SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 12, No. 4, (2026), pp. 4005-4017
Open Access. Online & Print

DOI: 10.5281/zenodo.20458038

PROFITABILITY OF INVESTMENT IN ECO-INDUSTRIAL PARKS AND POTENTIAL BENEFITS OF THE WATER SYMBIOSIS PROCESS: A GAME THEORY APPROACH

Adriana Yamilet Herrera Granizo[1]*, Fausto Danilo Erazo Guijarro[2], Pablo Mauricio Ochoa Ulloa[3], Natalia Estefanía Herrera Salazar[4], Christian Andrés Mazón López[5], Pablo Alberto Gaibor Costta[6]

[1]Ecuador Economista- Master Universitario En Economía Circular Y Desarrollo Sostenible, Universidad de Las Américas (UDLA).
ORCID iD: https://orcid.org/0000-0001-5090-5981, Email: adriana.herrera.granizo@udla.edu.ec
[2]Economista-Doctorado En Desarrollo Económico Y Sectorial Estratégico -Maestría En Desarrollo Económico Y Sectorial Estratégico, Universidad de las Fuerzas Armadas ESPE.
ORCID iD: https://orcid.org/0000-0002-8628-8898, Email: fderazo1@espe.edu.ec
[3]Economista Mención En Gestión- Magister En Formulación, Evaluación y Gerencia De Proyectos Para El Desarrollo Empresarial.
ORCID iD: https://orcid.org/0009-0007-4833-0251, Email: pableyo8a@gmail.com
[4]Ingeniera En Economía Mención En Finanzas Publicas Y Privadas- Master Universitario En Análisis Económico Especializado, Universidad de las Fuerzas Armadas ESPE, Departamento de Ciencias Económicas, Administrativas y de Comercio, Av. General Rumiñahui S/N.
ORCID iD: https://orcid.org/0009-0001-5387-9763, Email: neherrera1@espe.edu.ec
[5]Licence En Droit Economie, Gestion, Mention Economie Et Gestion- Economista- Master Universitario En Economía Y Gestión De La Innovación, Universidad de las Fuerzas Armadas ESPE, Departamento de Ciencias Económicas, Administrativas y de Comercio, Av. General Rumiñahui S/N.
ORCID iD: https://orcid.org/0009-0008-6399-2357, Email: camazon1@espe.edu.ec
[6]Ecuador Economista- Magister En Econometría, Universidad de las Fuerzas Armadas ESPE, Departamento de Ciencias Económicas, Administrativas y de Comercio, Av. General Rumiñahui S/N.
ORCID iD: https://orcid.org/0009-0008-4559-0362, Email: pagaibor@espe.edu.ec

Received: 17/08/2025
Accepted: 19/02/2026

Corresponding Author: Adriana Yamilet Herrera Granizo
(adriana.herrera.granizo@udla.edu.ec)

ABSTRACT

The proposed methodology for evaluating the implementation of Eco-Industrial Parks (EIPs) is divided into two phases: theoretical and practical. In the theoretical phase, a comprehensive literature review will be conducted to establish links between EIPs and the Sustainable Development Goals (SDGs), exploring their impact on emissions reduction, sustainable resource management, and employment promotion. The practical phase will focus on the return on investment (ROI) using economic equations and game theory. This approach will allow for a strategic assessment of the feasibility of water symbiosis and inter-firm interactions in EIPs. A cooperative game theory model is proposed to incentivize collaboration among firms, maximizing shared

benefits and addressing superadditivity and monotonicity in coalition building. The analysis also includes the formulation of profit functions for investors and developers, calculating conditions to ensure their profitability. Water symbiosis will be addressed through a framework that optimizes water resource management and establishes government incentives to encourage corporate participation. The study concludes by highlighting the need for effective policies that stimulate private investment in IEPs and the development of future research to address challenges, such as fluctuations in water supply and demand, while ensuring sustainable and inclusive development.

KEYWORDS: Eco-industrial Parks (IEPs), Sustainable Development Goals (SDGs), Water symbiosis, Cooperative game theory, and Return on investment.

1. INTRODUCTION

In a world where industrialization and economic growth have led to the unsustainable exploitation of natural resources and environmental degradation, the search for approaches that reconcile industrial progress with environmental conservation has become a pressing priority. In this context, eco-industrial parks have emerged as an innovative model that promises to address both economic and ecological imperatives, fostering collaboration and symbiosis among companies in a shared environment. Within this dynamic, the efficient management of water, an essential and increasingly scarce resource, has become fundamental, generating interest in understanding the profitability of investments in eco-industrial parks and how the process of water symbiosis can be a key driver in this equation.

The concept of eco-industrial parks is based on the idea that companies located in a geographically close area can leverage their interactions to achieve greater resource efficiency, waste reduction, and an improved environmental footprint. These parks foster collaboration and the exchange of byproducts between companies, transforming one entity's waste into raw materials for another. This approach not only has the potential to reduce production costs and improve profitability but also advocates for a more sustainable and circular industrial system.

Water availability has become an urgent concern in the context of climate change. According to the Economic Commission for Latin America and the Caribbean (ECLAC) (CEPAL, 2015), rising global temperatures are severely impacting water availability in our region. Furthermore, the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (United Nations, 2021)reveals that more than 2 billion people worldwide lack access to basic sanitation services, exposing them to water contaminated with feces. This crisis has devastating consequences, as diseases related to unsafe water and poor sanitation, such as childhood diarrhea, cause the deaths of 1.5 million children under five in developing countries each year. Moreover, reduced water resources can undermine economic growth, with estimates suggesting a decline of up to 6% of GDP by 2050 in certain regions (Banco Mundial, 2022; United Nations, 2021). To achieve global poverty alleviation goals, it is essential to protect and sustainably use our water resources through improved planning and the implementation of incentives. These data and percentages underscore the importance of taking decisive action to address the water crisis in the context of climate change and ensure a sustainable future for all (CEPAL, 2020).

