Circular Economy Investments: A Portfolio Selection Framework

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Abstract. This research explores the practical implementation of the circular economy into operations since it's been communicated as one of the main strategic goals of private and public organizations. Despite the commitments in society, there is still a debate on what a circular economy is. Such structural changes in the operations require investments, which will be prioritized based on existing business constraints. Therefore, a framework to assess projects is being proposed for organizations to implement their strategic sustainability targets, such as greenhouse gas neutralization. Through Design Science Research, the following work presents a literature review of the knowledge areas required to design and demonstrate a generic artifact. As a result, developing a specific portfolio to assess circular economy capital investments is recommended, increasing the strategic alignment between projects and sustainability targets. After collecting data at the project level, it starts with Multi-Attribute Utility Theory as the multicriteria decision tool to balance economic criteria and sustainability metrics measured by Life Cycle Assessment. Then it incorporates specific risks to the ranking and utilizes mathematical programming to adjust the portfolio to financial constraints. The artifact demonstration proves its potential to be applied in circular economy capital investment decision-making and as a foundation for further development under specific scenarios of different organizations.

Keywords: Circular Economy, Project Portfolio Management.

1 Introduction

For many years, life on earth was conducted with the sense of infinite, as there would always be somewhere else to migrate and explore. Economists, in particular, have difficulty recognizing that the environment should be considered a closed loop. As such, process outputs become inputs for other processes [1].

When observing economic activities ignoring environmental aspects, the economy works as a linear system [2]. The most seen economic model is based on finite resource extraction, production, consumption, and disposal. Textiles, clothing, and plastics exemplify the current economic model. It is estimated that 60% of all textiles and clothing produced worldwide are directed to either landfill or incineration after a year of production [3].

A new concept suggests an alternative to recover the value of disposed goods and prevent environmental impact, creating new operations to separate, treat and re-insert material into the production chain [4]. The circular economy (CE) transforms goods at the end of their life into new resources for the production chain, closing the production loop and minimizing waste generation. It proposes that it is possible to alter the logic of mass production to self-sufficiency: reuse of items that can be reused, recycling of things that cannot be reused, repair of damaged goods, and remanufacturing of materials [5].

The new model needs to overcome its status of being a trend, to become an inspiration for society to redesign the current economic model, increasing production efficiency. The production processes need to be structured in a way that there are tangible benefits to doing so [4]. Its broad implementation is harmed by multiple conceptualizations [6]. These different concepts add complexity to knowledge accumulation and prevent its progression [7]. Society believes a complete transition may never occur, with linear and circular products sharing the market [8]. Concurrently, there is a view that the new model proposed is only theoretical, as thermodynamic principles prevent a complete transition [9].

Its early adoption in products and services may provide business advantages to other market players [3]. However, a lack of knowledge sharing in its practices and methods prevents business development [10]. In the business environment, there are more risks in the circular business model than in the linear model. Its products and services are based on their linear versions and may be more expensive to produce as they require additional processes and logistics. Investment decision-making shall include particularities and specific risks of its context [11].

Life Cycle Assessment (LCA) supports evaluating circular strategies, their impact on the environment, the efficiency of how resources are being applied, and assessing changes in the production processes [12]. LCA-based decision-making contributes to a better adherence to the organization’s strategy, measuring an impact before and after a particular modification in a process [13]. Integrating multidisciplinary criteria in decision-making increases transparency and participation for decision-makers. Consequently, these are desirable effects when assessing sustainability policies [14].

Many countries, cities, communities, and organizations show interest in adopting the Paris Agreement. But in reality, public commitments are still limited. Further engagement could be achieved by implementing emission pricing mechanisms to reach the goals set in the Paris Agreement [15,16].

An organization sets strategic goals composed of tangible steps to progress toward its Vision. The execution of these concrete steps is managed through a project portfolio [17]. Using the organization strategy as a starting point for portfolio selection strengthens the connection of goals and work processes, increasing the likelihood of the strategy’s materialization after project execution [18]. Project portfolios should be designed to address a specific context of an organization’s strategy [19].

Circular investments may reduce operational costs and increase efficiency while boosting an organization’s reputation [20]. But, changing to a new model brings additional risks to profits, reducing incentives to accept changes [21]. Conversely, maintaining the linear economic model may be a lost opportunity for further economic development [3]. The lack of knowledge sharing, and multiple conceptualizations add risk to the circular business model and divert investments [6].

Inspired by Sven et al. [8], when analyzing the combination of different knowledge areas, using disruptive concepts will lead to new production models once it starts to be assessed as multidisciplinary. While researchers frequently address the main areas of this research separately, there is a knowledge gap in overlapping CE and project portfolio selection.

It is necessary to progress the conceptualization of how organizations will structure their CE project portfolio. Through circular measures like re-use, recycling and reutilization, organizations modify their processes to achieve carbon neutrality targets, demonstrating the importance of such conceptualization for investment decisions. Specifically, these investment decisions are not explored, and there is limited guidance on how a transition scenario from a linear model to a circular one impacts them. A decision-making framework could facilitate assessing its project portfolio and selection. **Therefore, the research question is how to structure a project portfolio selection framework to implement carbon neutrality goals, through CE, in a transition scenario between economic models**.

