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A methodology for identifying results and impacts in technological innovation projects

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ABSTRACT

As investments in policies and projects in science, technology, and innovation (STI) grow, it becomes increasingly important to determine the benefits society receives in return for the public resources thus invested. However, existing methodologies are somewhat limited in scope as they do not possess mechanisms for correctly identifying non-measurable, indirect results and impacts. This study addresses these knowledge shortcomings, and it proposes and validates an alternative method to identify the social, environmental, and economic outcomes and indirect impacts of STI projects. Findings indicate that the proposed method helps fills the gaps in knowledge about ex-post methodologies used to evaluate indirect results and impacts in STI projects. One aspect that sets the proposed method apart from the existing approaches is that it contemplates a wide range of analytical categories of indirect impacts for assessing the effects of STI projects. The principal academic and practical contribution of this study is the development of an accessible artifact that can identify the results and indirect impacts of projects in diverse areas of STI. The study extends the understanding on the methodologies to identifying results and indirect impacts of STI projects.

1. Introduction

The technological forecasting and competitiveness of a nation or an organization may be significantly affected by its policies and practice in the areas of science, technology, and innovation (STI) and its technology transfer [1,2]. That is, "in every nation, innovation and technology play a crucial role in maintaining and accelerating the economic development" [3; p., 1]. Thus, technological innovation projects play an essential role in development involving economic, social, environmental, and technological aspects [4].

In addition, the number of public and private financing bodies increasingly require the realization of strategic evaluation of the impacts on society and science [5]. This phenomenon is occurring because economic tensions are challenging public organizations and governments to demonstrate that the investments they make have a positive impact on society [6,7].

The literature argues that, to suitably measure the results (what was obtained from the project objectives) and impacts (the importance of the results achieved) of STI projects and to develop a reliable set of references for the decision-making processes of organizations and governments, it is necessary to develop new, well-structured models, methods, and tools [8–10]. Although it is difficult to know and fully measure STI projects' indirect impacts, criteria exist, and they must not be neglected when such projects are evaluated [11,12]. In addition, better approaches are required, since the studies carried out so far have not provided sufficient useful and valid methods to measure external technological and societal impacts [6,9,10,13,14].

Although the literature presents some methodologies to evaluate STI projects, they are limited in scope by the narrowness of their focus. This largely restricts the generality, applicability, and efficiency in the real-world [6,15–18]. The bibliometric method, for example, restricts itself to analyzing the publications, citations, and patents that originate from

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the project. Similarly, although the number of patents has been considered a measure of innovation, they are currently seen to indicate technological knowledge dynamics [19]. There is a restricted focus in econometric studies as well, since they evaluate outcomes only from a monetary standpoint [14,20,21,22].

The available methods also have a limited ability to measure most widely the outcomes of STI on the quality of life for society as a whole [8, 11,23,24]. Most of these techniques ignore the effects of a system in human and organizational terms [6]. Furthermore, measuring some types of impacts from STI projects is quite challenging. Finally, corroborating the relevance of these observations, our study is in line with the recent findings by Bozeman and Youtie [6] that identified five essential gaps in the literature in this area: the absence of a systematic technique to combine the outcomes of the diverse methods; failure to consider stakeholders' opinions; addressing social and economic impacts in isolation; lack of empiric contribution, and lack of integration among the methods.

Our research also addresses calls for more research [10,25,26] to measure the external technology impacts or market impacts of STI projects, using more logic models and mapping techniques. By doing this, this study addresses relevant issues involving technology in society [27]. Hence, from the knowledge gaps mentioned, the grounded research question guiding this study aims to examine

RQ. How to evaluate appropriately the social, environmental and economic results and impacts of STI projects in the society?

This paper proposed and validated an alternative method to identify and analyze the impacts of scientific and technological innovation projects. The six stages of the method proposed were validated empirically through two case studies of STI projects. Among its primary original contributions, this research addresses three main knowledge gaps. First, the method does not limit the type of impact that can be identified.