Within this framework, water emerges as a critical resource and a central element in the planning and execution of sustainable strategies. Proper water management not only drives the viability of industrial operations but is also essential for preserving aquatic ecosystems and safeguarding human health. Water symbiosis, where companies share and reuse water in their processes, is presented as a key component in optimizing water resources in these industrial parks. This practice not only offers environmental benefits by reducing freshwater extraction and pollutant discharge but also has the potential to generate economic advantages by reducing water-related operating costs.

This research will identify the return on investment of eco-industrial parks and potential benefits of the water symbiosis process using a game theory approach, and will design water symbiosis networks to solve the problem of water quality and safety by minimizing freshwater consumption or the discharge of pollutants.

In this context, the crucial question arises: how can the profitability of investments in eco-industrial parks be assessed, particularly in relation to the implementation of water symbiosis practices? The answer to this question involves not only traditional economic considerations, such as investment costs and expected cash flows, but also a deep understanding of inter-organizational dynamics and collaborative strategies within the park environment. In this regard, game theory emerges as a valuable analytical framework, as it allows us to examine how the strategic decisions of each company affect and are affected by the actions of others, and how these dynamics influence the overall profitability and sustainability of the eco-industrial park.

This thesis will explore case studies of eco-industrial parks that have successfully implemented water symbiosis strategies. It will examine the metrics used to evaluate the profitability of these investments and analyze how economic and environmental aspects are interconnected. Furthermore, it will employ game theory to examine how companies make strategic decisions regarding water sharing and how these decisions impact both their own performance and the overall functioning of the park.

This research aims to delve into the intricate interplay between the profitability of investments in eco-industrial parks and the potential benefits derived from the water symbiosis process . By addressing this critical intersection between economics and the environment, this study hopes to provide a deeper understanding of how business strategies, inter-organizational collaboration, and game theory can inform decision-making that will shape the path toward more sustainable and balanced industrial development.

To fully understand the relevance and importance of the background information preceding our topic, it is essential to delve into the issue of water availability in a world marked by climate change. Water availability is a crucial issue that addresses both environmental and humanitarian challenges. In the following paragraphs, we will explore the data and percentages that support the urgent need to address this problem, and how fluctuations in water availability can have a significant impact on the health, economy, and well-being of communities worldwide, as can be seen in Table 1.

Cheng et al. (2015)They emphasized the complexity and high uncertainties associated with offshore oil projects, particularly compared to onshore projects. They focused on the concept of floating production, storage, and offloading (FPSO) + wellhead development, examining its total investment composition, classification, and relationships between components and oil production. Using ordinary least squares (OLS) and Monte Carlo simulations, they quantitatively analyzed the impact of uncertainty on production and estimated the potential investment distribution.

Peerapong y Limmeechokchai (2014)They aimed to present proposals for feed-in tariffs for grid-connected photovoltaic power plants in Thailand. Their study, aligned with Thailand's renewable energy development plan, explored feed-in tariffs using the RETscreen model for three categories: residential rooftops, ground- and rooftop-integrated photovoltaic systems, and utility-scale installations exceeding 1 MW. The results yielded proposed feed-in tariffs based on an after-tax return on capital of 11.0% for each category.

Tominac y Mahalec (2017)They introduced a game theory framework for strategic planning in refinery production. They formulated strategic planning problems as non-cooperative potential games, employing a structure derived from a Cournot oligopoly game. The study demonstrated the usefulness of game theory in competitive production planning scenarios, interpreting the solutions as mutually beneficial responses in competitive planning games.

Korotin et al. (2017)They proposed a stochastic algorithm to construct an optimal portfolio under uncertainty regarding the tax regime and refining margin. The algorithm, illustrated with a case study of a Russian oil company, facilitated the optimization of refinery upgrade projects to maximize net present value. The model's flexibility allowed for rapid adaptation to different objectives, such as maximizing light crude or minimizing project investment costs.

Boix et al. (2015)They explained the design of industrial water networks using a multi-objective optimization strategy. Their approach, based on mixed-integer linear programming, minimized freshwater flows, reclaimed water, and network connections. The strategy was validated through industrial examples, including the design of an Eco-industrial Park involving three companies, considering different regeneration scenarios and connection conditions.

Chin et al. (2021)They presented a systematic resource selection procedure for multi-contaminant water recycling/reuse networks. They developed a resource allocation model, considering the limitations of each water sink due to specific contaminants. The approach, demonstrated through industrial case studies, provided insights into optimal resource allocation strategies to minimize resource use.

Fadzil et al. (2018)They applied the concept of a centralized one-way water reuse header (CWRH) to simplify and manage water reuse and exchange within industrial sites. The centralized water integration methodology aimed to minimize freshwater requirements and wastewater generation across the site. A case study illustrated a 72.3% reduction in total freshwater needs and wastewater generation, highlighting the efficiency of the centralized water integration approach.

The profitability of investment in eco-industrial parks and the benefits derived from the water symbiosis process are critical aspects at the intersection of business management and environmental sustainability. This theoretical framework delves into understanding these two fundamental elements using a game theory approach, which allows for the systematic analysis of the strategies and decisions of the actors involved in these complex processes.

Eco-industrial parks represent an innovative strategy for integrating industrial activities with sustainable practices. These collaborative spaces aim to optimize the use of shared resources, minimize waste, and promote energy efficiency.

The return on investment in eco-industrial parks involves evaluating not only direct economic benefits but also long-term environmental and social impacts. Game theory, by modeling the strategic interactions between companies within these parks, provides a valuable tool for understanding how individual decisions affect overall profitability and the achievement of sustainability goals.

In parallel, the water symbiosis process focuses on efficient collaboration in water resource use among companies within these parks. Water reuse and exchange can generate significant environmental benefits while simultaneously contributing to financial profitability. Game theory becomes an essential tool for analyzing the incentives and challenges associated with implementing water symbiosis practices. Cooperation and competition strategies are explored, considering the maximization of individual and collective benefits.