2 Background

2.1 Circular Economy

CE results from the progression of different conceptualizations found in academic research, such as environmental economics, industrial ecology, and sustainable development. It seeks to become an alternative to the neoclassic economic model, setting a formal relationship between economy and environment [2,4,22,23].

The linear economic development logic transforms natural resources into commodities and goods through manufacturing processes. The circular logic uses reutilization, reduction, and recycling as its main principle, reducing the insertion of new material into the production chain [5]. Although multiple definitions are available, they all suggest a closed-loop economic model [24]. It has the potential to enable new consumption patterns and support society to achieve sustainability and well-being, with minimum impact in material, energy, and environmental effects [4].

The environment provides resources to support life and absorbs disposals, maintaining nature at a steady state. In its original framework proposed by [2], the environment regenerates at a certain rate. Like a mass balance equation, resource accumulation or balance conditions can only be achieved if disposals are less than the overall system regeneration rate.

Kirchherr et al. [7] performed a literature review of CE definitions. The authors identify 114 different proposals of what it means. 95 of the 114 definitions were different between themselves. In their research, the authors suggested that researchers clearly state their work's definition. Accepting the authors' suggestion, this research utilizes Kirchherr et al. [7, p. 224] definition:

> "A circular economy describes an economic system that is based on business models which replace 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations".

CE represents a fundamentally new approach to economic systems, rather than simply an adjustment to existing models [7]. Kirchherr et al. [25] propose in their research about barriers to implementing it that lack of consumer knowledge and interest and hesitational organization culture are critical threats to its progress.

The combination of its poor interpretation and extreme concept simplification creates a risk of the circular model becoming obsolete [24]. Innovation in reutilization, remanufacturing, and reprocessing materials compete with traditional waste disposals practices such as landfills and incineration [9]. Regulation is an area that will require policymakers' action to allow its complete implementation. Goods disposal and reinsertion into the production chain may require additional labor and incentives [5].

A linear business's useful life differs from a circular business, which needs to be considered in capital projects' economic and risk analysis [11]. Organizations report concerns about profits in the CE model. Investment decisions are based on metrics such as Payback, Internal Rate of Return (IRR), and Net Present Value (NPV) [21]. Once most players adopt CE in the market, the competitive advantage obtained by early adopters will reduce once circular characteristics are not a difference between products/services [26].

Decision-making related to circular strategies can be frequently addressed through LCA, giving visibility on environmental metrics such as greenhouse gas emissions, water, energy, and others [13]. Despite the academic debate between methods for environmental assessment, life cycle management is frequently used successfully [12]. It supports researchers in assessing technologies [27], creating a quantitative analysis of environmental impacts as described in ISO 14040 for decision-making [28,29].

However, for long-term analysis of an existing process, the LCA will not address that the technology was rightfully selected. Since the inception of a process change, different technologies should be assessed considering their entire useful life [27]. Roos et al. [12] suggest that to create a strong connection between CE and LCA, clear metrics with targets should be part of communicating an organization's strategic goals. Despite different scholars and workstreams, a definition of how to apply LCA holistically for CE still does not exist [13].

The vast data range and multiple options for entering data into a life cycle model add complexity to the analysis. Auxiliary methods such as multiple criteria decision tools may provide a more structured assessment [30].

2.2 Project Portfolio Management

A project portfolio comprises a group of initiatives managed concurrently to achieve strategic organization goals [17]. The portfolio needs to be connected to an external environment and provide specific responses through different initiatives to risks that the organization faces. This process should be reviewed with sufficient frequency as there are changes in the external environment [19]. Hansen and Svejvig [37] performed a literature review on project portfolio management and propose that scholars conceptualize the topic in different areas, including portfolio selection and optimization.

Portfolio selection and optimization aim to drive the decision-making process in selecting the best mix of projects for an organization, optimizing resource utilization, and reducing risks [31]. The overall expectancy of the selection process should acknowledge that there is no such thing as a perfect portfolio selection and that the desired outcomes should be used to structure the decision process [32].

In the context of innovation projects, considering the strategic advantages that a particular project enables once implemented enhances the effectiveness and quality of the portfolio selection process, resulting in better decision-making [33].

Another strategic advantage example was shown by Kock and Gemünden's research [34]. There are positive correlations between project sequencing and portfolio success. The authors demonstrated that proactive sequencing enables incremental improvements by implementing new projects that are available only after the completion of previous ones.

Projects should be individually assessed in the portfolio selection process and then aggregated to provide a prioritized ranking of their value to the organization as a group using a multicriteria decision tool [35]. The decision-making process should be multidimensional, incorporating different criteria and considering stakeholders' perspectives [32].

The project portfolio selection problem can be generalized as a multicriteria decision. Portfolio goals are set in a way that contains multiple criteria with relative importance to establish a ranking [36]. Applying decision tools is a fundamental step in the portfolio selection process, assessing a project's adherence to short and long-term goals and different stakeholders' expectations [32]. Developing the selection method with the project team contributes to increasing the acceptance of the results obtained by a project portfolio selection process [37].

Resource availability, segment, and business environment may require specific methods for a multicriteria decision problem, from more technical tools to more socialization. The tool's complexity should depend on resources, data, and availability of time [37]. Finding the balance between the tool's complexity and socialization is a necessary step that organizations shouldn't overlook. The experiment shown in

Phillips and Bana e Costa's [38] research suggests that socializing the decision brings additional value to the portfolio selection process.