Although the literature offers frameworks to evaluate social, economic, and knowledge implications, among others, the research conducted so far has not shown any method that indicates how to classify the impacts. Second, in our proposed artifact, the interests of all the stakeholders are considered in the identification and exposition of the results. Third, the method integrates elements used in other recognized approaches in STI literature. Fourth, this study contributes to the theory and practice representing an effort to build a foundation for more systematic artifacts for evaluating the social, environmental, and economic outcomes and indirect impacts in STI projects. The paper is organized as follows. Section one introduced the research topic and knowledge gaps. Next, the theoretical framework is presented to critique the existing methods for evaluating impacts in scientific and technological projects. The third section describes how to prepare for and apply the method developed, the full description of the application and its elements. In the fourth section, results and the empiric validation exploring two case studies of technological projects are presented. Section five discusses the findings, analyses of contributions, and the policy and management implications. The research closes with the conclusions and suggestions for future research in the area.

2. Literature review

Important dynamics underlie the politics and policy connected to projects in Science and Technology, and it is challenging to understand them [28]. Before analyzing these topics, it is essential to comprehend the concept of Science and Technology. While Science seeks to discover the causes of phenomena to explain them to support the adaptation of life and society to new economic and social environments, Technology, on the other hand, is a system of technical elements that interact with other systems to solve problems and/or satisfy needs generating economic and social changes [25]. More precisely, "Technology is a complex system, composed of more than one entity and a relationship that holds between each entity and at least one other entity in the system, to satisfy needs, achieve goals, and solve problems of adopters to take advantage of important opportunities or to cope with consequential environmental threats for purposes of adaptation and/or survival in highly differentiated and volatile environments" [29].

Zhong and Wu [30] clarify that just as successful and effective projects promote and enrich companies, failed projects can cause human and financial losses beyond the company's bankruptcy [26,31,32]. has already observed that technology and knowledge are essential inputs in society's economic space, indicating that, how more is the geoeconomic space between the source of knowledge to users, low is the impact of knowledge and technology transfer process. The author underlines the relevance to measuring their impacts, answering the recurrent question: "How could the impact of technology and knowledge be measured?" [26; p.,106]

Various studies have offered ways to classify STI projects. Sbragia [33] and Piric and Reeve [34]; for example, consider divide them into "ex-ante," "of progress," and "ex-post." Ex-ante is performed before a program begins. It is a management tool for selecting projects. It helps to decide whether a project should be carried out [35]. An evaluation "of progress" is used when a program must be evaluated regarding tracking and monitoring [36]. Ex-post evaluations are carried out after projects are completed. They aim to measure project outcomes, which can be direct or indirect. Munhz et al. [37] stated that "the direct outcomes come from the targets achieved and they can generate economic impacts related to the sale of the new product, process or service." They can be seen as the effects which are directly related to the objectives of the project as defined in the contractual relationship between the agency and the group of contractors" [38; p.,191].

Indirect impacts are outcomes that were not foreseeable in the objectives of the project. They may affect the economic, social, and environmental spheres [37]. They "correspond to the effects in terms of creation of new knowledge, transfer of technology, building up of new competencies, quality improvements, acquisition of new processes, development of new markets, etc. that the contracting bodies derive from their participation in space programs and that they are able to use elsewhere" [38;p., 191).

Nonetheless, the literature presents some problematic ex-post evaluation methods. The bibliometric approach, for example, consists of collecting quantitative data from publications and citations, scientific mapping, and patent citations [24,39]. It can measure the quantitative impacts of knowledge, social impacts, and technology through indicators. However, Reis and Pinto [36] emphasize that those outcomes are restricted to publications, so they cannot amply demonstrate the indirect impacts of the project. Econometric studies, on the other hand, relate input variables to output variables to determine the ratio of the cost to the benefit [24]. This category analyses the direct impacts and indirect economic and monetary impacts. However, they are limited in only assessing monetary impacts and not sufficiently identifying other categories of results [35].