This theoretical approach seeks to contribute to a holistic understanding of the profitability of investment in eco-industrial parks and the benefits of water symbiosis, highlighting the complex strategic relationships between companies. Game theory offers a robust analytical framework for unraveling the underlying dynamics and provides valuable insights that can guide decision-making toward more sustainable and profitable business practices.

Profitability

Profitability, according to various authors, refers to the ability to generate profits or earnings in relation to the investment made. Below are some definitions of profitability from different authors: According to [author's name] Aguirre et al. (2017), financial profitability is an indicator that measures the relationship between the profit obtained and the investment required to achieve it. It is a measure of the effectiveness of a company's management.

Jin et al. (2020)They Strouhal et al. (2018)consider profitability a tool for decision-making. Decisions are based on the process of evaluating the profitability of an investment or business.Barrero (2013) It highlights that profitability is a relevant topic related to profit generation. These are just a few perspectives from different authors on profitability. Each author may have their own definition and approach, so it is important to consider various sources to gain a comprehensive understanding of the concept of profitability.

Investment

According to the literature and search results provided, different definitions and approaches to investment can be found among various authors. Here are some authors' perspectives on the concept of investment: According to some, Gitman y Joehnk (2009)investment refers to the acquisition of financial assets, such as stocks, bonds, or real estate, with the goal of obtaining future returns or profits. They also emphasize the importance of diversifying investments to reduce risk.

For them Vano et al. (2009), investment involves allocating financial resources to projects or assets with the purpose of generating profits or increasing the value of the invested capital. They emphasize the importance of investment strategy and risk analysis.

Eco-industrial parks

Eco-industrial parks are communities of companies located in the same site that seek to achieve better economic and environmental performance through collaboration and the implementation of sustainable practices (Montastruc et al., 2013). These parks focus on process integration and resource optimization to minimize environmental impact and promote energy efficiency.

An eco-industrial park aims to create synergies among its member companies, promoting collaboration and the sharing of resources such as water, energy, and waste. This can include the reuse of byproducts or the implementation of cleaner management systems and technologies (Montastruc et al., 2013).

Some of the objectives of eco-industrial parks include:

- Reduction of natural resource consumption.
- Minimizing the generation of waste and polluting emissions.
- Promotion of energy efficiency and the use of renewable energy.
- Promoting innovation and the development of green technologies.
- Improving the competitiveness of companies through sustainability.
- These parks offer benefits both for businesses and for the environment in which they are located.

Companies can reduce costs, improve their corporate image, and access new business opportunities. Furthermore, eco-industrial parks contribute to environmental protection, job creation, and the sustainable development of the wider community.

It is important to emphasize that the implementation and success of an eco-industrial park depend on the collaboration and commitment of the participating companies, as well as the support of local authorities and other relevant stakeholders. Furthermore, each eco-industrial park may have specific characteristics and approaches depending on its geographic location and the needs of the companies involved (Park et al., 2015).

Symbiosis process

The process of aquatic symbiosis refers to the beneficial and mutually dependent interaction between different aquatic organisms. In this process, two or more organisms interact in a way that benefits both. In the case of water, symbiosis can occur between different species of aquatic plants, algae, and bacteria, among others (Moran, 2007).

In aquatic symbiosis, aquatic plants can provide a safe habitat and nutrients for algae and bacteria, while the bacteria help the plants obtain essential nutrients through nitrogen fixation and the release of organic compounds. Furthermore, algae can produce oxygen through photosynthesis, which benefits other aquatic organisms (Mattila et al., 2010).

This symbiotic water process is fundamental to the balance and health of aquatic ecosystems. It helps maintain water quality, promotes biodiversity, and contributes to food production and the regulation of nutrient cycling in aquatic ecosystems (Mahler, 1967).

It is important to note that aquatic symbiosis can vary depending on environmental conditions and the species involved. Furthermore, the interaction between aquatic organisms can be complex and influenced by factors such as temperature, nutrient availability, and the presence of other organisms in the aquatic ecosystem (Moran, 2007).

2. METHODOLOGY

The proposed methodology for evaluating the implementation of Eco-industrial Parks (EIPs) with a focus on the Sustainable Development Goals (SDGs) consists of two phases: a theoretical phase and a practical phase.

In the theoretical phase, a comprehensive literature review will be conducted, generating theoretical results that establish the connections between the implementation of sustainable industrial practices (SIPs) and their contribution to the Sustainable Development Goals (SDGs). This involves analyzing how the adoption of eco-industrial practices can positively impact areas such as reducing greenhouse gas emissions, sustainably managing natural resources, and promoting decent work, thus aligning with specific SDGs.

The second phase will focus on practical results, specifically determining the return on investment in the construction of Eco-Industrial Parks and the implementation of water symbiosis projects. This will be carried out using economic equations and game theory to evaluate the profitability of these projects. Cooperative game theory models can be applied to analyze the strategic interactions between companies within the Eco-Industrial Park and how these collaborations impact economic outcomes.

Economic equations will be used to calculate the costs associated with the construction and operation of the PEIs, including initial investments, environmental management costs, and potential savings derived from operational efficiency and the attraction of sustainable businesses. In addition, equations will be incorporated to assess the economic viability of water symbiosis, considering the costs associated with the shared and sustainable management of water resources.

Cooperative game theory will allow for modeling the strategic interactions between companies within the PEI, evaluating how collaboration can generate shared economic benefits. Incentives for adopting sustainable practices and participating in water symbiosis can be considered. Theory to be applied

In game theory, the "Minimum Safe Standard Conservation Approach" refers to a strategy players can adopt to minimize their potential losses in a game with uncertain outcomes. This approach involves players selecting strategies that guarantee a minimum acceptable return, even in the worst-case scenario. In a broader context, this strategy relates to minimizing risk and maximizing certainty in decision-making. Players may adopt this approach when faced with situations where uncertainty about the actions of other players could have unfavorable consequences (Palmini, 1999).

