollution abatement interventions". The article further reports that expressing the services of nature in amounts of money can help policymakers and markets to understand their value and act sustainably. Furthermore, Molinos-Senante et al.[11] published a report with a case study of environmental valuation in water distribution networks. This article states that environmental valuation can effectively reduce water losses in the water distribution network.

Pollution control (positive)

According to Bherwani et al.[7], if actions are adopted in the early stage of environmental pollution, it will result in lower restoration costs of the externalities. It states, "... the cost of prevention in case the environment is lesser than curing it, so it is better to prevent than restore in the end".

Impact awareness and accountability (positive)

Several of the articles report that environmental valuation translates ecological impacts into economic terms, enhancing awareness of environmental damages and benefits, which supports more informed, efficient, and sustainable decision-making across policy, regulation, and resource management[7, 8, 9, 10, 11, 15, 16, 17].

For example, Bherwani et al.[7] link environmental valuation to the polluter pays principle, helping to quantify and understand damage in economic terms. Furthermore, Platts et al.[14] highlight that monetizing ecosystem services can reveal the often-overlooked value of nature. Finally, Gourevitch et al.[8] connect environmental valuation with positive health, ecological, and economic outcomes stemming from improved water quality.

Inaccurate valuation (negative)

According to four of the articles, the process of environmental valuation can lead to inaccurate valuation[3, 5, 6, 11]. The articles report that this is due to the inherent complexity and interdependence of ecological systems. These challenges undermine the reliability of valuation results and, in many cases, lead to the exclusion of environmental variables from decision-making processes.

For example, Tavakolnia et al.[3] explain that many environmental services are mutually dependent, making it difficult to isolate and assign accurate monetary values to them. The article also reports that incorrect assumptions, such as failing to understand whether a service has local or global significance, can lead to incomplete or inadmissible valuations. Mirzabaev et al.[6] point out that assigning accountability for externalities can be difficult due to the absence of assignable property rights for collective resources like the atmosphere and oceans. Similarly, Molinos-Senante et al.[11] note that because a standardized method for calculating environmental and resource costs is still lacking, certain issues, such as water leakage, are generally excluded from policy considerations. Finally, Gould et al.[5] critique common economic tools like cost-benefit analysis and contingent valuation used in environmental decisions. It reports that these methods limit who can participate and reduce all values to money, which often ignores important non-monetary values.

Unethical (negative)

Two of the articles critique the ethical implications of monetizing the environment and its natural resources[3, 5]. The articles argue that valuation reduces nature to an economic resource and ignores its intrinsic and moral value. It raises concerns about the environment existing solely for human purposes.

For instance, Tavakolnia et al.[3] warn that assigning an economic value to animals risks framing them as marketable assets, thereby ignoring their ecological roles and ethical standing. Gould et al.[5] further expand on this issue by critiquing the utilitarian foundations of mainstream economics, which treat nature as something to be used and traded off, rather than protected for its own sake. The article argues that intrinsic values are not to be included in cost-benefit analysis and should be recognized in environmental governance.

Environmental valuation methods

Figure 3 summarizes the positive and negative aspects of environmental valuation methods in keywords. The terms listed under each tool's positive and negative aspects are drawn from a systematic literature review and reflect the authors' synthesis of recurring themes. This table provides a structured overview to support critical analysis of the effectiveness, challenges, and broader implications of these tools in environmental decision-making.

Category	Tool	Positive aspects	Negative aspects
Mitigation	**Shadow Pricing**	Cost internalization, Emission reduction incentives, Policy guidance, Economic efficiency, pollution control, implicit cost measurement, environmental accounting, prevention over restoration, operational efficiency [1, 11, 12, 13, 18, 19, 20]	High variability, Inaccuracy across contexts, Technical complexity, Oversimplification, Lacks intrinsic valuation, Misrepresents ethical/moral values, Data requirements, Unreliable in developing contexts, instrumentalizes nature[1, 3, 19, 20]

Mitigation	**Ecosystem Valuation**	Justifies conservation, Captures co-benefits, Assists cost-benefit analysis, Informs sustainable land use, Supports investment in natural capital/resources, Reflects full economic value, Policy-oriented metrics, Enables comparison across alternatives[14]	Multiple stakeholders with different goals, Service interaction complexity, Inequitable distribution of costs/benefits, Limited valuation methodologies, Data uncertainty, Scope of benefit sharing, Geographic/ecological specificity[14]
Compensation	**Biodiversity Offsets**	Incentivizes conservation, No Net Loss (NNL) principle, Market-based compensation, Pro-conservation economic tool, structured recovery pathway, enables accountability[2]	Ecological inequivalence, Time lags in recovery, Underpriced compensation, Insufficient conservation impact, Social loss/deprivation, Misalignment with conservation goals, Displacement effects[2]
Compensation	**Carbon Credits/Costs**	Quantification of emissions, informs mitigation policy, Basis for carbon taxes, reflects climate impact, Policy alignment, Technology incentivization[19]	Lack of additionality, Market failure, Mispricing, Ineffectiveness in Emissions reduction, verification issues, Temporal disconnect[4]

(Figure 3, positive and negative aspects of environmental valuation tools)

Shadow pricing

Policy design and mechanism (positive)

Four of the articles report that shadow pricing is an effective tool for designing environmental policies, especially in creating or supporting emission trading systems, carbon tax frameworks, and environmental regulation [1, 13, 18, 19, 20]. The articles argue that by estimating the marginal abatement cost (MAC) or the opportunity cost of pollution, shadow pricing helps inform policy choices that are economically efficient and environmentally effective.

For example, Maziotis et al.[1] state that a better understanding of shadow prices in the water utility sector could lead to the creation of a GHG market. Furthermore, Molinos-Senante et al.[19] explain that CO_2 shadow prices are important for determining carbon tax rates and permit pricing in emissions trading systems. Additionally, Lee et al.[20] Reinforce this by stating that shadow pricing provides valuable input for setting allowance prices and penalty rates in environmental markets. Finally, Tang et al.[18] further adds to this, stating that regions with lower pollution abatement costs can be targeted first, improving cost-effectiveness in national environmental policies.

Resource allocation and prioritization (positive)

Three of the articles report that shadow pricing can help allocate environmental resources efficiently by identifying where pollution reduction efforts are the most efficient or cost-effective[11, 12, 19]. This prioritization supports environmental investments and policy targeting.

For example, Molinos-Senante et al.[11] use shadow pricing to reveal the variability of leakage costs across water utilities, enabling better investment prioritization in leakage reduction. Furthermore, Streimikis et al.[12] highlight that shadow prices point to directions for GHG reduction in agriculture at the country level, helping guide strategic improvements. Finally, Molinos-Senante et al.[19] similarly demonstrates that CO_2 shadow price differences between wastewater treatment plants (WWTPs) provide insights into which facilities should be prioritized for emission reduction.