The Bureau d'Economie Teorique et Apliquée (BETA), for example, considers the direct and indirect outcomes of R&D projects and their impacts [40]. However, that approach restricts the evaluation of the indirect impacts solely to the project participants. It does not include the gains achieved by other stakeholders who are not researchers [9, 41,42]. The Multi-Dimensional Assessment (MDA) is a spinoff of the BETA methodology, and it can be combined with other methods [41]. As it is an open method, its downside lies in the fact that it must take into consideration the internal components in every case where it is applied [41]. Computational General Equilibrium (CGE) is a simulation method that models the interactions among the domestic, productive, governmental, and commercial sectors [35]. CGE is suitable for evaluating programs because it has several resources, and it provides information on how the impacts of an innovation program are mediated by prices [13]. Because it is a simulation-based method, it must be modelled for each specific project. Its weakness lies in proposing future forecasts and from them, anticipating indirect impacts. Rodrigues et al. [43] have proposed an evaluation method that starts at the program's conception and goes through all the program phases up to the evaluation of outcomes and direct and indirect impacts. The authors affirm that this method is suitable for managing and evaluating government-supported programs. Nevertheless, they present only a theoretical model without a clear-cut detailed way to apply it.

Besides that, some methods have been developed exclusively for a specific area or a specific program, making them unviable for evaluating the indirect impacts of other types of technological projects. For instance, Beegle et al. [44] used a randomized controlled trial to evaluate the direct and indirect effects of a public program in Malawi. Kwayu et al. [79] used a multi-method and quasi-experimental approach of qualitative and quantitative methods to examine the direct and indirect impacts of a land management program in Tanzania. Monte and Scatteia [75] evaluated the return on public investment for the European space sector from an ample econometric perspective. Nishimura and Okamuro [45] empirically analyzed the spillover effects of Japanese government-sponsored R&D consortiums using the data obtained from the companies and the propensity score matching method. The synthesis of the relevant literature examined, and the repercussion to the purpose of our study is summarized (Table 1).

Table 1 details the relevant activities performed by the proposed method and informs the decisions taken to articulate the main literature in the study. Based on the analyses of the various methods of ex-post evaluation of STI projects, it is possible to confirm the need for more ex-post studies to examine the capital, human, and organizational impacts of projects, because these cannot be measured easily . "If at the beginning of a technology transfer effort there is at least some attention to providing a rationale for the expected domain of influence of the transfer then there is a guidepost to help one understand the diffusion of impacts" [10; p. 42).

2.1. Indicators of indirect economic, social, and environmental impacts

The economic dimension encompasses everything that generates a financial outcome [38,49,51,52,54]. One list includes the following indicators of indirect economic impacts: increment in the productive activity (new products and services and process improvements, increased productivity, increased competitiveness [51]; new businesses started up, spinoffs/new businesses, leverage of funds/credit, development of new products [49]; new products being sold [49,51]; advanced technologies used, increased sales due to new products/processes or improved ones [69]; cost reduction [49,69]; patents and licensing [49,51].

Francisco [69] and Reis [35] defined the social impacts of R&D projects as outcomes that affect the community at large, the enterprise, or the research center, whether beneficially or not. Social impacts also imply hiring new human resources and acquiring significant experience by the project staff as outcomes of the learning process that takes place during a project, which increases their competence and technological capability [42]. The indicators mentioned in previous studies regarding indirect social impacts include the number of jobs created [49,51], measures of customer satisfaction, the number of scientific publications and the number of collaborators in publications [49], the mortality rate, accessibility to health services, and changes to the literacy rate [52]. Other aspects that can be measured include the number of jobs eliminated, the number of people who became skilled during or after the project, the number of participants in training sessions, the academic disciplines that use the knowledge generated, the students who attended the disciplines per year, and the enterprises and institutions that used the knowledge/technology generated [69] . Still other outcomes include improvement in security and occupational health, improved food security, the degree of new knowledge generated, theses/dissertations written about the technology [35], and the number of classes, training programs, and technical assistance rendered [64]. Last, indicators may include verifying whether the project led to the establishment of other cooperative projects, increased the probability of conducting joint research work [53], or established a cultural element as a means of integrating community members [63,64].