When selecting the appropriate multicriteria decision tool, it is possible to classify them into outranking and utility value methods. The outranking methods consider that there is a preference of the decision maker between the options in specific criteria. Despite its logical application, the outranking techniques in a portfolio selection problem may have vulnerabilities when including qualitative aspects that are less technical and become subjective to the decision maker's perspective [39–41].

Methods such as the Multi-Attribute Utility Theory (MAUT) and Analytical Hierarchy Process (AHP) are based on the utility value of multiple criteria in a decision problem. These methods set the relative importance of certain criteria, providing a ranking for the decision maker. MAUT allows the combination of qualitative and quantitative variables in the multicriteria decision model as a numeric ranking. Due to the pre-set relative importance of each criterion, it is a tool that facilitates the comprehension of the decision for different stakeholders, facilitating the acceptance of the output of the decision model [41–44]. AHP is also a method used for different knowledge areas and is adaptable. Despite its application and comparison with an outranking method in Zak's [45] research for portfolio selection, Dutra [40] suggests that it is inappropriate for large portfolios since the pair-wise comparison between multiple options undermines its advantages.

Munda [14] proposes using methods that do not allow compensation between economic and environmental criteria in determining a preference ranking. Zanghelini et al. [30] found 109 academic publications involving LCA and propose that multiple criteria tools are important to account for trade-offs between economic and environmental criteria. Although the author indicates AHP as the tool more frequently used, Zanghelini et al. [30] agree with Munda [14] that outranking methods are preferable as they reduce the compensation potential in methods based on the utility theory. However, applications based on the utility theory provide satisfactory results and a more transparent application.

The decision model may include other variables, such as financial resources. Mathematical programming can contribute to the portfolio selection problem [46]. Both Abbasi et al. [47] and Dutra [40] and propose that its application can include different restrictions, such as project interdependency, sequencing, mutually exclusive projects, and others.

Thus, combining multicriteria decision tools with mathematical programming may provide an optimal combination for the portfolio selection problem.

3 Research Methodology

The chosen research strategy to design the portfolio selection framework was Design Science Research (DSR) due to its prescriptive nature to fill gaps between the theory and practice of knowledge areas [48]. The central aspect of design science is to present an innovative design to a problem related to the practical application of specific knowledge areas [49]. The research shall propose an artifact capable of completing the intended functionality and prove through an application that the artifact promotes the progress of its scientific field [50,51]. The research artifact is not by itself a scientific product. It needs to show functionality to a practical problem to result in a product with scientific significance [52].

Peffers et al. [53] have proposed a generic approach for DSR, seeking the unification of multiple approaches found in the literature. The steps identified by the authors are problem and motivation identification, defining the artifact, design and development, demonstration, validation, and communication. March and Smith [50] indicate that frameworks are potential artifacts proposed by design science. Hevner, March, and Park [51] propose different validation methods for artifacts, which include simulation with artificial data and description of its functionality under different scenarios.

This research intends to utilize Peffers et al. [53] approach to generate a portfolio selection framework. Sections 1 and 2 identify the research problem and contextualize the artifact's development. Section 4 defines the artifact, demonstrates its design and application, and reviews its utilization with simulation using artificial data [51]. The final step is the communication of the artifact, which is accomplished through sharing our research.

4 Results

4.1 Artifact Design

Martinsuo and Geraldi [19] propose in their research that a portfolio shall be designed to achieve targeted goals from the organization's strategy, and the design of its work processes must consider the particular context of the targeted goals.

Given that: (*i*) organizations set targets to progress to their carbon neutralization target utilizing circular measures, and (*ii*) CE investments share the same business environment as their linear competitors, using the portfolio management knowledge, it is possible to group these initiatives into a single portfolio. This is possible because the projects share the same target, so their business case will be built similarly, and use combined selection criteria. When seeking the optimal investment decision, different risk factors have a more comprehensible interpretation if they are integrated into risk factors. This proposal is based on the work of Abbasi et al. [33], which suggests that a broad risk assessment leads to a more effective portfolio selection and contributes to identifying new risks for innovative projects. The risks involving a CE project portfolio are shown in Table 1, combining them into groups of different risk factors.

One of the most relevant risk factors is the Conceptual Risk. To effectively perform an investment decision, the strategy goal needs to be defined coming from a unified view from the organization. The portfolio aims to materialize the organization´s Mission and Vision through different initiatives.

Conceptual Risk: An organization should communicate its conceptual view of CE, and its goals towards sustainability. Investments shall be aligned with the strategy and demonstrate to the organization the progression they offer compared to the current state.