Economic valuation of environmental damage (positive)

Four of the articles report that shadow pricing plays a role in placing an economic value on environmental harm, which is essential for incorporating externalities into decision-making[11, 12, 18, 19]. It enables a monetary representation of pollution costs, facilitating cost-benefit analysis and environmental accounting.

For example, Streimikis et al.[12] highlight how shadow prices reflect the value of reducing one unit of pollution, supporting progress toward climate-smart agriculture. Furthermore, Tang et al.[18] interpret pollution costs as shadow values, equating them to opportunity costs of abatement, which are critical for policy formulation and evaluation. Finally, Molinos-Senante et al.[19] emphasize the importance of including both market and non-market environmental costs in decision-making through shadow pricing.

Variability in estimates (negative)

Three of the articles highlight that shadow pricing results vary significantly due to differences in methods, firm efficiency, and context, which can undermine their policy applicability and consistency[1, 19, 20].

For example, Maziotis et al.[1] report significant fluctuation in the shadow price of CO_2eq during the study period and between companies, pointing out that this variability can make uniform carbon taxes inappropriate and suggesting that market-based solutions may be better suited. Similarly, Molinos-Senante et al.[19] note high variability in shadow prices across wastewater treatment plants (WWTPs), suggesting limited generalizability. Finally, Lee et al.[20] emphasize that directional choices in estimation models critically affect outcomes, with no universally accepted direction, resulting in widely different shadow price estimates.

Technical challenges (negative)

Three of the articles report that the complexity, sensitivity, and lack of standardization in shadow pricing methodologies make replication and comparison difficult[1, 19, 20].

For instance, Maziotis et al.[1] critique the inconsistency between econometric and linear programming approaches, mentioning that previous studies often excluded direct emissions. Adding to that, Lee et al.[20] warn that shadow pricing methods cannot estimate prices for inefficient firms and that using projections adds uncertainty, especially with multiple pollutants. It states that this can lead to inaccurate or overly optimistic views of how well emission controls are working.

Unethical (negative)

Similar to environmental valuation, Tavakolnia et al.[3] provide a philosophical critique, arguing that assigning shadow prices to environmental goods promotes a purely instrumental valuation of nature, which obscures its intrinsic value and may foster unsustainable mindsets.

It states that “allocating a number can have dangerous effects” as it encourages people to see nature only through its economic utility, excluding appreciation for non-monetary values like biodiversity, cultural importance, and ecological integrity.

Ecosystem valuation

Incentivizing conservation (positive)

According to Platts et al.[14], ecosystem valuation can incentivise conservation. It states that “A billion rural people live near tropical forests. Urban populations need them for water, energy, and timber. Global society benefits from climate regulation and knowledge embodied in tropical biodiversity.” The article reports that understanding these dependencies through ecosystem valuation can lead to conservation efforts.

Incomplete and oversimplified (negative)

According to Platts et al.[14], most valuations fail to account for complex interactions such as those between ecosystem services. Additionally, it reports that direct and indirect costs of land management options are often not fully considered. Because of this, the understanding of ecological and economic trade-offs is often incomplete. It further mentions that comprehensive assessments are scarce, due to a lack of data in, for example, developing countries.

Lack of equity in decision-making (negative)

Platts et al.[14] further reports that valuations rarely consider how benefits and costs are distributed among stakeholders. This makes it hard to design fair and socially sustainable conservation strategies. This causes the distribution of impacts to be ignored and undermines the potential for inclusive interventions.

Biodiversity offsets

Environmental effectiveness and accountability (positive)

According to Huber et al.[2], the biodiversity offset's goal is (NNL), no net loss. This means that biodiversity should be at least as good and ideally better than the situation before execution. According to this article, this is more effective than shadow pricing as it will make it easier to properly balance out biodiversity losses. It further reports that the offset price (OSP) set by the public authority helps avoid both private and public losses. It acts as the minimum price where the developer only starts making a profit after the biodiversity has been restored. Suggesting that there can only be real value once the offset is fully completed.

Ineffectiveness and delayed benefits (negative)

According to Huber et al.[2], biodiversity offsets are often criticized for being unrealistic. As no net loss is often debated to be difficult to achieve reliably. Additionally, before recovering biodiversity, there is a period of loss of access to ecosystem services and temporary depreciation. The article also points out that biodiversity offsets are not yet a strong enough incentive for sustainability, as often in developing and developed countries, a complete change in land use, such as for habitat or agriculture, causes biodiversity loss.

Carbon credits/costs

Policy design and mechanism (positive)

Molinos-Senante et al.[19] highlight that reducing the carbon footprint of wastewater treatment plants (WWTPs) is both an environmental and economic challenge. Introducing a carbon cost on electricity generated from fossil fuels creates a financial incentive for WWTP operators to adopt systems that balance multiple sustainability goals. This includes minimizing carbon emissions while also reducing operational costs. Ideally, this would align economic efficiency with environmental responsibility.

For example, Molinos-Senante et al.[19] explain that carbon pricing motivates WWTPs to implement greener technologies that serve both climate goals and cost savings.

Resource allocation and prioritization (positive)

Article Molinos-Senante et al.[19] report that by factoring in the carbon cost of electricity, operators can better prioritize investments and operational strategies that optimize both emissions reductions and financial performance. This incentivizes efficient resource allocation within WWTPs to meet sustainability objectives effectively.

Ineffective and credibility concerns (negative)

Groom et al.[4] report on concerns with the effectiveness of forest carbon credits in tropical forests. Specifically, it shows that only 10% of verified forest carbon credits in voluntary carbon markets actually add new carbon savings that wouldn’t have happened without the credit system and funding. The article states that this is a real issue regarding the impact of many carbon credits, undermining their credibility and environmental value.

Discussion and conclusion:

The majority of the evidence suggests that environmental valuation, through tools like shadow pricing, ecosystem valuation, carbon credits, and biodiversity offsets, can support more informed, economically efficient, and environmentally effective policy decisions. These tools translate ecological impacts into economic terms, helping policymakers to prioritize interventions, allocate resources, and design mechanisms such as pollution taxes or emission trading systems. For example, several articles demonstrate how placing economic value on clean water or ecosystem services aids in raising awareness, accountability, and ultimately, better environmental management[7, 8, 9, 11, 15, 16, 19]. Shadow pricing, in particular, is widely acknowledged as a policy tool to reflect the opportunity cost of pollution and guide cost-effective interventions[18, 19, 20].