The measures of indirect environmental impact demonstrate how a project affects the natural surroundings [24]. Adkin [4], for example, examined the use of innovation projects as a key element of climate change policies in society. He found that technology innovation projects related to climate change should consider the relevance of social knowledge and citizen participation in the process. Lima [24] argued that those impacts relate to whether resources are used in an environmentally friendly way. Other indicators of indirect environmental impacts include, productivity improvement because of the reduced cost of production/increased yield/quality improvement [51]; improvement of environmental quality, creation of programs/training on environmental education ; energy intensity and the participation of renewable sources in the offer of power [52]; value-added increment; new/improved products or processes that adopt clean technologies; reduction in the quantity of raw materials used; reduction in the monthly volume of water used; reduction in the amount of energy used [69]; and reductions in the emission of pollutants [35].

Despite the diversity of indicators observed in the literature, more recent studies carried out in developing economies may bring more options for each dimension mentioned. Insights from developing economies could help identify additional indirect impacts from technological projects in regions with a less developed industrial base.

Therefore, based on the literature's scope and the deficits mentioned above, the next section of this study describes the proposed method for identifying the outcomes and indirect effects (social, environmental, and economic) of STI projects. The artifact proposed in our study considers the premise that the process of technology transfer involves multiple parties with multiple objectives and criteria of effectiveness.

Table 1
Main literature implications to the proposed method.

Activity		Reference	Implications for the proposed method
Project selection		[34]	Definition of objectives and evidence
		[46]	Project objectives as a prerequisite for evaluation
		[47]	Project completion time
		[36]	Definition of objectives achieved
Identify the stakeholders		[24,40,48]	Definition and role of stakeholders in the project
Identify the objectives		[46]	Objectives easily identifiable as a prerequisite for evaluation
Analyze evidence that confirm the achievement of objectives		[34,41]	Evidence proves the direct results achieved
		[49]	It is possible to identify indirect results in the evidence
Identify indirect results		[50]	Definition of indirect results
Identify indirect impacts	social	[49,51,52, 53, 63, 64, 69]	List of possible indirect social impacts
Identify indirect impacts	economics	[49,51, 69]	List of possible indirect social impacts
Identify indirect impacts	environmental	[51]	List of possible indirect economics impacts
		[35, 52, 69]	

3. Materials and methods

3.1. Sample and data

This paper examines how appropriately measure the social, environmental and economic results and impacts of STI projects in society. Regarding the research objectives, this paper is exploratory and aims better to understand a research problem with societal effects (Gil, 2002). The steps for case study research (i.e., research question, selection, instruments and protocols, field research, analysis, shaping hypotheses, comparison with literature and closure) indicated by Eisenhardt [55] were adopted along with the research. Two case studies in a developing economy were examined to generate knowledge that can be applied in a practical way to solve specific problems.

Two Brazilian STI cases involving technology transfer were selected to validate the proposed method. One project was developed by a public university; the second, by a private university. They were chosen because they meet the prerequisites for applying the proposed method: they are technology-oriented projects, completed no less than two years ago, have well-defined objectives, have clear and documented evidence to demonstrate that the project objectives have been achieved, and have a significant number of stakeholders who were affected. The time of completion that they adopted is in line with the parameters suggested by the Department of Business, Innovation and Competencies of the United Kingdom (UK)[67; p., 51].

The selection of STI projects with distinct stakeholders and objectives led by universities,one a private and small university and another, a public and internationally recognized University, allows us to appropriately test the proposed method's performance. The heterogeneity of the cases examined is, therefore, suitable for illuminating and addressing the research objectives.

3.2. Measures of variables

The primary definitions for ex-post evaluations of projects applied to the research design are as follows. First, the STI project objectives must be well defined to perform an ex-post evaluation [41,46]. Second, the project generates direct outcomes. Third, indirect outcomes may emerge from the objectives and/or from the direct outcomes [41,50,]. Therefore, the premises identified by observing these definitions are primarily two: (i) technologic projects present direct and indirect outcomes; (ii) outcomes can be observed from accomplishing the objectives. One can conclude that the indirect results of STI projects can be identified from the achievement of the objectives. In addition to that, when the indirect issues have been identified, it is possible to identify the indirect impacts by utilizing appropriate impact measures.