The Minimum Safe Standard Approach to Conservation in game theory focuses on selecting strategies that ensure a minimum return, providing players with some guarantee against the risks and uncertainties inherent in the game. This strategy reflects a concern for minimizing losses rather than maximizing gains in situations where security and stability are paramount (Berrens, 2001).

Part One

Uncertainty regarding future information causes delays in the initiation of eco-industrial park projects. Evaluating water symbiosis projects using traditional approaches such as net present value is imprecise and can lead to erroneous decisions. To address this problem, Leete et al. (2013)they employed an options model based on the volatility of production prices.

As previously mentioned, the objective of this study is to encourage investors to enter the market, as opposed to the opposite problem of preventing market entry. Various methods can be used to discourage entry, such as lowering prices, adopting advanced technologies, and implementing strategies to ensure customer loyalty (Wang et al., 2016).

Babajide et al. (2014)They introduced a game-theory approach to the deterrence-entry dilemma, involving a leader and a follower. Initially, only the leader produces, and the price is set in a way that discourages the follower from entering the market. In this article, this method is applied to another scenario where the leader seeks to attract the follower into the market as a new player.

The model considers four agents and is analyzed using Stackelberg's game theory framework. The intermediate producer acts as the leader, and the investor as the follower. The leader seeks to encourage the follower's investment by fulfilling two objectives: maximizing their own profit and simultaneously providing financial and non-financial support, as well as making adjustments that benefit the investor. The investor's entry process is explored across three phases. The model variables comprise the quantity of output generated by the intermediate producer and the investor, along with the water price coefficient.

First phase: In the initial stage, we assume that the intermediate producer operates independently in the market. Under these circumstances, the intermediate producer decides the production quantity that maximizes their profit, thus establishing the optimal profit level and the price at which they sell their intermediate product. During this phase, it is essential to consider the conditions under which both the production quantity and the producer's profit are positive.

Second phase: Following the analysis of the previous phase, we propose that the investor takes into account the intermediate producer's output, obtained in the first stage. They then incorporate this value into their profit function and calculate their own output by maximizing this function. Since it is desirable for the investor to enter the market, it is essential that their profit be greater than zero. The range for the producer's output will be established based on the objectives of this stage.

Third phase: In this phase, the intermediate producer evaluates the investor's profit, assuming the investor participates in the market, considering the investor's production level obtained in the previous phase. The intermediate producer adjusts their production level and other parameters so that the investor achieves a profit on their investment. The intermediate producer's profit is also calculated. Finally, the conditions that ensure positive values for the dependent variable must be verified.

Second

This section explains the proposed framework for synthesizing the optimal network of industrial symbiosis for water compensated by the relevant authority. It summarizes the industrial symbiosis model considering both cost and environmental objectives. The problem formulation is presented, using a cooperative game theory approach to determine the optimal government subsidy rates for each participating industrial plant. The development of the binding contract for the plants is also explained in this section. The general framework for the authority's compensation is presented, and finally, the game theory analysis of the tax policy that the authority can impose on stakeholders is explained.

3. PRACTICAL IMPLEMENTATION RESULTS

The first stage

To the author's knowledge, there is no investment profitability function for eco-industrial parks. At this stage, the profitability established by the intermediary developer is defined as a linear function of the construction volume as follows:

$p(q_1) = \alpha - bq_1$(1)

The profit of the intermediate producer is defined as a function of the sum of sales revenue plus investment subsidies, minus the cost of construction.

$$\varpi(q_1) = q_1(p(q_1) + \ i - c), \quad (2)$$

$$\varpi(q_1) = q_1(n + i - c) - bq_1^2$$

The profit function of $\varpi(q_1)$is concave at q_1.. The output volume of the intermediate producer and the related maximum of the profit function are calculated as follows:

$q_1 = \frac{(n-c+i)}{2p}$(3)

$\rho_1 q_1 = \frac{(n-c+i)^2}{4p}$(4)

The construction price is a function of the construction volume, so it can be calculated as follows.

$\rho q_1 = \frac{(n+c-n)}{2}$(5)

Considering the maximum point ρq_1provided in q_1.

In all steps, the conditions under which the variable becomes positive must be checked, so it is necessary to consider some of the parameter adjustments.

The construction price for the investor is considered as a function of the total construction by both the intermediate builder and the investor (6). The water produced by the intermediate builder is equal to equation (3), according to the first phase. Substituting this quantity into (6) yields the price function (7).

$$\rho(q_1,q_2) = n - \beta q_1 - \beta q_2 (6)$$

$$\rho(q_2) = n - \frac{(n-c+i)}{2} - \beta\rho q_2 (7)$$

The investor's profit is a function of the sum of sales revenue and the grant awarded to the investor, less the cost of construction.

$$\varpi(q_2) = \rho q_2 + \Pi q_2 - (cq_2 + \varphi) \quad (8)$$

$$\varpi(q_2) = q_2(\Pi + n - c - \frac{(n-c+i)}{2} - \beta q_2^2 - \varphi$$

The profit function is $\varpi(q_2)$ concave at q_2.. The investor's maximum profit function and the related construction volume are calculated as follows.

$$q_2 = \frac{(n-c+2\Pi-i)}{4\beta}(10)$$

$$\varpi_2 = \frac{(-n+c-2\Pi+i)^2-16\beta\varphi}{16\beta}(11)$$

Considering the demonstration of the maximum point of $\varpi(q_2)2$ in q_1. In all steps the condition on the positivity of the variable must be verified, so it is necessary to consider some of the conditions on the parameters.