Context and Source	Risk Factors
CE has different definitions and approaches [6,7]	Conceptual
CE public commitments are not aligned regarding concept and mitigation actions [54]	
Public commitment to CE is still limited [55].	
There are different formats to measure circularity [12]	
The environmental assessment should be performed individually to each project [9].	Methodo-logical
The LCA is a tool applied to measure the efficiency of CE strategies with before/after scenarios [12,13].	
Continue to operate in the linear economy may increase taxes [55]	Financial
Maintain economic profit [21]	
Economic advantages of CE may be reduced once it becomes a market standard [26].	
Not adopting CE may prevent development of economic value [3].	
CE investments also target increase in productivity and reduction of operational cost [20].	
Traditional investment appraisal metrics are applicable to CE [21].	
A complete transition to a circular economy may not occur, with linear and circular products available in the marketplace [8].	Transition
CE framework is not thermodynamically feasible [9,56].	
Lack of a common strategy and knowledge sharing [6,10]	
Competition between linear and circular products/services [9].	
Increased complexity and unknown risks of new processes [27]	
CE framework is not thermodynamically feasible [9,56].	
Lack of a common strategy and knowledge sharing [6,10]	
Competition between linear and circular products/services [9].	
Lack of understanding of how the consumer values circular products [7].	Commercial
Improve organizational reputation [20].	
Increase competitiveness in the market [3].	
Lack of consumer interest is a barrier to further implementation of CE [25].	
The Paris Agreement targets may be incorporated into the Law [57].	Legal
Increase in complexity of operations regulations when replacing virgin feedstock with post-consumer residuals [21].	
Technology evolution of recycling methods and techniques [5]	Technology
Increased complexity and unknown risks of new processes [27]	

Tab.1. Relevant risk factors in a CE investment decision.

The LCA is an essential tool to demonstrate progression compared to the current state. It also can be used to monitor how the organization progresses to certain commitments with a due date and how a specific project may significantly impact a commitment. Additionally, the standardized approach proposed by ISO 14040 supports the communication of targets with stakeholders and the market.

> **Methodological Risk:** CE Investments should be individually assessed by their sustainability benefits. A consolidated method such as the LCA is recommended for consistency purposes.

Return on invested capital is a fundamental aspect of any organization structured to have a profitable operation. These investments are performed at the micro level following [7] conceptualization. Although sustainability investments aim to make an environmental contribution, the literature shows that an increase in productivity is also expected for this type of investment. In a transition scenario between linear and circular economic models, both types of products/services will be competitors in the market.

> **Financial Risk:** Investments are looking to reduce operations' fixed and variable costs and are appraised through traditional methods. These investments should pursue economic improvements and capture local incentives in their business case.

> **Transition Risk:** Investments should consider transition scenarios between linear and circular economic models and that both types of products/services will be competitors in the marketplace.

> **Commercial Risk:** Investments should be structured when applicable in commercial studies, demonstrating the expected consumer behavior and contribution margin improvements.

Some risks, such as legal and technology, are particular to the research context. These factors need to be considered in the portfolio selection process. The PMI [17] proposed generic approach is a reference for managing risks and methodologies applicable to a specific context. However, setting a single risk assessment may result in an ineffective decision model. The recommendation is that these knowledge areas should be addressed but prescribing a more specific risk assessment tool requires the context of an organization as a primary input.

> **Legal Risk:** Investments should monitor the local regulations regarding legal aspects (such as permitting, incentives, and carbon taxes) for circular business models.

> **Technology Risk:** Investments should perform a risk analysis of the applied technology.

Grouping different risks into risk factors brings additional consistency in risk management [17], facilitating the design of a generic CE portfolio selection framework.

Meyer et al. [58] propose to divide the portfolio selection problem into three steps. First, restrict the candidates to a predetermined criterion. Second, the selected candidates will be ranked following a multicriteria decision method, and third, the rank will be communicated to stakeholders for investment decisions.

Following this proposal, an entry requirement must be set for the artifact as its first step. The portfolio entry requirement blocks a project from being included and going through the designed selection process if it is outside the strategic goal set in the entry requirement. Allowing a project to enter a portfolio with a conceptual misalignment undermines the decision model's capability of providing an optimal result.

> **Entry requirement:** Must have as a business objective the accomplishment of the sustainable strategic goals set by the organization and demonstrate through the LCA method that they contribute tangibly to the organization's target.

The second step proposed by [58] demands a structured analysis, running the portfolio through a decision model with pre-set criteria. Caballero et al. [46] recommend structuring this step based on the existing organization knowledge, culture, project type, and resource availability. Project-level deliverables should be inputs to the decision model to assess the investments further.

Projects that rely on external data, such as circular market predictions and product transition from linear to circular, should require a study to support the economic model. These projects will compete for financial resources in the portfolio selection process with projects that rely only on internal information, or compete with established linear competitors, for example. In addition, a sensitivity analysis in combination with probabilistic methods can further strengthen the portfolio decision model.

Considering the transition between linear and circular products/services, carbon pricing should be part of the economic model depending on where the projects are executed. The World Bank Group [59] published a dashboard monitoring where carbon pricing mechanisms have been incorporated and how the topic progresses.

Legal and Technology risks should be part of the selection framework through specific tools and methods used in each product/service segment. The reviewed literature suggests that building scenarios around carbon pricing mechanisms, linear to circular transition, using proven/not-proven technologies, and legal barriers should be explored.

All these data points should be integrated through a multicriteria decision model, providing a structured ranking for decision-makers. Based on the literature review, the framework proposed utilizes a utility value method. The CE context is dynamic, and there is still an open debate on applying its principles in practical actions. Using an outranking method in a generic portfolio can become a challenge once the decision-makers have to prefer one project over the other. The utility value method provides a better format to combine different quantitative and qualitative factors and weights for different criteria. The vulnerabilities indicated in utility value methods for environmental decisions by Munda [14], and Zanghelini et al. [30] are recognized but have not been made in the portfolio selection decision problem. Once the portfolio has a defined entry criterion, such as achieving carbon neutrality, all the initiatives under that portfolio have a common goal. The outcome of the decision model will provide the best group of projects to accomplish the goal.