However, the evidence is mixed, and the implementation of these economic tools comes with significant challenges. One critical issue is the inaccuracy and variability in valuation results, as ecological complexity and methodological inconsistencies can undermine the reliability of monetary assessments[3, 5, 6, 11]. Three of the articles report that fluctuating shadow prices, firm inefficiency, and a lack of standard methods reduce the consistency and generalizability of findings [1, 19, 20]. For example, shadow pricing, used to estimate the cost of emissions or resource use, can be calculated through different measurement approaches or starting assumptions leading to divergent shadow prices[1, 12, 19]. Similarly, valuation methods based on, for example, willingness-to-pay, as seen in articles on urban flooding or biodiversity loss, are sensitive to socio-cultural context and framing effects[14, 17]. Even when articles apply the same valuation method, results can vary due to contextual factors. For example, both Sweeney et al.[13] and Tang et al.[18] assess the economic costs of pollution, yet their findings differ substantially due to geographical, ecological, and economic conditions. These limitations suggest that while economic valuation is influential, it is not consistently reliable or easily replicable in practice.

Moreover, Tavakolnia et al.[3] and Gould et al.[5] warn against commodifying natural entities like animals or ecosystems, arguing that this instrumental view risks neglecting intrinsic and cultural values.

The articles suggest that environmental valuation may prioritize human benefits over ecological integrity. This critique also applies to shadow pricing and carbon markets, where the simplification of nature into market terms can lead to underappreciation or exploitation of ecosystems[3, 4].

From a political perspective, choosing which side of the mixed evidence to prioritize is both a value-based and strategic decision. On one hand, economic tools enable quantifiable, cost-efficient decision-making that aligns well with political and institutional frameworks focused on growth and resource optimization. On the other hand, over-reliance on these tools may perpetuate existing inequalities or lead to environmentally unsustainable outcomes framed as efficient solutions. While articles highlight the instrumental benefits of environmental valuation, such as incentivizing conservation or reducing emissions, they also stress that many methods fail to consider who benefits and who bears the costs.[5, 14, 19]. This points out the importance of social and ethical considerations in valuation methods.

Based on the reviewed articles, shadow pricing appears to be the most effective environmental valuation method in policy design and resource allocation, particularly in sectors like wastewater treatment and agriculture. Several articles highlight its importance in informing carbon tax rates, emissions trading systems, and prioritizing pollution abatement efforts[1, 11, 12, 18, 19, 20]. For instance, Molinos-Senante et al.[19] and Streimikis et al.[12] emphasize how shadow pricing reveals the economic value of emissions reductions, thereby guiding investments toward cost-effective environmental improvements. Shadow pricing can internalize environmental costs directly into financial decisions and support policy efficiency. However, this effectiveness is highest in contexts where reliable data exists and where market conditions and environmental impacts can be clearly measured, such as in industry.

In contrast, the findings suggest that biodiversity offsets and carbon credits often suffer from credibility issues or delayed benefits, while ecosystem valuation faces challenges in data availability and equitable impact distribution[2, 4, 14]. For example, Huber et al.[2] critique biodiversity offsets for delayed benefits and limited incentive power, while Groom et al.[4] report doubts on the effectiveness of voluntary forest carbon credits.

Furthermore, environmental valuation also takes on different roles depending on the intentions behind its use. On the one hand, these tools are useful for advancing economic objectives. By assigning monetary values to natural resources and environmental impacts, they allow policymakers to integrate environmental considerations into cost-benefit analyses, justify investments in sustainability, and develop market-based mechanisms like carbon credits or biodiversity offsets. In this way, valuation supports economic efficiency and can strengthen policy making by making environmental trade-offs visible and actionable.

On the other hand, this economic perspective can come at the expense of ecological integrity. Therefore, using environmental valuation as a means to achieve ecological integrity may be counterproductive. This can lead to policies that appear efficient on paper but fail to protect ecosystems or recognize the full complexity of ecological systems. When nature is treated primarily as a commodity, environmental outcomes are likely to be shaped by economic optimization rather than ecological integrity.

Because this paper focuses specifically on environmental valuation as a tool for environmental sustainability, the emphasis has been on its effectiveness as a policy tool, leaving out ethical and philosophical considerations.

Given the weight of the evidence, it is clear that environmental valuation can be an effective and practical tool for achieving environmental sustainability. When applied transparently, it allows for more informed decisions, drives efficient allocation of resources, and creates incentives for conservation and pollution control. Despite limitations in accuracy and the risk of oversimplification, the overall effectiveness demonstrated across sectors, water, energy, agriculture, and biodiversity shows that environmental valuation helps make progress towards environmental sustainability. With further improvements, environmental valuation can play a key role in supporting environmental sustainability. Overall, the evidence indicates that environmental valuation can act as an effective economic tool for achieving environmental sustainability.

Limitations

A key limitation of this study is its original focus on shadow pricing, which shaped the selection of articles and may have led to the exclusion of relevant literature on other valuation methods. As a result, the evidence base is relatively stronger for shadow pricing compared to tools like carbon credits, biodiversity offsets, or ecosystem valuation. While the scope was later expanded to include a broader range of mechanisms, the uneven distribution of data limits the ability to assess the effectiveness of all methods equally.

Furthermore, the effectiveness of environmental valuation was evaluated from a political perspective. Ethical and philosophical debates, particularly those concerning the moral implications of assigning monetary value to nature, were not included in the outcome. These perspectives could influence the overall assessment of effectiveness, as they raise fundamental questions about the appropriateness and legitimacy of economic valuation in environmental decision-making.

Final reflections

This thesis explored whether environmental valuation can act as an economic solution for environmental sustainability. Using a systematic literature review, it assessed tools such as shadow pricing, carbon credits, biodiversity offsets, and ecosystem valuation.

The research found that these tools can improve policy efficiency by internalizing environmental costs and guiding resource allocation. However, methodological inconsistencies and ethical concerns limit their reliability and ecological effectiveness.

Ultimately, the study shows that environmental valuation supports economic decision-making but may fall short in protecting ecosystems for their own sake. Its use should depend on whether the goal is economic efficiency or ecological integrity. Recognizing this distinction is crucial for applying these tools responsibly in sustainability efforts.

Further research on environmental valuation

Although this study was initially designed to assess the effectiveness of shadow pricing alone, the research process revealed a range of related mechanisms and concepts that also fall within the broader concept of environmental valuation. As a result, the scope of the paper was expanded to cover environmental valuation more comprehensively. Through an in-depth analysis of the collected data, several key terms and themes emerged that are relevant for future research in this field. These terms and themes are stated in Figure 4. Accordingly, this paper recommends that the identified terms stated in the table below can serve as a foundation in research strings for similar future studies in environmental valuation.