The artifact developed in this research also considers the expectations of the stakeholders, including their requirements of the project, so that the indirect outcomes of projects can be identified. Last, the method has been evaluated according to the evaluation criteria proposed by March and Smith [74], including the following evaluation attributes: ease of use, efficiency, generality, and operability. An essential aspect of building generalizable theory from case studies is the potential of replication of research [56,68]. In this regard, the internal structure and the detailed steps proposed contribute to further replicating the proposed artifact. Another aspect to consider is the recursive use of multiple data collection, ensuring the study rigor and validity. We attempt to address this aspect in two ways. The first is through data triangulation collected from each project during the research. In this regard, the primary materials used for triangulation included the relevant literature selected, qualitative or quantitative data from project documentation and reports, interviews and meetings with project leaders and participants, and formal evidence confirming the achievement of project objectives (e.g., patent register, scientific publications, etc.). The second is by conducting a comprehensive comparative analysis between the results from the two STI projects examined embedded in empirical data, among them those resulting from triangulation.

3.3. Data analysis and proposed method

March and Smith [74; p., 257] defined a method as a set of steps used to perform a specific task. The proposed approach aims to identify the indirect outcomes of projects and their indirect impacts on society.

Our approach follows a rationale that starts from the objectives achieved and goes on to identify the indirect outcomes and impacts of the STI projects. The indirect impacts can be verified using the indicators mapped in the literature on technology transfer. Applying this method does not preclude the identification of other unlisted indirect impacts. Next, we describe the structure of our approach and give step-by-step instructions for applying it (Fig. 1).

Selecting the project. The first step consists of selecting the project. The main recommended prerequisites for applying the method are the following: it must be a project of technological innovation, completed no less than two years ago [67]. It must have clearly defined objectives and goals, often called specific objectives or deliverables, linked to a time-frame, and evidence that the objectives have been achieved [34,46]. It must be clear that the goals achieved are the outcomes that were indeed attained at the project completion, i.e., they are not the expected outcomes, generally described throughout the project [36].

Identifying the stakeholders. The number of participants in projects keeps increasing, and "this evidently renders the assessment even more complex, at least as regards the identification and evaluation of causalities and the standpoint to be adopted" [40; p., 78]. Thus, it becomes necessary to identify the stakeholders, assess their importance, and get in touch with the main participants to collect data about the progress, the outcomes, and impacts of the project.

The more stakeholders contacted, the higher the possibility of identifying different outcomes and impacts, because every stakeholder looks at the project in terms of their own interests. The group of stakeholders includes every person interested in the project and "whose life is affected by the change in the project" [24; p.,55]. In this phase, all the individuals involved with the project (the public or private institution that carried out the project, sponsors, customers, suppliers, partners, researchers, society, regulatory agencies, etc.) must be mapped and listed.

Identifying the proposal objectives. With the project in hand, one must identify the proposal objectives and the goals achieved. According to Cotta [46; p.,107), "to be capable of being evaluated, the programs and projects should have easily identifiable objectives." In this phase, it is essential to pay particular attention to the verbs that describe each goal or specific objective (e.g., verbs such as: to prepare, to build, to report, to design, to develop, to publish, to accomplish). This aspect is important because the verb essentially indicates what was proposed, i.e., what hope will be accomplished upon completion of the project. The objectives of STI projects can be varied, and based on our own experience, some of the most commonly used verbs are the following: to develop, to alter, to optimize, to improve, to simplify, to facilitate, to treat a product or a process, to build, to prepare, to design, to document, to commercialize, to import, to export prototype or product or artifact or model. It is essential to create a list of the proposal objectives, the objectives achieved, and clear and documented evidence to prove that they have been achieved. As a rule, the project completion report or the project leader can help to determine the proof of accomplishment.