While AHP is commonly used in the CE context [30], combining tangible and intangible criteria requires a matrix to assess the cost vs. benefit of each criterion, then a pair-wise comparison. Since it has yet to be known the size of the portfolio that the framework will be applied, AHP may increase the complexity of the selection process. Therefore, MAUT is more adaptable for small to large portfolios and facilitates the combination of qualitative and quantitative criteria. A recommendation is to incorporate decision blocks instead of a numeric ranking. The blocks will cover a specific numeric interval, representing a final investment decision: (*i*) Invest (>80 points), (*ii*) Analyze (30 to 80 points), e (*iii*) Reject (<30 points). The framework incorporates the second and third steps proposed by Meyer et al. [58], selecting alternatives using pre-set criteria and establishing a ranking for decision-makers. A stepwise selection process has also been proposed by Dutra et al. [60] and Polyashuk [36].

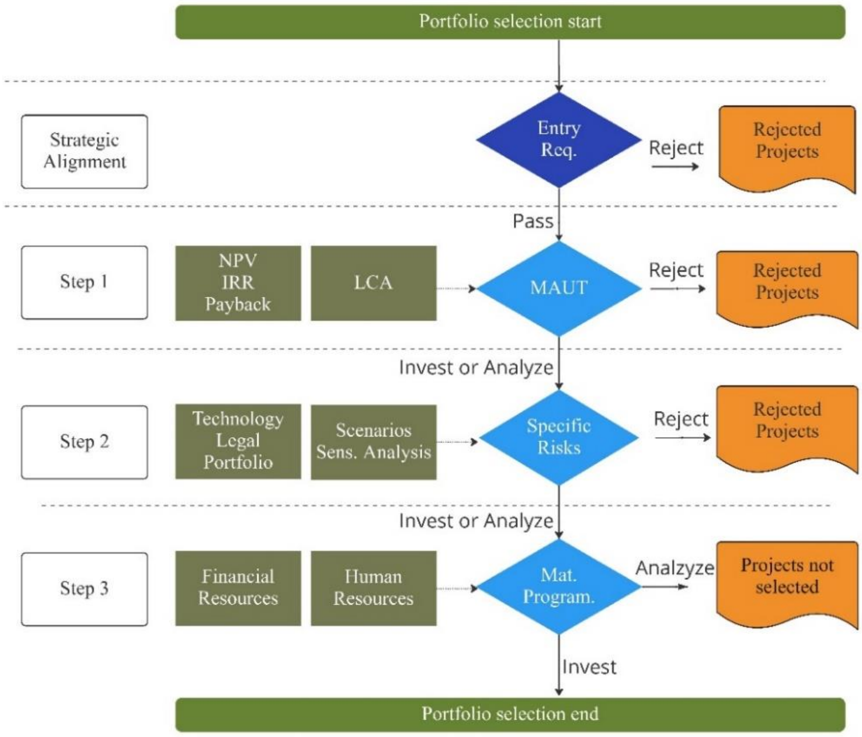

Fig. 1. Research's proposed framework.

The artifact for portfolio selection proposed by this research is demonstrated in Figure 1. It combines theories, methods, and tools to appraise investments to achieve an organization's sustainable targets. The first step is applying MAUT as a multicriteria decision model, setting numeric scores from 0 to 100, and classifying the proposed budget in decision blocks. The second step includes incorporating specific portfolio and CE contextual risks, allowing projects to move blocks depending on the risk assessment. Finally, a third step comprises external restrictions through mathematical programming.

In the first step, typical investment appraisal factors were combined with the LCA focused on a carbon neutrality goal. Table 2 summarizes these risks and proposes weights and ranges for each metric appraised on the investments.

Risk Factor	Criteria	Weight	Score	Points
NPV	NPV ≥ Project Cost	20%	100	20
	NPV > 0		50	10
	NPV ≤ 0		0	0
IRR	IRR ≥ Capital cost + 5%	20%	100	20
	IRR > Capital cost		50	10
	IRR ≤ Capital cost		0	0
Discounted Payback	Payback < 2 years	20%	100	20
	Payback between 2 to 5 years		50	10
	Payback > 5 years		0	0
Sustainability (LCA)	1.5 × Project cost for t/CO2 < Local cost of tCO2eq	40%	100	40
	Project cost for t/CO2 < Local cost of tCO2eq		50	20
	Project cost for t/CO2 > Local cost of tCO2eq		0	0
	Total Points range:			0 - 100

Tab. 2. Summary of MAUT in Step 1.

To increase the potential of a broad application of the proposed framework, it has been suggested to divide the total score weight into 60% economic and 40% sustainability, requiring a combination of both factors to be assigned in the Invest block. These weights should be carefully selected for each organization's context. An equal weight between financial aspects has been given to NPV, IRR, and Discounted Payback, which can be adjusted based on preference. In sustainability, all projects have been vetted by an entry criterion and mitigate risks of prioritizing economic factors. However, due to local differences in carbon pricing policies, individual analysis of each project is required to evaluate their sustainable contribution on a cost basis. After Step 1 and accounting for points in each criterion, projects should be classified and grouped into blocks for decision-makers review. Rejected projects should not proceed to Step 2 due to their low attractivity.