Category	**Key Terms**
Valuation Tools & Mechanisms	Shadow Pricing, Ecosystem Valuation, Biodiversity Offsets, Carbon Credits, Carbon Offsetting, Nature Credits, Internal Carbon Pricing, Environmental Pricing, Pigouvian Tax, Environmental Damage Valuation, Biodiversity Banking, Offset Prices (OSP), Emission Reduction Credits (CER), Biodiversity Metrics, Carbon Crediting Mechanisms, Shadow Value, Marginal Abatement Cost (MAC), Opportunity Cost of Pollution, Pollution Cost Internalization
Economic Instruments	Market-Based Approaches, Pricing Mechanisms, Cost-Benefit Analysis (CBA), Social Cost of Carbon (SCC), Net Present Value (NPV), Sustainability Accounting, Environmental Taxation, Carbon Tax,

	Emission Trading Systems (ETS), Discount Rates, Financial Incentives, Green Technologies, Economic Efficiency, Resource Allocation Strategies
Policy & Governance	Polluter Pays Principle, No Net Loss (NNL), Environmental Regulation, Green Economy, Climate Policy, Legal Frameworks, Agenda 21, Paris Agreement, Kyoto Protocol, UNFCCC, Rio Declaration, NEPA (National Environmental Policy Act), IFC Performance Standard 6, Science Based Targets Initiative (SBTi)
Conceptual Foundations	Environmental Valuation, Natural Capital/resources, Extrinsic Value, Intrinsic Value, Anthropocentric Perspective, Ecocentric Perspective, Environmental Externalities, Resource Depletion, Environmental Ethics, Ecological Risk, Non-Market Goods, Uncompensated Environmental Effects, Ecosystem Degradation, Sustainable Development, Economic Trade-offs, Material Well-being, Environmental Decision-Making, Economic Utility, True Cost Valuation

Ecosystem Services	Provisioning Services, Regulating Services, Cultural Services, Supporting Services, Ecosystem Service Pricing, Soil Retention, Water Purification, Carbon Sequestration, Climate Regulation, Disease Control, Nutrient Cycling, Photosynthesis, Biodiversity, Shoreline Protection, Pollination, Ecological Function, Habitat Area, Species Richness, Ecosystem-Based Disaster Risk Management
Methodologies & Frameworks	Mitigation Hierarchy (Avoidance, Mitigation, Compensation), Cost-Benefit Analysis (CBA), Social Cost of Carbon (SCC), Net Present Value (NPV), Sustainability Accounting, TEEB (The Economics of Ecosystems and Biodiversity), SEEA (System of Environmental Economic Accounting), Millennium Ecosystem Assessment, Paris Agreement (Article 6.4), Kyoto Protocol (CDM & Article 17), Agenda 21, Rio Declaration, NEPA, Brundtland Report, UNFCCC, IFC Performance Standard 6, SBTi (Science Based Targets Initiative)
Ethical & Practical Challenges	Inaccurate Valuation, Variability in Estimates, Technical Challenges, Ethical Critiques of Monetization, Lack of Standardization, Temporal Delay of Benefits, Oversimplification, Limited Stakeholder Participation, Lack of Equity in

	Decision-Making, Complexity of Ecological Systems, Difficulty Assigning Property Rights, Non-representative Carbon Credits, Credibility Issues, Market Imperfections, Philosophical Critiques
Application Sectors	Water Management, Agriculture, Wastewater Treatment, Forestry, Urban Planning, Infrastructure Development, Energy Projects, Habitat Restoration, Tropical Forest Conservation, Biodiversity Conservation, Corporate Sustainability, Public Policy, Climate Mitigation Strategies
Emerging Areas for Study	Biodiversity Metrics, Standardized Valuation Models, Internalization of Externalities, Ecosystem-Based Valuation Standards, Interdisciplinary Environmental Valuation, Long-Term Cost-Benefit Frameworks, Environmental Accountability, Valuation of Non-Market Services, Environmental Impact Transparency, Sustainability Incentives, Role of Discount Rates, Financial Mechanisms in Environmental Policy

(Figure 4, several key terms and themes for future research on environmental valuation)

Sources consulted for findings

[1] Maziotis, A., Sala-Garrido, R., Mocholi-Arce, M., & Molinos-Senante, M. (2022, March). Estimation of greenhouse gases shadow price in the English and Welsh water industry. *Environmental Science and Pollution Research International*.

[2] Huber, C., Doyen, L., & Ferrari, S. (2024, May). When profitability meets conservation objectives through biodiversity offsets. *Natural Resource Modeling*.

[3] Tavakolnia, E. (2023, May). Making animals visible in sustainability accounting with critical look at financial valuation. *International Journal of Management, Accounting & Economics*.

[4] Groom, B., & Venmans, F. (2025, January). The social value of temporary carbon removals and delayed emissions. *Environmental & Energy Policy & the Economy*.

[5] Gould, R. K., Himes, A., Anderson, L. M., Arias Arévalo, P., Chapman, M., Lenzi, D., Muraca, B., & Tadaki, M. (2024, April). Building on Spash's critiques of monetary valuation to suggest ways forward for relational values research. *Environmental Values*.

[6] Mirzabaev, A., & von Braun, J. (2022). True cost of food and land degradation. *Russian Journal of Economics*.

[7] Bherwani, H., Musugu, K., Nair, M., Gupta, A., & Kumar, R. (2022, March). Valuation of environmental damages of Kasardi River: A case for benefits of timely action. *CSIR-National Environmental Engineering Research Institute*.

[8] Gourevitch, J. D., Koliba, C., Rizzo, D. M., Zia, A., & Ricketts, T. H. (2021, September). Quantifying the social benefits and costs of reducing phosphorus pollution under climate change. *University of Vermont*.

[9] Onofri, L., & Nunes, P. A. L. D. (2020, August). Economic valuation for policy support in the context of ecosystem-based adaptation to climate change: An indicator, integrated based approach. *TESAF - University of Padova & FAO*.

[10] Nurmi, V., & Ahtiainen, H. (2018, August). Distributional weights in environmental valuation and cost-benefit analysis: Theory and practice. *Finnish Meteorological Institute & University of Helsinki*.

[11] Molinos-Senante, M., Mocholí-Arce, M., & Sala-Garrido, R. (2016, October). *Estimating the environmental and resource costs of leakage in water distribution systems: A shadow price approach*. Pontificia Universidad Católica de Chile.

[12] Streimikis, J., Shen, Z. Y., & Balezentis, T. (2024, September). *Does the energy-related greenhouse gas emission abatement cost depend on the optimization direction? Shadow pricing based on the weak disposability technology in the European Union agriculture*. Lithuanian Centre for Social Sciences.