Analyzing the evidence of objective accomplishment. The evidence of objective accomplishment consists of seeking out as many signs of what was affected as possible to prove that the goals have been met. It is important to note that the evidence demonstrates direct outcomes through the accomplishment of the proposal objectives [34]. Moreover, as the evidence is analyzed, it is possible to identify signs or even proof of non-predicted outcomes, that is, indirect results.

From the evidence collected, it is possible to identify the outcomes and impacts, which means, for the most part, seeking to illustrate the

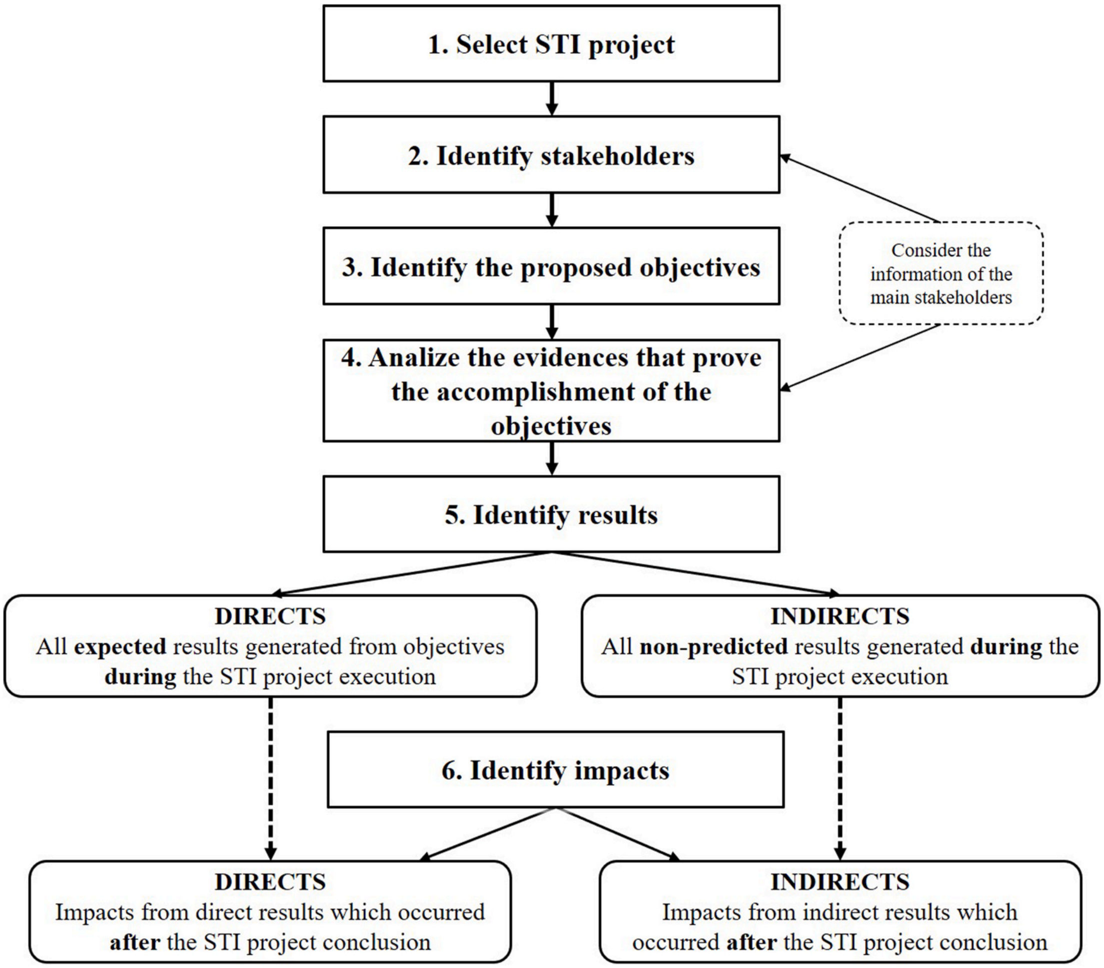

Fig. 1. Method for identifying results and impacts in technological innovation projects.

level of activity involved in executing the project [49]. The first action is to interview the attendees of training events or presentations to find out how many attendees were expected and ask them a few questions to verify how much they have learned. Depending on the number of attendees, it may be possible to interview all of them or maybe just a representative sample. In the interviews, we indicate use the following main questions: (i) Have you put in practice what you have learned from the event in any way, perhaps in an academic paper, an article, on the job, in some new product or process? (ii) Did you talk about the event content with friends or workmates? (iii) Has a new company been set up as an outcome of this new knowledge? (iv) Was the content relevant to you in any way?