Step 2 includes incorporating specific risks, allowing projects to move between blocks if they present favorable conditions in the circular and portfolio context. Due to the higher complexity in Step 2, eliminating rejected projects in Step 1 allows the organization to focus resources on projects with a more positive perspective on their outcome. Appendix A presents scales to incorporate risks to the resulting ranking of Step 1. Once these risks are included, projects are classified again in blocks for review by decision-makers, as shown in Table 3.

Projects	**Points after S1**	**Blocks after S1**	**Specific risks**	**Points after S1 and S2**	**Blocks after S1 and S2**
Project *x*	80	Invest	x	80+x	-
Project *y*	50	Analyze	y	50+y	-
Project *z*	10	Reject	Not performed	Rejected	Rejected

Tab. 3. Block classification after step 1 and step 2.

Step 3 utilizes results from Step 2 and incorporates external restrictions to the portfolio with mathematical programming. Organizations may have different acceptance levels for the complexity of mathematical programming. Still, the goal could be as simple as selecting projects that meet a budget allowance for the portfolio. It is critical to evaluate if the proposed financial disbursement is flexible enough to adjust without affecting project results. Therefore, if mathematical programming processes the information without socializing the incorporation of the restrictions, the model may result in a sub-optimal decision.

Suppose an organization has a defined budget for a future period. In that case, the decision problem can be simplified with mathematical programming to two different outcomes: either the portfolio will adjust and fit into the budget with schedule adjustments, or lower-ranked projects will be rejected because they exceed the organization’s budget. With the proposed portfolio, projects not selected that are part of the Invest or Analyze blocks will be reviewed in the following portfolio selection cycle.

Portfolio management is a dynamic work process with multiple information inputs. The proposed framework intends to incorporate the relevant decision-making aspects of sustainability investments and project portfolio management.

4.2 Framework Application

Selecting a portfolio is one of the strategic decisions taken by an organization, as it involves differentiating products/services from competitors. Therefore, the framework application utilizes one Company and listed projects, but the project-level information is filled with artificial data.

The application utilizes a multinational energy company with a public commitment to eliminate greenhouse gas emissions based on the Paris Agreement definitions. Seven projects will be processed through the decision model to test the framework proposed by this research.

To start, projects must meet the entry criteria proposed, with a tangible contribution to the sustainability targets. LCA should be applied to each project, showing the reduction from the current state of the Company's emissions. In this case, emissions are measured in grams of CO_2eq/MJ. After validating that the projects meet the entry requirement criteria, this research inserts artificial data to appraise the projects, as shown in Table 4.

Project	**Period 0**	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Budget**
1	$ 2	$ 10	$ 3			**$15**
2	$ 6	$ 8	$ 10	$ 2		**$26**
3	$ 6	$ 3				**$9**
4	$ 1	$ 2				**$3**
5	$ 1	$ 1	$5	$ 10	$ 2	**$19**
6	$ 3	$ 4	$ 7	$ 2		**$ 16**
7	$ 2	$ 10	$ 15	$ 5		**$ 32**
Total	**$ 21**	**$ 38**	**$ 40**	**$ 19**	**$ 2**	

Tab. 4. Financial planning with yearly disbursements (in millions)

Projects should be developed using the organizational project management processes, providing deliverables for portfolio selection. Preferably, all investments should be at a minimum development stage. Appendix B demonstrates the application of the LCA and carbon pricing for Step 1. For the sustainability criteria, it utilizes the local cost of carbon versus the carbon reduction proposed by a particular project divided by its budget. After accounting for all factors, Step 1 is summarized in Appendix C. With the scores of Table 5, investments are allocated to blocks recommending a course of action given their results.

Project	**Period 0 budget**	**Points after S1**	**Block after S1**	**Specific Risks (S2)**	**Points (S1+S2)**	**Block after S1 and S2**
Project 1	$2	60	Analyze	To be performed in Step 2		
Project 2	$6	0	Reject			
Project 3	$6	30	Analyze			
Project 4	$1	80	Invest			
Project 5	$1	20	Reject			
Project 6	$ 3	90	Invest			
Project 7	$ 2	60	Analyze			

Tab. 5. Block summary after Step 1 (budget in millions)

Step 2 starts with projects in the Investment or Analyze block and their current score. Appendix D provides details of the assessment of specific risks and their incorporation into the ranking and blocks. Table 6 shows the summary of Steps 1 and 2, with the current prioritization ready to initiate Step 3.