[13] Sweeney, K., Dittrich, R., Moffat, S., Power, C., & Kline, J. D. (2023, December). *Estimating the economic value of carbon losses from wildfires using publicly available data sources: Eagle Creek Fire, Oregon 2017*. University of Portland & USDA Forest Service.

[14] Platts, P. J., Schaafsma, M., Turner, R. K., Burgess, N. D., Fisher, B., Mbilinyi, B. P., ... & Ahrends, A. (2023, November). *Inequitable gains and losses from conservation in a global biodiversity hotspot*. Various institutions including University of York and UNEP-WCMC.

[15] Del Villar, A., & García-López, M. (2023, January). *The potential of wastewater reuse and the role of economic valuation in the pursuit of sustainability: The case of the Canal de Isabel II*. University of Alcala & University of Alicante.

[16] Okada, T., Mito, Y., Tokunaga, K., Sugino, H., Kubo, T., Akiyama, Y. B., & Kuwae, T. (2023). *A method for evaluating ecosystem services that can be used for the management of nature-based solution*

projects: A case study of Shiosai-Nagisa in Tokyo Bay. National Institute for Land and Infrastructure Management, Japan.

[17] Dugstad, A., Ben Hammou, H., & Navrud, S. (2025, January). *Valuing the benefits of climate adaptation measures to reduce urban flooding: Community preferences for nature-based solutions*. Norwegian University of Life Sciences.

[18] Tang, K., Gong, C., & Wang, D. (2016, January). *Reduction potential, shadow prices, and pollution costs of agricultural pollutants in China*. China University of Geosciences & University of Western Australia.

[19] Molinos-Senante, M., Hanley, N., & Sala-Garrido, R. (2015, April). *Measuring the CO_2 shadow price for wastewater treatment: A directional distance function approach*. Pontificia Universidad Católica de Chile & University of St. Andrews.

[20] Lee, C., & Zhou, P. (2015). Directional shadow price estimation of CO 2 , SO 2 and NO x in the United States coal power industry 1990–2010. *Energy Economics*, *51*, 493–502. https://doi.org/10.1016/j.eneco.2015.08.010

Resources

AccountingInsights Team. (2024, May 24). The Role of Shadow Prices in Economic Decision Making – Accounting Insights. Accounting Insights. https://accountinginsights.org/the-role-of-shadow-prices-in-economic-decision-making/

AccountingInsights Team. (2024, September 14). Shadow Pricing: Concepts, Calculations, and Applications – Accounting Insights. Accounting Insights. https://accountinginsights.org/shadow-pricing-concepts-calculations-and-applications/

Assessment report on diverse values and valuation of nature. (2022). UNEP - UN Environment Programme. https://www.unep.org/resources/report/assessment-report-diverse-values-and-valuation-nature

Balch, O. (2024, November 5). BrandWatch: Putting a price on their climate impact remains big challenge for companies. Reuters. https://www.reuters.com/sustainability/boards-policy-regulation/brandwatch-putting-price-their-climate-impact-remains-big-challenge-companies-2024-11-05/

Bansal, P., & DesJardine, M. R. (2014). Business sustainability: It is about time. Strategic Organization, 12(1), 70–78. https://doi.org/10.1177/1476127013520265

Biodiversity offsets. (2016, December 7). OECD. https://www.oecd.org/en/publications/biodiversity-offsets_9789264222519-en.html

Biodiversity strategy for 2030. (2025, May 15). Environment. https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

Boardman, A. E., Greenberg, D. H., Vining, A. R., & Weimer, D. L. (2018). Cost-benefit analysis: Concepts and practice (5th ed.). Cambridge University Press.

https://students.aiu.edu/submissions/profiles/resources/onlineBook/E5V5H3_Cost-benefit%20analysis%20_%202018.pdf

Business and Biodiversity Offsets Programme (BBOP). (2009). Business, Biodiversity Offsets and BBOP: An Overview. BBOP, Washington, D.C. https://www.forest-trends.org/wp-content/uploads/bbop/overview-phase-1-pdf.pdf

Business and Biodiversity Offsets Programme (BBOP). (2012). Guidance notes to the Standard on Biodiversity Offsets. BBOP, Washington, D.C. https://www.forest-trends.org/wp-content/uploads/imported/BBOP_Standard_Guidance_Notes_20_Mar_2012_Final_WEB.pdf

Brander, L., De Groot, R., Schägner, J., Guisado-Goñi, V., Van 't Hoff, V., Solomonides, S., McVittie, A., Eppink, F., Sposato, M., Do, L., Ghermandi, A., Sinclair, M., & Thomas, R. (2024). Economic values for ecosystem services: A global synthesis and way forward. Ecosystem Services, 66, 101606. https://doi.org/10.1016/j.ecoser.2024.101606

Calculate biodiversity value with the statutory biodiversity metric. (2024, February 27). GOV.UK. https://www.gov.uk/guidance/biodiversity-metric-calculate-the-biodiversity-net-gain-of-a-project-or-development

Causes of climate change | US EPA. (2025, March 25). U.S. Environmental Protection Agency. https://www.epa.gov/climatechange-science/causes-climate-change

CE Delft. (2023, March 10). Environmental Prices Handbook 2023. Methodological justification of key figures used for the valuation of emissions and environmental impacts - CE Delft - EN. CE Delft - EN. https://cedelft.eu/publications/environmental-prices-handbook-2023/

Center for Climate and Energy Solutions. (2017, October 27). COP 15 Copenhagen - Center for Climate and Energy Solutions. https://www.c2es.org/content/cop-15-copenhagen/

CFI (2023, November 22). Pigouvian tax. Corporate Finance Institute.
https://corporatefinanceinstitute.com/resources/economics/pigouvian-tax/

Climate Change: Arctic sea ice summer minimum. (2022, October 18). NOAA Climate.gov.
https://www.climate.gov/news-features/understanding-climate/climate-change-arctic-sea-ice-summer-minimum

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. Nature, 387(6630), 253–260. https://doi.org/10.1038/387253a0

Costanza, R., De Groot, R., Sutton, P., Van Der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., & Turner, R. K. (2014). Changes in the global value of ecosystem services. Global Environmental Change, 26, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002

Crook, J. (2024, November 14). Cooking the climate books: New peer-reviewed study finds carbon credit impact vastly overstated. Carbon Market Watch.
https://carbonmarketwatch.org/2024/11/14/cooking-the-climate-books-new-peer-reviewed-study-finds-carbon-credit-impact-vastly-overstated/

De Bruyn, S., Korteland, M., Markowska, A., Davidson, M., De Jong, F., Bles, M., & Sevenster, M. (2010). Shadow Prices Handbook (Environment / Effects / Costs / Prices / Economy / Analysis / Measure / Method 10.7788.25a ENG). CE Delft.
https://ce.nl/wp-content/uploads/2021/03/7788_defMainReportMaKMV.pdf

Delmas, M. A., & Burbano, V. C. (2011). The drivers of greenwashing. In California Management Review (Vols. 54–54, Issue 1, pp. 64–65).
https://www.ioes.ucla.edu/wp-content/uploads/2017/04/2011-Delmas-Cuerel-Burbano-California-Management-Review.pdf

Diviv Group. (n.d.). Shadow carbon price. https://www.wesfarmers.com.au/sustainability/fy2022/our-priorities/climate-change-resilience/shadow-carbon-price#:~:text=Shadow%20carbon%20pricing%20is%20a,efficient%2C%20other%20things%20being%20equal.