Substituting the quantity for " q_2" found by (9) in (7) yields the price quantity as follows:

$$\rho(q_2) = \frac{1}{4}(n + 3c - 2\Pi - i)(11)$$

In this phase, the price is considered based on the total construction.

$$\rho(q_1,q_2) = n - \beta(q_1 + q_2)(12)$$

This price is used to calculate the profit function.

$$\varpi_2 = (q_1, q_2) = \rho(q_1 + q_2)q_2 - (cq_2 + \varphi) + \Pi q_2(13)$$

Next, the investor's construction volume that maximizes the profit function is calculated. The investor's construction volume is a function of q_1.

$$q_2 = \frac{(n-c+\Pi-\beta q_1)}{2\beta}(14)$$

The maximum profit is calculated as follows.

$$\varpi_2 = \frac{(n-c+\Pi)^2+bq_1(-2(n-c+\Pi)+\beta q_1)-4\beta\varphi}{4\beta}(15)$$

Then, the range of the intermediate builder's construction volume can be calculated so that the investor's profit is positive. The intermediate builder must produce within this range for the investor's profit to be positive. Finally, the most favorable price, the construction volume of both the intermediate builder and the investor, the total construction, and the investor's profit are calculated.

Second phase: Water Symbiosis Process

In this section, as shown in Figure 4, the proposed framework for synthesizing the optimal network of industrial symbiosis of water compensated by the corresponding authority is explained.

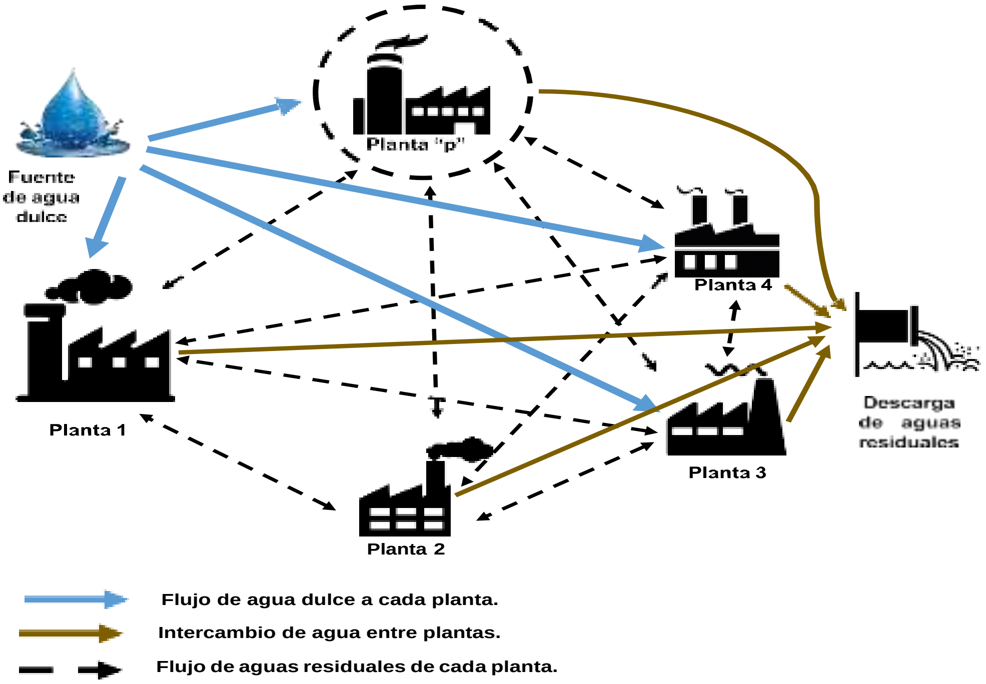

Figure 1a water exchange model in an eco-industrial park.

This shows the visualization of the water network in the industrial park. Water exchange in the industrial park is modeled with three sets of equations. Mass balance equations for sources and sinks, as well as constraints for properties or contaminants, limit the sinks.

The mass balance for all sinks $'j'$for a specific process $'p'$; the water sources come from (a) the water sources of all other plants $'pp'$, including itself ($F_{pp,SRi,SKj,p}$), b) freshwater ($F_{FW,p,SKj}$). The total flow rate from the water sources must equal the sink flow rate ($F_{p,SKj}$). It denotes the mass balance of the source for the entire source $'i'$and process $'p'$, i.e., the sum of the water sent to (a) wastewater treatment ($F_{p,SRi,WW}$), and the recycling from the source $'i'$to all sinks in the other processes , $'pp'$including itself ($F_{p,SRi,SKj,pp}$), is equal to the source flow rate ($F_{p,SRi}$).

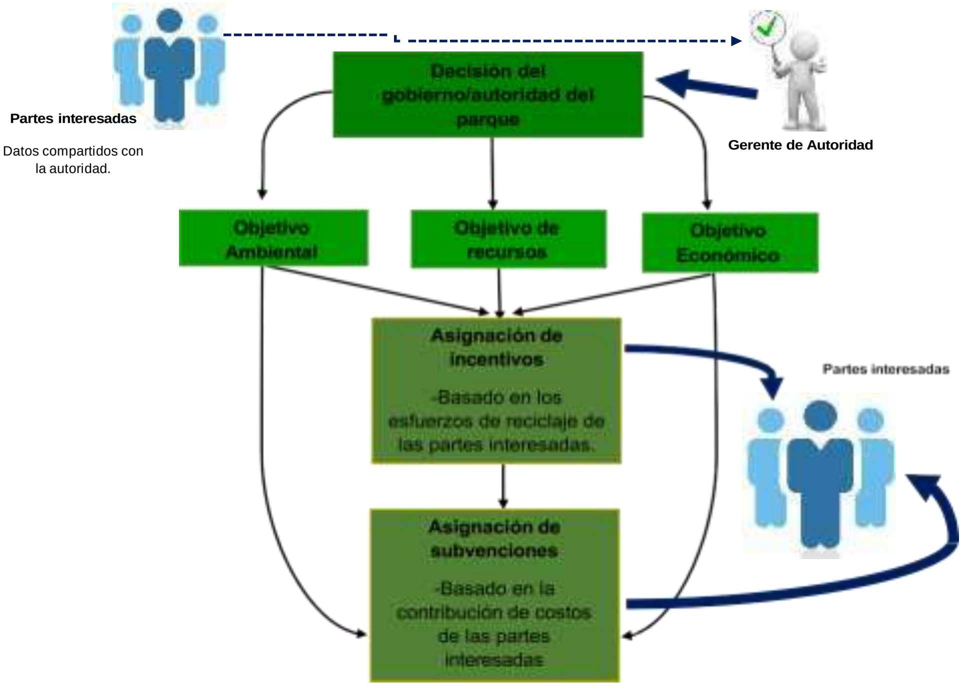

Figure 2A proposed general framework for the allocation of government incentives and subsidies to the water eco-industrial park.