Project	Period 0 budget	Points after S1	Block after S1	Specific Risks (S2)	Points (S1+S2)	Block after S1 and S2
Project 1	\$2	60	Analyze	0	60	Analyze
Project 3	\$6	30	Analyze	-10	20	Reject
Project 4	\$1	80	Invest	+40	120	Invest
Project 6	\$ 3	90	Invest	-15	75	Analyze
Project 7	\$ 2	60	Analyze	-15	45	Analyze

Tab. 6. Block summary after Step 1 and Step 2 (budget in millions)

As the final step, Step 3 includes an external restriction. For example, the organization has been set to have \$7 million as a restriction for the capital budget for the following year. Therefore, the following mathematical equations are proposed. After applying these equations, Projects 1, 4, and 6 are selected.

$$60\times x1 + 120 \times x4 + 75 \times x6 + 45 \times x7 = \text{Maximize } \Sigma \quad (1)$$
$$and \text{ X}i \geq 0; \; Xi \; = \leq \; 1; \text{ and X } = \text{ Integer} \quad (2)$$
$$2 \times x1 + 1 \times x4 + 3 \times x6 + 2 \times x7 \leq \text{y} \quad (3)$$
$$y = \text{available budget} \quad (4)$$

Mathematical programming does not consider projects' flexibility in their spending curve. Table 4 presented a summary of the expenditures per year that were suggested initially for each project. However, in a capital restriction scenario, projects may be able to adjust the spending curve to utilize the entire budget for a particular portfolio. As a result, Equation 3 would have to be reviewed. Figure 2 shows the evolution of all steps proposed in the artifact. If the organization's dynamic is required, the bar chart shown can be presented step-by-step to decision-makers.

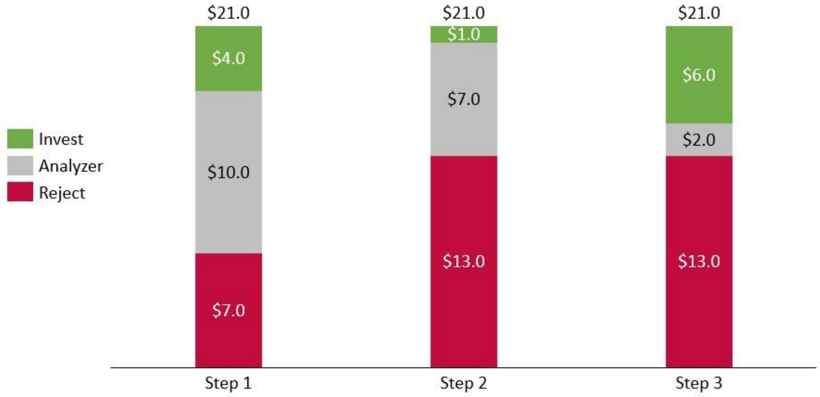

Fig. 2. Portfolio progression by blocks [35].

Project 7 maintains its block with two potential outcomes: either being included in the portfolio with reduced a budget if possible or being postponed to the next budgeting cycle.

4.3 Framework Review and Validation

The portfolio selection framework was tested in a practical situation, utilizing an organization's portfolio that intends to become carbon-neutral in its operations. An organization with more than 230 projects was used to build the demonstration of the artifact, using only 7 for simplification purposes.

The Entry Criteria and the LCA requirement are critical factors in ensuring strategic alignment between projects and goals. Both combined demonstrate tangibly how much that specific project contributes to the goal. Step 1 reviews economic and environmental factors. It is sufficiently generic to be adapted to different segments and/or methodologic preferences. Still, it prescribes guidance to practitioners on the main aspects based on the literature review. Step 2 includes specific risks and further develops the economic analysis with more sophisticated methods. Lastly, Step 3 incorporates external restrictions. In the application, this research utilized budget as a single restriction.

The artifact was functional and provided a practical format to design and select a CE project portfolio for organizations that intend to neutralize their carbon emissions. Once the sustainability commitments expand to further goals, new criteria can be added to the framework. Although artificial data was used at the project level, actual data may change the projects selected by the framework, but for this research, it would not affect the goals.

The requirements for an effective portfolio selection process suggested in Patanakul's research [61] were also identified in the framework application. Through the Entry Criteria, projects not aligned with the portfolio's strategic goals are rejected. Incorporating specific risks and allowing flexibility in the framework's design makes it adaptable to changes in internal and external scenarios. The indicators utilized to select projects are aligned with the CE context and best practices identified through a literature review of the knowledge areas here applied. The utilization of the visual format, as shown in Fig.2, inspired by Mavrotas et al. [35] research, allows visual interpretation of data for decision-makers.

One of the strengths of the proposed framework is its adaptability. The Entry Criteria can be adjusted to different organizational goals. Step 1 utilized MAUT as the multicriteria decision method because of its flexibility and potential to easily adjust weights between other criteria. Incorporating specific risks in Step 2 and external restrictions in Step 3 was proposed as steps into the selection process, enabling different organizations to adjust based on their preference for tools and data availability.

5 Conclusion

This research proposes a framework to select CE economy investments in a project portfolio. One of its uses is to choose projects that intend to move organizations toward their carbon neutrality goals. Section 2 reviewed the knowledge foundations of the areas utilized in the framework design to achieve the research goal. The research method was presented in Section 3, referencing its use to resolve practical problems through academic research. The artifact's design process, testing, and assessment were discussed in Section 4, identifying the main risk factors involving CE investments and demonstrating how the dynamic of the portfolio selection would occur in an example with artificial data.

Despite being conceptually designed, implementing a circular model is still a challenge for society to overcome [62]. Ghisellini et al. [4] propose that it has the potential to radically transform the current model to one that provides a more balanced approach between economic development and sustainability. The framework proposed is a step to enable further discussion. Its generic approach was intended to embrace the portfolio selection of different segments. In its design, each component might require customization of the selection criteria. Therefore, a simpler artifact facilitates its continuous development by other researchers and customization by different organizations.