Dixon, J., *. (n.d.). Environmental Valuation: Challenges and practices. Conservation Stategy Fund. https://www.conservation-strategy.org/sites/default/files/field-file/Tropics_Conference_Dixon_Environmenal_Valuation.pdf

Eccles, R. G., Ioannou, I., & Serafeim, G. (2014). The impact of corporate sustainability on organizational processes and performance. Management Science, 60(11), 2835–2857. https://www.hbs.edu/ris/Publication%20Files/SSRN-id1964011_6791edac-7daa-4603-a220-4a0c6c7a3f7a.pdf

Economists fail to account for 'natural capital' – report. (2009). WWF. https://wwf.panda.org/wwf_news/?180342/Economists-fail-to-account-for-natural-capital--report

EEA. (n.d.). European Environment Agency. https://www.eea.europa.eu/help/glossary/eea-glossary/social-cost

Elmor, L., Ramos, G. A., Vieites, Y., Andretti, B., & Andrade, E. B. (2024). Environmental sustainability considerations (or lack thereof) in consumer decision making. International Journal of Research in Marketing. https://doi.org/10.1016/j.ijresmar.2024.08.003

Emissions Trading | UNFCCC. (n.d.). https://unfccc.int/process/the-kyoto-protocol/mechanisms/emissions-trading

ESCWA. (n.d.). United Nations Economic and Social Commission for Western Asia. https://www.unescwa.org/sd-glossary/environmental-externalities

Estimating shadow prices of pollution in selected OECD countries. (2014, August 21). OECD. https://www.oecd.org/en/publications/estimating-shadow-prices-of-pollution-in-selected-oecd-countries_5jxvd5rnjnxs-en.html

EEA - Exploitation of Natural Resources. (n.d.). European Environment Agency's Home Page. https://www.eea.europa.eu/en/analysis/publications/92-826-5409-5/page013new.html

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A., & Pappas, G. (2008). Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and weaknesses. The FASEB Journal, 22(2), 338–342. https://doi.org/10.1096/fj.07-9492LSF

Fund, N. I. M. (1988). Policy reform, shadow prices, and market prices. IMF Working Paper, 88(91), 1. https://doi.org/10.5089/9781451951608.001

Gillenwater, M., & Seres, S. (2011). The Clean Development Mechanism: A review of the first international offset program. Energy Policy, 39(10), 6346–6358. https://www.c2es.org/wp-content/uploads/2011/03/clean-development-mechanism-review-of-first-international-offset-program.pdf

Glanemann, N., Willner, S. N., & Levermann, A. (2020). Paris Climate Agreement passes the cost-benefit test. Nature Communications, 11(1). https://doi.org/10.1038/s41467-019-13961-1

Global Environment Outlook 6. (n.d.). UNEP - UN Environment Programme. https://www.unep.org/resources/global-environment-outlook-6

Global Footprint Network. (2020, May 11). Net Present Value Plus - Global Footprint Network. https://www.footprintnetwork.org/npvplus/

Global Resources Outlook 2019 | Resource Panel. (n.d.). Global Resources Outlook 2019 | Resource Panel. https://www.resourcepanel.org/global-resources-outlook-2019

Hardin, G. (1968). The tragedy of the Commons. Science, 162(3859), 1243–1248.
https://doi.org/10.1126/science.162.3859.1243

Heal, G. M. (2001). Nature and the Marketplace: Capturing the value of ecosystem services. ResearchGate.
https://www.researchgate.net/publication/37717209_Nature_and_the_Marketplace_Capturing_The_Value_Of_Ecosystem_Services

Hernández-Solano, A., Avila-Foucat, V. S., & Dyer, G. A. (2023). Estimating shadow prices in economies with multiple market failures. PLoS ONE, 18(11), e0293931. https://doi.org/10.1371/journal.pone.0293931

How to assign value to ecosystem Services. (2024, February 19). Development Asia.
https://development.asia/explainer/how-assign-value-ecosystem-services#:~:text=Recognizing%20the%20value%20of%20nature,but%20also%20for%20future%20generations.

IFC Performance Standard 6: Biodiversity Conservation and Sustainable Management of living Natural Resources. (2019). IFC. https://www.ifc.org/en/insights-reports/2012/ifc-performance-standard-6

IMF. Externalities: Prices do not capture all costs. (2018, June 1).
https://www.imf.org/external/pubs/ft/fandd/basics/38-externalities.htm

Inter-American Development Bank. (2018). Implementation guideline: Economic cost-benefit analysis (CBA) of project environmental impacts and mitigation measures for wastewater treatment projects (WWTPs).
https://publications.iadb.org/en/implementation-guideline-economic-cost-benefit-analysis-cba-project-environmental-impacts-and

IISD. What is an externality? - Sustainable Asset Valuation (SAVi). (2019, March 15). Sustainable Asset Valuation (SAVi). https://www.iisd.org/savi/faq/what-is-an-externality/

IPBES (2019). Global Assessment Report on Biodiversity and Ecosystem Services. https://www.ipbes.net/global-assessment

IUCN Biodiversity Offsets Technical Study Group. (2014). Biodiversity Offsets Technical Study Paper. IUCN. https://portals.iucn.org/library/sites/library/files/documents/2014-044.pdf

Jacob-Lopes, E., Zepka, L. Q., & Deprá, M. C. (2021). Carbon footprint and carbon market. In Elsevier eBooks (pp. 91–116). https://doi.org/10.1016/b978-0-12-823411-2.00009-8

Johnston-Leek, E. (2024, March 27). Here are 23 Times Carbon Offsets Were Found to be Dodgy. The Australia Institute. https://australiainstitute.org.au/post/here-are-23-times-carbon-offsets-were-found-to-be-dodgy-2/