In the concept of solving a cooperative game, the objective is to identify a fair and equitable distribution of costs or gains for different players (plants). A cost-saving allocation problem can be modeled as a cooperative game with transferable utility, that is, a pair $(\mathrm{K}, \varsigma\tau)$where $K = \{1,\ 2,\ \dots\ ,\ \psi\}$ denotes the entire set of firms, also known as the grand coalition. The characteristic function CSassigns to any Snon-empty coalition, and the Cost Savings $\varsigma\tau\ (\tau)$are achieved if the firms τcooperate, as shown in Figure 5. Cost savings for industrial symbiosis can occur in different contexts, such as utility cost savings or annualized total cost savings. The two conditions for a Cooperative Game are superadditivity and monotonicity. Full details of the background of cooperative game theory can be found in Appendix B of the supplementary material.

$Súper\ -\ aditividad\ :\ \varsigma\tau\ (\tau \cup \psi) \geq \varsigma\tau(\tau) + \varsigma\tau(\psi) \forall \tau, \psi \subseteq K, \tau \cap \psi = \Theta$(16)

$Monotonía$: $\varsigma\tau\ (\tau) \leq \varsigma\tau(\psi)\ \forall \tau \subseteq \psi \subseteq K$ (17)

Superadditivity implies that the cost savings resulting from the merger of any two coalitions are greater than the sum of the cost savings of those coalitions separately. This provides an incentive to form the larger coalition. Similarly, monotonicity implies that a larger coalition is more beneficial than a smaller one. From the perspective of industrial symbiosis, these properties also hold true. The property of superadditivity means that stakeholders are only convinced to join the larger symbiosis (with all other stakeholders) if the overall benefits are greater than the benefits without sharing resources with other stakeholders. Otherwise, it is preferable to pursue process integration alone rather than combining efforts with others. The property of monotonicity suggests a similar concept, whereby stakeholders gain greater benefits by cooperating with more stakeholders rather than forming a smaller coalition.

There is an additional property, convexity, which implies that the incentives for a new plant to join a symbiotic network increase as the network grows. However, this property does not always hold true for industrial symbiosis. This is because the cost of integrating with the newcomer may be higher due to the new plant's geographic location relative to other plants, or because it may have low-quality waste discharge and high fresh resource requirements. Nevertheless, considering environmental and resource objectives, this property could be valid, since greater collaboration among plants can maximize resource savings and reduce pollutant discharges.

$$\varsigma\tau\,(\tau \cup \{i\}) - \varsigma\tau(\tau) \leq \varsigma\tau(\psi \cup \{i\}) - \varsigma\tau(\psi) \qquad \forall \tau \subseteq \psi\ y\ i \notin \psi (18)$$

Water symbiosis in eco-industrial parks is a strategic approach that seeks to optimize water use and reduce environmental impact in an industrial setting through collaboration among companies. This process involves a comprehensive assessment of the water needs of all companies within the industrial park, identifying available water sources such as groundwater or rainwater. An integrated infrastructure is then developed to connect the facilities of all companies, implementing efficient water treatment and purification technologies, such as filtration and biological treatment systems.

Water reuse and recycling are essential components, with systems established to treat wastewater generated by companies and promote its reuse in industrial processes or for non-potable purposes. Continuous monitoring of water quality and facility performance, along with a centralized management system, ensures efficiency and effective coordination among participating companies. Education and engagement play a crucial role in raising awareness among companies about the economic and environmental benefits of sustainable water management, fostering collaboration and communication.

Furthermore, the successful implementation of this approach involves introducing incentives and regulations that promote participation in water symbiosis programs. These may include government policies, environmental regulations, and financial benefits for companies committed to sustainable practices. It is a dynamic process that requires continuous adaptation, evaluating system performance and making adjustments as needed, as well as integrating new technologies and practices as best practices in water management evolve.

4. DISCUSSION

Efficient water resource management and strategies to encourage private investment have become critical issues, especially in the context of rapid economic and industrial growth in developing countries. The construction of eco-industrial parks is presented as a key solution to facilitate water symbiosis and address the growing demand for industrial water consumption. In this regard, it is imperative that governments promote alternative policies that stimulate private investment, whether in the construction of new parks or in the development of alternatives at existing refineries.

However, there is a lack of clarity in the process of motivating private companies to commit to sustainable projects. While some investors may be inclined to participate in projects that promise profitability, legitimate concerns exist regarding the recoverability of investments and ambiguous financial aspects that could discourage their involvement. Analyzing these projects from a game theory perspective, considering investors, government, developers, and customers as key actors, provides a framework for understanding the complexities of strategic decisions in this environment.

The most significant policy implication of these studies is the critical need to attract private investment, both domestically and internationally, in high-value projects. It is acknowledged that market conditions can vary, and this study considers several simplified scenarios, employing a common approach in the literature. The price of water is treated as a linear function of production volume and profit, simplifying the analysis and enabling a clearer understanding of the dynamics involved.

While sensitivity analyses offer adequate accuracy in the model's results, practical simulation has limitations due to the model's simplification and insufficient data. Nevertheless, attracting government investment can guarantee a minimum level of demand, given that the investment benefit exceeds the zero threshold. However, the magnitude of the benefit depends on the investor's actions and their willingness to take risks. The importance of a fair and equitable allocation of subsidies and incentives to facilitate the implementation of sustainable practices is highlighted, as is the need for a cooperative game theory approach to comprehensively evaluate distribution schemes.