One of the advantages of the proposed framework is the combination of the LCA analysis for environmental metrics with the economic model. The work process suggested by ISO 14040 promotes listing all inputs and outputs, which can be later converted into financial data for the economic model.

This research contributed to the practical implementation of the CE. Similar research was not identified during the research process, where a CE project portfolio, risks, criteria, and how investment decisions could be made were jointly explored.

For future research, it is suggested to test the framework with real data and socialize its results with decision-makers and experts. In addition, a broader view of risk management provided by Enterprise Risk Management could be beneficial.

One limitation identified is that the framework does not consider project financing and considers project selection for the first year of the portfolio, not considering that it may compromise cash flow in future years. In the second year of the portfolio selection, projects in execution should be considered while assessing new projects. Organizations and researchers should consider the following considerations in their context.

After noticing the conceptual debate surrounding the CE, this research reviewed its original conceptualization [2] and how it has grown in organizations and society. Our work intended to refrain from participating in the conceptual debate of CE but to contribute practically to implementing it. Lastly, the framework's design was intended for organizations planning to achieve at least economic neutrality with their product/services. A fundamental pillar of the framework is to consider a project's economic outlook and the business's financial health when assessing CE investments.

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Appendix

A. Specific Risk Factors

Risk Factor	Scenario	Follow up action	Score modifier
Economic Model	Cost data is internal, low risk of change	Update score	+5
	Cost structure is based on transition scenarios and/or commercial studies.	Perform specific study for the Project and update metrics with probabilistic economic model.	0
Legal	Location with established law for CE.	Update score	+10
	Location with local law in transition to CE.	Update score and perform scenario analysis with carbon pricing.	+0
	Location does not have legislation for CE.	Update score and perform scenario analysis with carbon pricing.	-10
Technology	Project uses established technology, state of the art already achieved.	Update score	+20
	Project uses technology under development, with potential upgrades during operations.	Specific technology analysis and update economic model, if applicable.	0
	Pilot technology, not existing on a commercial scale.	Specific technology analysis and update economic model, if applicable.	-10
Project Sequencing	Restricts other projects in the portfolio	Update score	+10
	Can be replicated internally in the organization.	Update score	+5
	No benefit	-	0
Portfolio	No resource conflicts.	Update score	+5
	Conflict with other projects in the portfolio, resolved by integrated planning.	Integrate planning and resolve conflicts.	0
	Conflict with other projects in the portfolio, which cannot be solved by planning.	Review scope and resolve conflicts, so both projects do not conflict with their goals and resource utilization	0

B. **Carbon pricing analysis in Step 1**

Project	**Location**	**Budget**	**LCA**				
			Project cost in US$ / tCO2e	Local legislation?	Local CO2 US$ / tCO2e	Average regional cost	Score for Step 1
Project 1	Spain	$ 15	$ 8.00	Yes	$ 16.58		40
Project 2	Brazil	$ 26	$ 12.00	No		$ 4.99	0
Project 3	Portugal	$ 9	$ 32.00	Yes	$ 26.44		0
Project 4	Germany	$ 3	$ 21.00	Yes	$ 33.16		40
Project 5	Canada	$ 19	$ 27.00	Yes	$ 39.96		20
Project 6	Peru	$ 16	$ 3,00	No		$ 4.99	40
Project 7	Morocco	$ 32	$2,50	No		$9,84	40

Source: World Bank Group [59].

C. **End of Step 1.**

Project	**Location**	**Budget**	**NPV**		**IRR**		**Discounted Payback**		**LCA**		**Score after Step 1**
		$ million	$ million	Score	%	Score	years	Score	$	Score	
Project 1	Spain	$ 15	$ 14	10	10%	10	6	0	$ 8.00	40	60
Project 2	Brazil	$ 26	- $ 2	0	5%	0	12	0	$ 12.00	0	0
Project 3	Portugal	$ 9	$ 3	10	8%	10	3	10	$ 32.00	0	30
Project 4	Germany	$ 3	$ 4	20	15%	20	2	20	$ 21.00	40	80
Project 5	Canada	$ 19	$ 6	10	7%	10	9	0	$ 27.00	20	20
Project 6	Peru	$ 16	$ 18	20	17%	20	4	10	$ 3,00	40	90
Project 7	Morocco	$ 32	$ 3	10	7%	10	8	0	$ 2,50	40	60
Average WACC: 6%.											

D. Specific Risks assessment.

Project	**Economic Model**		**Legal**		**Technology**		**Sequencing**		**Portfolio**		**Score after Step 2**
	Risk	Score	Risk	Score	Risk	Score	Risk	Score	Risk	Score	Total
Project 1	Transition/ commercial	0	Existing legislation	+10	Pilot	-20	Yes, in another unit	+5	No conflicts	+5	0
Project 3	Transition/ commercial	0	Existing legislation	+10	Pilot	-20	No benefits	0	Conflicts resolves by new resources	0	-10
Project 4	Internal Project	+10	Existing legislation	+10	State of art	+20	No benefits	0	Conflicts resolves by planning.	0	+40
Project 6	Internal Project	+10	Local law does not exist	-10	Pilot	-20	Yes, in another unit	+5	Conflicts resolves by planning.	0	-15
Project 7	Transition/ commercial	0	Local legislation does not exist	-10	Pilot	-20	Yes, restricts portfolio	+10	No conflicts	+5	-15