Josefsson, J., Widenfalk, L. A., Blicharska, M., Hedblom, M., Pärt, T., Ranius, T., & Öckinger, E. (2021). Compensating for lost nature values through biodiversity offsetting – Where is the evidence? Biological Conservation, 257, 109117. https://doi.org/10.1016/j.biocon.2021.109117

Kerr, A. (2024, March 5). NC State professor's book explores the history of environmental economics. College of Agriculture and Life Sciences. https://cals.ncsu.edu/news/pricing-the-priceless-spencer-banzhaf/

Khatri, A., Eis, J., World Economic Forum, & McKinsey & Company. (2023). Biodiversity Credits: Demand analysis and Market Outlook. In I N S I G H T R E P O R T [Report]. https://www3.weforum.org/docs/WEF_2023_Biodiversity_Credits_Demand_Analysis_and_Market_Outlook.pdf

Kono, N. (2014). Brundtland Commission (World Commission on Environment and Development). In Springer eBooks (pp. 450–452). https://doi.org/10.1007/978-94-007-0753-5_441

Lampert, A. (2019). Over-exploitation of natural resources is followed by inevitable declines in economic growth and discount rate. Nature Communications, 10(1). https://doi.org/10.1038/s41467-019-09246-2

Lawton, H. (2025, April 8). Article 6 and the future of carbon markets: What organisations need to know. EcoAct. https://eco-act.com/blog/article-6-what-organisations-need-to-know

Ledec, G. C., Johnson, S., & World Bank. (2016). Biodiversity Offsets: a User guide (By M. Lovei, C. J. Warner, & Wychwood Biodiversity). https://documents1.worldbank.org/curated/en/344901481176051661/pdf/110820-WP-BiodiversityOffsetsUserGuideFinalWebRevised-PUBLIC.pdf

Lovell, H., et al. (2009). Carbon offsetting: Sustaining consumption? Environment and Planning A, 41(10), 2357–2379. https://www.researchgate.net/publication/46559824_Carbon_Offsetting_Sustaining_Consumption

M. D. a. N. E., & Heydon, M. J. (2023). The Biodiversity Metric 4.0 User Guide. ResearchGate. https://doi.org/10.13140/RG.2.2.15795.60968

McCauley, D. J. (2006). Selling out on nature. Nature, 443(7107), 27–28. https://doi.org/10.1038/443027a

Meier, S., Balmford, B., Faccioli, M., & Groom, B. (2024). Biodiversity, public preferences and substitutability with an application to Cost-Based shadow pricing SSRN. https://doi.org/10.2139/ssrn.4954302

Microsoft. (2024). 2024 Environmental Sustainability Report | Microsoft CSR. Microsoft Sustainability.

Miller, G. T., & Spoolman, S. (2016). Environmental science (15th ed.).

Millennium Ecosystem Assessment. (n.d.). 6 Concepts of ecosystem value and valuation approaches. https://www.millenniumassessment.org/documents/document.304.aspx.pdf

Millennium Ecosystem Assessment. (2005). Ecosystems and human well-being: Synthesis. Island Press. https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Mitigation Banks under CWA Section 404 | US EPA. (2024, June 28). US EPA. https://www.epa.gov/cwa-404/mitigation-banks-under-cwa-section-404

Ninan, K., & Inoue, M. (2013). Valuing forest ecosystem services: What we know and what we don't. Ecological Economics, 93, 137–149. https://doi.org/10.1016/j.ecolecon.2013.05.005

Nordhaus, W. D. (2017). Revisiting the social cost of carbon. Proceedings of the National Academy of Sciences, 114(7), 1518–1523. https://doi.org/10.1073/pnas.1609244114

O'Dea, R. E., Lagisz, M., Jennions, M. D., Koricheva, J., Noble, D. W. A., Parker, T. H., Gurevitch, J., Page, M. J., Stewart, G., Moher, D., & Nakagawa, S. (2021). Preferred reporting items for systematic reviews and meta-analyses in ecology and evolutionary biology: A PRISMA extension. Biological Reviews, 96(5), 1695–1722. https://doi.org/10.1111/brv.12721

OECD. (2022). Climate Tipping Points: Insights for Effective policy action. In OECD Publishing. https://www.oecd-ilibrary.org/docserver/abc5a69e-en.pdf?expires=1728507249&id=id&accname=guest&checksum=646A194A02D3B85C7F972355B33D574E

OECD. The interplay between voluntary and compliance carbon markets. (2024, July 18). https://www.oecd.org/en/publications/2024/07/the-interplay-between-voluntary-and-compliance-carbon-markets_a2bc1649.html

Organisation for Economic Co-operation and Development. (2025). Recommendation of the Council on guiding principles concerning international economic aspects of environmental policies (OECD/LEGAL/0102). https://legalinstruments.oecd.org/public/doc/4/4.en.pdf

Ortega, J. & University of Wisconsin Stevens Point. (n.d.). Natural Capital's role in sustainable development. https://minds.wisconsin.edu/bitstream/handle/1793/80657/current%20submissionOrtega%2BJ%2BNatural%2BCapital%2Bfinal%2Bsubmission.edited.pdf?sequence=3&isAllowed=y

Ozili, P. K. (2021). Sustainability Accounting. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3803384

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R. T., Dessane, E. B., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S. M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y. S., Amankwah, E., Asah, S. T., . . . Yagi, N. (2017). Valuing nature's contributions to people: the IPBES approach. Current Opinion in Environmental Sustainability, 26–27, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006

Pazos, J. (2024, July 30). Carbon offsets often ineffective for cutting corporate emissions, new evidence reveals - Beyond Fossil Fuels. Beyond Fossil Fuels. https://beyondfossilfuels.org/2024/07/30/carbon-offsets-often-ineffective-for-cutting-corporate-emissions-new-evidence-reveals/

Pearce, D. W., and R. K. Turner (1991). Economics of Natural Resources and the Environment. Baltimore MD: Johns Hopkins University Press, 1990, 378 pp., $42.50, $19.50 paper. American Journal of Agricultural Economics, 73(1), 227–228. https://doi.org/10.2307/1242904

Pearce, R. (2024, March 4). Explainer: What are ecosystem services? Earth.Org. https://earth.org/what-are-ecosystem-services/

Pollination Group. (2024, October 3). Integrity at the forefront as biodiversity credit markets grow - Pollination | Climate Change Investment & Advisory Firm. Pollination | Climate Change Investment & Advisory Firm. https://pollinationgroup.com/media_post/integrity-at-the-forefront-as-biodiversity-credit-markets-grow/