Furthermore, it is proposed that future research address more realistic issues, such as fluctuations in supply and demand, environmental benefits for authorities, wastewater treatment plants, and water price variations. Comparison with studies by other authors, such as [authors' names], [authors' names Cheng et al.(2015)] Peerapong y Limmeechokchai

(2014), Tominac y Mahalec (2017)and Fadzil et al. (2018)[authors' names], highlights the diversity of approaches and models used to address similar problems. For example, while Cheng et al. focus on the impact of uncertainty on offshore oil projects, [authors' names] Peerapong y Limmeechokchai (2014)explore investment in photovoltaic solar power plants. This diversity of topics and models underscores the complexity of investment decisions across different sectors (Tominac & Mahalec, 2017). Tominac y Mahalec (2017)They contribute a game theory framework for the strategic planning of oil refineries, highlighting the importance of rational and resilient decisions in competitive environments. Furthermore, Korotin et al. (2017)they propose a multi-criteria approach for selecting optimal portfolios of refinery upgrade projects, incorporating uncertainty regarding margins and tax regimes.

Boix et al. delve into industrial water management through multi-objective optimization, using mixed-integer linear programming to evaluate solutions in eco-industrial parks. Finally, Fadzil et al. (2018)they address water minimization in industrial facilities through a centralized, one-way water reuse header approach.

Comparing these studies reveals a variety of methodological approaches and models used to address specific problems in different industrial contexts. While some focus on uncertainty, others explore investment efficiency in renewable energy or strategic planning in refineries. These differences highlight the need to adapt approaches to the specific characteristics of each sector and underscore the importance of considering the diverse factors that influence investment decisions.

Taken together, these studies provide valuable insights into the complexities of decision-making in industrial settings, highlighting the importance of government policies, the allocation of subsidies and incentives, and strategies for attracting private investment in sustainable projects. The variety of models and approaches offers a comprehensive overview for addressing these challenges, and comparing them underscores the diversity of possible strategies for fostering sustainable and efficient practices across different industrial sectors.

5. CONCLUSIONS AND RECOMMENDATIONS

The study highlights the critical importance of investing in the construction of Eco-Industrial Parks (EIPs) in response to rapid economic and industrial growth in developing countries. These parks play an essential role in facilitating water symbiosis and meeting the growing industrial demand for this vital resource. However, the lack of clarity regarding private companies' motivations for investing in EIPs reveals a dilemma between investors' pursuit of profitability and concerns about the recoverability of their investments.

The proposed methodology, which incorporates game theory and economic equations, allows for the analysis of market entry conditions from the perspective of various key players. It highlights the need for effective government policies to stimulate private investment at both the national and international levels. Despite the accuracy of the model's results during the sensitivity analysis, the limitations of the practical simulation are acknowledged, due to the model's simplification and insufficient data.

The fair allocation of subsidies and incentives for implementing water symbiosis in PEI is a crucial aspect addressed in this study. A multi-stage cooperative game theory approach is proposed, highlighting the fundamental role of the park authority in resource allocation and the influence of stakeholder decisions on recycling flows. However, the assumption of rationality among stakeholders is acknowledged, and more realistic approaches, such as evolutionary game analysis, are suggested for further exploration.

The study raises additional questions for future research, including fluctuations in supply and demand, water price variations, and the need for additional levels of government oversight. Ultimately, it highlights the need to address these challenges holistically to ensure the success of Integrated Water Resources (IWR) projects, thereby contributing to environmentally sound and sustainable economic development in developing countries

BIBLIOGRAFÍA

1. Aguirre, D. S., … M. M. A.-E. periplo, & 2017, undefined. (2017). Rentabilidad de hoteles boutique explicada desde la experiencia memorable. *Scielo.Org.Mx*. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1870-90362017000200081
2. Babajide, N., Ogunlade, C., … D. A.-… J. of S., & 2014, undefined. (2014). Comparative analysis of upstream petroleum fiscal systems of three (3) petroleum exporting countries: Indonesia, Nigeria and Malaysia. *Researchgate.NetNA Babajide, CA Ogunlade, DO Aremu, ST Oladimeji, OA AkinyeleInternational*

Journal of Sciences: Basic and Applied Research, 2014•researchgate.Net, *15*(2), 99–115. https://www.researchgate.net/profile/Nathaniel-Babajide/publication/289676503_Comparative_Analysis_of_Upstream_Petroleum_Fiscal_Systems_of_Three_3_Petroleum_Exporting_Countries_Indonesia_Nigeria_and_Malaysia/links/57095d5708aed09e916f95c1/Comparative-Analysis-of-Upstream-Petroleum-Fiscal-Systems-of-Three-3-Petroleum-Exporting-Countries-Indonesia-Nigeria-and-Malaysia.pdf?_sg%5B0%5D=started_experiment_milestone&origin=journalDetail