The second action recommended is to verify the scientific databases to find out if any scientific publication been published on the subject. It is recommended initially to research studies in the language in which the article was prepared or to search for the authors' names. Another option is to check if the article or chapter of the book published has been cited by other researchers.

Another essential strategy is to interview the project leader to verify if the prototype has turned into a product or if it has been used as a starting point to give origin to any product. The prototype may have generated demonstrative/explanatory talks, or it may have received outside visitors who wanted to get to know it. It would be useful to find out what destination has been given to the laboratory built for the project. Has it been used for further research or for developing new products that benefit society in some way? Did the laboratory yield non-predicted economic outcomes (rental, cost reduction and so on)?

To verify the evidence in practice, it is suggested to read all the descriptive documentation about the product/process developed during the project. After this, it is suggested to request an interview with the project leader and specialists to determine the following aspects: (i) Does the project generated cost reduction or process licensing? (ii) Was the product manufactured and sold? (iii) Has the project generated different products based on the original project product (product line)? (iv) Was any patent or license agreement generated? (v) Did the development of the process/product generate or eliminate jobs? (vi) Did it improve the health or quality of life of anyone? (vii) Did the development of the process/product decrease or increase waste or energy consumption, and did it have an environmental impact?

In the particular case of the a project on a specific subject (analysis, data collection, case study, diagnostic), it is necessary to analyze the report to verify the following factors: (i) If the project led to scientific publications (e.g., books, articles etc.), training programs, talks, or courses; (ii) The amount of new knowledge generated by the project and if any academic discipline deals with the subject; (iii) If there are companies that are using the knowledge generated; (iv) If the study generated the opportunity to use clean technologies or if it generated any environmental impact (volume of energy, raw material, pollutants).

Furthermore, we recommend interviewing the primary stakeholders (those most deeply involved with the project) to gather pertinent information and get to know how they feel about the project. The interviews should be structured according to the project scope and the role of the interviewee during the project. They should be asked questions proportionate to their degree of involvement or participation following a predefined protocol: What was your participation in the project? Were you paid to participate in it? Did the project generate any new process, product, or service which had not been foreseen? Was there any course or talk as an outcome of this project? Was the knowledge you acquired from the project used in another application or another project? Did it generate partnerships for new projects? Did this project give rise to any publication? Was it expected? Did this project generate new knowledge in addition to the expected outcomes? Do you know if a new company was set up or new processes? Did it create or eliminate jobs? Did it create new discussion topics in class? Did it generate any patent? Did this project bring about any economy of natural resources (raw material, energy, water, etc.)? Did it make the use of clean technologies possible? Did the project decrease or increase waste? Did it cause any environmental impact? What is the significant contribution of this project to the stakeholders (what is the project's repercussion on the participants)? What are the significant contributions of the project to society, and did the project content have any relevance to you? The project members might generate additional questions to complement these above recommended.

Identifying direct and indirect results. Next, the direct and indirect results should be put in a list. Result refers to what was obtained from the project objectives. Indirect results are all the project outcomes that were not intended in the objectives [50], whereas the direct outcomes are all the outcomes intended, i.e., they are the accomplished objectives.

Identifying the direct and indirect impacts. Impacts are the effects on society brought about by the project [57]. It refers to the importance (impact) of the results achieved. Thus, through the fourth step of the method, it is possible to include in this stage: (i) direct impacts arise out of the immediate outcomes that happened after the project was completed; and (ii) indirect effects arising out of the indirect outcomes that happened during or after the project was completed. The literature classified indicators as social, economic, and environmental. These can help in the identification of such impacts. Last, the fact that an outcome can generate one or more impacts is noteworthy. Therefore, every impact originates from some result/outcome.