Rea, A. W., & Munns, W. R. (2017). The value of nature: Economic, intrinsic, or both? Integrated Environmental Assessment and Management, 13(5), 953–955. https://doi.org/10.1002/ieam.1924

Rossi, A., & Fujii-Rajani, R. (2024, December 3). Could financial markets incorporate the value of nature? Brookings. https://www.brookings.edu/articles/could-financial-markets-incorporate-the-value-of-nature/

Samuel, N. S. A. (2025). Carbon pricing mechanisms for reducing greenhouse gas emissions and encouraging sustainable industrial practices. World Journal of Advanced Research and Reviews, 25(2), 001–024. https://doi.org/10.30574/wjarr.2025.25.2.0350

Schröter, M., Rusch, G. M., Barton, D. N., Blumentrath, S., & Nordén, B. (2014). Ecosystem services and opportunity costs shift spatial priorities for conserving forest biodiversity. PLoS ONE, 9(11), e112557. https://doi.org/10.1371/journal.pone.0112557

Sheetal. (2024, November 21). Short-Term Profitability vs. Long-Term Sustainability. Hmsa Consultancy Services LLP. https://hmsaconsultancy.com/short-term-profitability-vs-long-term-sustain

Solomon, J. (2024, March 4). Why Environmental Decision Making Is Difficult (and what to do about it). Accendo Reliability. https://accendoreliability.com/why-environmental-decision-making-is-difficult-and-what-to-do-about-it/

Standard on Biodiversity Offsets - Forest Trends. (2017, October 13). Forest Trends. https://www.forest-trends.org/publications/standard-on-biodiversity-offsets/

Stern, N. (2006). The economics of climate change: The Stern review. HM Treasury. http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf

Stern, N. (2007). The economics of climate change: The Stern review. Cambridge University Press. http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf

Stiglitz, J., et al. (2017). Report of the High-Level Commission on Carbon Prices. https://academiccommons.columbia.edu/doi/10.7916/d8-w2nc-4103

Sustainability Report 2023 | Swiss Re. (2024, August 5). Sustainability Report 2023 | Swiss Re. https://www.swissre.com/sustainability/stories/sustainability-report-2023.html

Taaffe, D. (2024, November 21). COP29: Climate Action Network responds to latest Article 6.2 text - Climate Action Network. Climate Action Network. https://climatenetwork.org/2024/11/21/climate-action-network-experts-expressed-dismay-and-called-for-transparency-and-accountability/

Tax Foundation. (2024, February 8). Pigouvian Tax Definition | TaxEDU Glossary. https://taxfoundation.org/taxedu/glossary/pigouvian-tax/

Team, C. (2024, June 1). Shadow pricing. Corporate Finance Institute. https://corporatefinanceinstitute.com/resources/economics/shadow-pricing/

The Clean Development Mechanism | UNFCCC. (n.d.). https://unfccc.int/process-and-meetings/the-kyoto-protocol/mechanisms-under-the-kyoto-protocol/the-clean-development-mechanism

The value of nature: Economic, intrinsic, or both? | Science Inventory | US EPA. (n.d.). https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHEERL&dirEntryId=338690

Twidale, S. (2024, May 21). Global carbon emissions pricing raised record $104 bln in 2023. Reuters. https://www.reuters.com/sustainability/climate-energy/global-carbon-emissions-pricing-raised-record-104-bln-2023-2024-05-21/

U.S. Department of Agriculture - Natural Resource Economics. (2025). Nation Institute of Food and Agriculture. https://www.nifa.usda.gov/topics/natural-resource-economics

UNEP (2021). Making Peace with Nature. https://www.unep.org/resources/making-peace-nature

United Nations. (n.d.). United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 3-14 June 1992 | United Nations. https://www.un.org/en/conferences/environment/rio1992

United Nations. (n.d.). United Nations Conference on the Human Environment, Stockholm 1972 | United Nations. https://www.un.org/en/conferences/environment/stockholm1972

United Nations Environment Programme. (n.d.). New UN report details ecosystem services of almost one billion dollars annually in four pilot countries. UNEP. https://www.unep.org/news-and-stories/story/new-un-report-details-ecosystem-services-almost-one-billion-dollars-annually

Valuing ecosystem services. (2014). In Edward Elgar Publishing eBooks. https://doi.org/10.4337/9781781955161

Varutti, M. (2023). Claiming ecological grief: Why are we not mourning (more and more publicly) for ecological destruction? AMBIO, 53(4), 552–564. https://doi.org/10.1007/s13280-023-01962-w

Wackernagel, M., Hanscom, L., & Lin, D. (2017). Making the Sustainable Development Goals Consistent with Sustainability. Frontiers in Energy Research, 5. https://doi.org/10.3389/fenrg.2017.00018

Wang, S., Fu, B., Wei, Y., & Lyle, C. (2013). Ecosystem services management: an integrated approach. Current Opinion in Environmental Sustainability, 5(1), 11–15. https://doi.org/10.1016/j.cosust.2013.01.003

What is the Kyoto Protocol? | UNFCCC. (n.d.). https://unfccc.int/kyoto_protocol

What is the National Environmental Policy Act? | US EPA. (2025, April 11). US EPA. https://www.epa.gov/nepa/what-national-environmental-policy-act

Webber Wentzel. (2023). National Biodiversity Offset Guideline finally published. https://www.webberwentzel.com/News/Pages/national-biodiversity-offset-guideline-finally-published.aspx

White, P. S. (2013). Derivation of the Extrinsic Values of Biological Diversity from Its Intrinsic Value and of Both from the First Principles of Evolution. Conservation Biology, 27(6), 1279–1285. https://doi.org/10.1111/cobi.12125

World Bank. (2020). State and Trends of Carbon Pricing. https://openknowledge.worldbank.org/entities/publication/bcc20088-9fbf-5a71-8fa0-41d871df4625

World Bank. (2023). State and trends of carbon pricing 2023. Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/58f2a409-9bb7-4ee6-899d-be47835c838f

World Bank Group. (2024, May 21). Global carbon pricing revenues top a record $100 billion. World Bank. https://www.worldbank.org/en/news/press-release/2024/05/21/global-carbon-pricing-revenues-top-a-record-100-billion

World Commission on Environment and Development (WCED). (1987). Our Common Future. Oxford University Press. https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf

World Wide Fund for Nature. (2020). Living Planet Report 2020: Bending the curve of biodiversity loss (R. E. A. Almond, M. Grooten, & T. Petersen, Eds.). WWF. https://www.wwf.org.uk/sites/default/files/2020-09/LPR20_Full_report.pdf

WWF (2022). Living Planet Report. https://www.worldwildlife.org/pages/living-planet-report-2022