3. Banco Mundial. (2022, September 2). *Agua: Panorama general*. https://www.bancomundial.org/es/topic/water/overview
4. *Barrero (2013) rentabilidad - Google Académico*. (n.d.). Retrieved August 23, 2023, from https://scholar.google.com/scholar?hl=es&as_sdt=0%2C5&q=Barrero+%282013%29+rentabilidad&btnG=
5. Berrens, R. P. (2001). The safe minimum standard of conservation and endangered species: a review. *Environmental Conservation*, *28*(2), 104–116. https://doi.org/10.1017/S037689290100011X
6. Boix, M., Montastruc, L., Azzaro-Pantel, C., & Domenech, S. (2015). Optimization methods applied to the design of eco-industrial parks: a literature review. *Journal of Cleaner Production*, *87*(1), 303–317. https://doi.org/10.1016/J.JCLEPRO.2014.09.032
7. CEPAL. (2020, August 4). *The part played by natural resources in addressing the COVID-19 pandemic in Latin America and the Caribbean | CEPAL*. https://www.cepal.org/en/insights/part-played-natural-resources-addressing-covid-19-pandemic-latin-america-and-caribbean
8. CEPAL, N. (2015). *La economía del cambio climático en América Latina y el Caribe: paradojas y desafíos del desarrollo sostenible*. https://repositorio.cepal.org/handle/11362/37310
9. Cheng, C., Wang, Z., Liu, M., & Zhao, Y. (2015). A Quantitative Analysis of the Impact of Production Uncertainty on the Offshore Oil Project Investment. *Energy Procedia*, *75*, 3007–3013. https://doi.org/10.1016/J.EGYPRO.2015.07.614
10. Chin, H. H., Varbanov, P. S., Liew, P. Y., & Klemeš, J. J. (2021). Pinch-based targeting methodology for multi-contaminant material recycle/reuse. *Chemical Engineering Science*, *230*, 116129. https://doi.org/10.1016/J.CES.2020.116129
11. Fadzil, A. F. A., Wan Alwi, S. R., Manan, Z., & Klemeš, J. J. (2018). Industrial site water minimisation via one-way centralised water reuse header. *Journal of Cleaner Production*, *200*, 174–187. https://doi.org/10.1016/J.JCLEPRO.2018.07.193
12. *Gitman y Joehnk (2009) - Google Académico*. (n.d.). Retrieved August 23, 2023, from https://scholar.google.com/scholar?hl=es&as_sdt=0%2C5&q=Gitman+y+Joehnk+%282009%29&btnG=
13. Jin, C. X., Li, F. C., Zhang, K., Xu, L. Da, & Chen, Y. (2020). A cooperative effect-based decision support model for team formation. *Enterprise Information Systems*, *14*(1), 110–132. https://doi.org/10.1080/17517575.2019.1678071
14. Korotin, V., Popov, V., Tolokonsky, A., Islamov, R., & Ulchenkov, A. (2017). A multi-criteria approach to selecting an optimal portfolio of refinery upgrade projects under margin and tax regime uncertainty. *Omega*, *72*, 50–58. https://doi.org/10.1016/J.OMEGA.2016.11.003
15. Leete, S., Xu, J., & Wheeler, D. (2013). Investment barriers and incentives for marine renewable energy in the UK: An analysis of investor preferences. *Energy Policy*, *60*, 866–875. https://doi.org/10.1016/J.ENPOL.2013.05.011
16. Mahler, M. S. (1967). On Human Symbiosis and the Vicissitudes of Individuation. *Journal of the American Psychoanalytic Association*, *15*(4), 740–763. https://doi.org/10.1177/000306516701500401
17. Mattila, T. J., Pakarinen, S., & Sokka, L. (2010). Quantifying the total environmental impacts of an industrial symbiosis-a comparison of process-, hybrid and input-output life cycle assessment. *Environmental Science and Technology*, *44*(11), 4309–4314. https://doi.org/10.1021/ES902673M
18. Monsalve, S. (2003). John Nash y la teoría de juegos. *Lecturas Matemáticas, ISSN-e 0120-1980, Vol. 24, Nº. 2, 2003, Págs. 137-149*, *24*(2), 137–149. https://dialnet.unirioja.es/servlet/articulo?codigo=7175604
19. Montastruc, L., Boix, M., Pibouleau, L., Azzaro-Pantel, C., & Domenech, S. (2013). On the flexibility of an eco-industrial park (EIP) for managing industrial water. *Elsevier*, *43*, 1–11. https://doi.org/10.1016/j.jclepro.2012.12.039ï

20. Moran, N. A. (2007). Symbiosis as an adaptive process and source of phenotypic complexity. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(SUPPL. 1), 8627–8633. https://doi.org/10.1073/PNAS.0611659104
21. Palmini, D. (1999). Incertidumbre, aversión al riesgo y los fundamentos de la teoría de juegos del estándar mínimo seguro : una reevaluación. *Economía Ecológica*. https://www.sciencedirect.com/science/article/pii/S0921800998000937
22. Park, J., Park, J., production, H. P.-J. of cleaner, & 2016, undefined. (2015). A review of the National Eco-Industrial Park Development Program in Korea: Progress and achievements in the first phase, 2005–2010. *Elsevier*. https://doi.org/10.1016/j.jclepro.2015.08.115
23. Peerapong, P., & Limmeechokchai, B. (2014). Investment Incentive of Grid Connected Solar Photovoltaic Power Plant under Proposed Feed-in Tariffs Framework in Thailand. *Energy Procedia*, *52*, 179–189. https://doi.org/10.1016/J.EGYPRO.2014.07.069
24. Pérez, J., & Jimeno, J. L. (2004). *Teoría de juegos*. https://www.academia.edu/download/52517410/33040062.pdf
25. Strouhal, J., Štamfestová, P., Ključnikov, A., Strouhal, J., & Vincúrová, Z. (2018). DIFFERENT APPROACHES TO THE EBIT CONSTRUCTION AND THEIR IMPACT ON CORPORATE FINANCIAL PERFORMANCE BASED ON THE RETURN. *Researchgate.NetJ Strouhal, P Štamfestová, A Ključnikov, Z VincúrováJournal of Competitiveness, 2018•researchgate.Net*. https://doi.org/10.7441/joc.2018.01.09
26. Tominac, P., & Mahalec, V. (2017). A game theoretic framework for petroleum refinery strategic production planning. *AIChE Journal*, *63*(7), 2751–2763. https://doi.org/10.1002/AIC.15644
27. United Nations. (2021). *Agua | Naciones Unidas*. https://www.un.org/es/global-issues/water
28. Vano, E., Sanchez, R., Fernandez, J. M., Gallego, J. J., Verdu, J. F., De Garay, M. G., Azpiazu, A., Segarra, A., Hernandez, M. T., Canis, M., Diaz, F., Moreno, F., & Palmero, J. (2009). Patient dose reference levels for interventional radiology: A national approach. *CardioVascular and Interventional Radiology*, *32*(1), 19–24. https://doi.org/10.1007/S00270-008-9439-9
29. Wang, L., An, H., Liu, X., & Huang, X. (2016). Selecting dynamic moving average trading rules in the crude oil futures market using a genetic approach. *Applied Energy*, *162*, 1608–1618. https://doi.org/10.1016/J.APENERGY.2015.08.132