4. Findings

The proposed method was empirically validated through the analysis of two STI projects that involved technology transfer. The first one was developed by a public university and the second one by a private university. The wealth of information and documentation available for the analysis was of the essence in selecting the projects since some organizations do not make such information available for reasons of confidentiality. All the data about these two projects was obtained from official documents, meetings with project leaders, and interviews with the project members.

4.1. Case study A

Selecting the Project. Project A was called "Development of Sustainable Products in Environments of the Product-Service System," and it was funded by the National Brazilian Council for Scientific and Technologic Development (CNPq), one of most important national scientific fundations. It was coordinated by a senior professor and researcher from the postgraduate program in Production Engineering of the Federal University of Rio Grande do Sul, ranked as the best Brazilian federal University. This technological project aimed to develop sustainable products by using alternative materials resulting in a product-service system business model. We found that the objectives were clearly defined, and the documentation confirmed the fulfilment of the objectives. The project started at the end of 2008, and its full term was 48 months.

Identifying the stakeholders. The project stakeholders are as follows: the public educational institution where the project was developed; the national funding body, the Council for Scientific and Technologic Development; the member researchers of the project; the prototype-developing partner companies; the partner laboratories that provided the testing space; all the educational institutions that collaborated by providing researchers; the companies that are interested in sustainable products (customers), and those in society who are interested in the benefits from sustainable products.

Table 2
Project A: Overall and specific objectives.

Overall objective	Specific Objectives	Objective attained?
Biodegradable diaper	a) Gather information and test the materials designed to increase the absorbent capacity of the cellulose pulp	Yes
	b) Develop a biodegradable diaper prototype	Yes
	c) Test the diaper prototype	No
	d) Choose the best prototype and manufacturing method	No
	e) Consolidate the quality control methods	No
Cleaning system concept	a) Study and conception of the cleaning system and its elements	Yes
	b) Define the degree of influence of the system elements and determine customer needs	Yes
	c) Translate the requirements from the previous phase into external functions	No
	d) Define the technical functions and the respective Project solutions	No
	e) Complete the development of the cleaning system concept	No

Identifying the project objectives. Project A had two goals to be attained through the product-service system: (i) to develop a biodegradable diaper, and (ii) to develop a housecleaning system concept. The specific objectives are shown in Table 2, which also shows that not all specific objectives had been achieved by the project.

The objectives marked as unachieved could not be achieved due to a lack of funds to carry out those activities. The analysis of the proposal objectives revealed that there was too much detail in executing the specific objectives identified as a) and b), which took longer and cost more than expected.

Analyzing the evidence of achievement of objectives. The analysis of evidence for Project A revealed that the founding document and the request for a time extension, all the specific goals, the test reports and analyses, technical visit reports, research and publication documentation had been verified. The actions included interviews of the project leader and some researchers. Besides, an analysis of the curriculum of the project leader and the leading researchers. Also verified were all the technical reports from the partner companies, reports of the technical tests performed in the laboratories of the university, thesis and scientific paper resultants, and the number of citations for each publication. (see Fig. 2).

Identifying the results and indirect/direct impacts. Based on the actions carried out in the previous steps, the direct and indirect impacts were identified and summarized in a worksheet. Next, a diagram presenting the findings was developed (Fig. 2.).

It was observed that, although not all specific objectives had been achieved, four years after the termination of the project, three direct impacts were identified: one economic impact (disclosure for investors), a social impact (learning), and an environmental impact (disclosure of the sustainability case). Thirteen scientific papers were published and four masters' research theses were generated during the project. These were identified as indirect outcomes. These indirect results generated indirect social impacts through the dissemination of knowledge in society. Other academics have cited these scientific articles, and the thesis results led to the publication of two other articles in top-ranking journals in the area of product-service systems and the development of a textbook. Besides that, one of the articles presented at a Brazilian Conference on Production Engineering area calls the attention of the Embraer

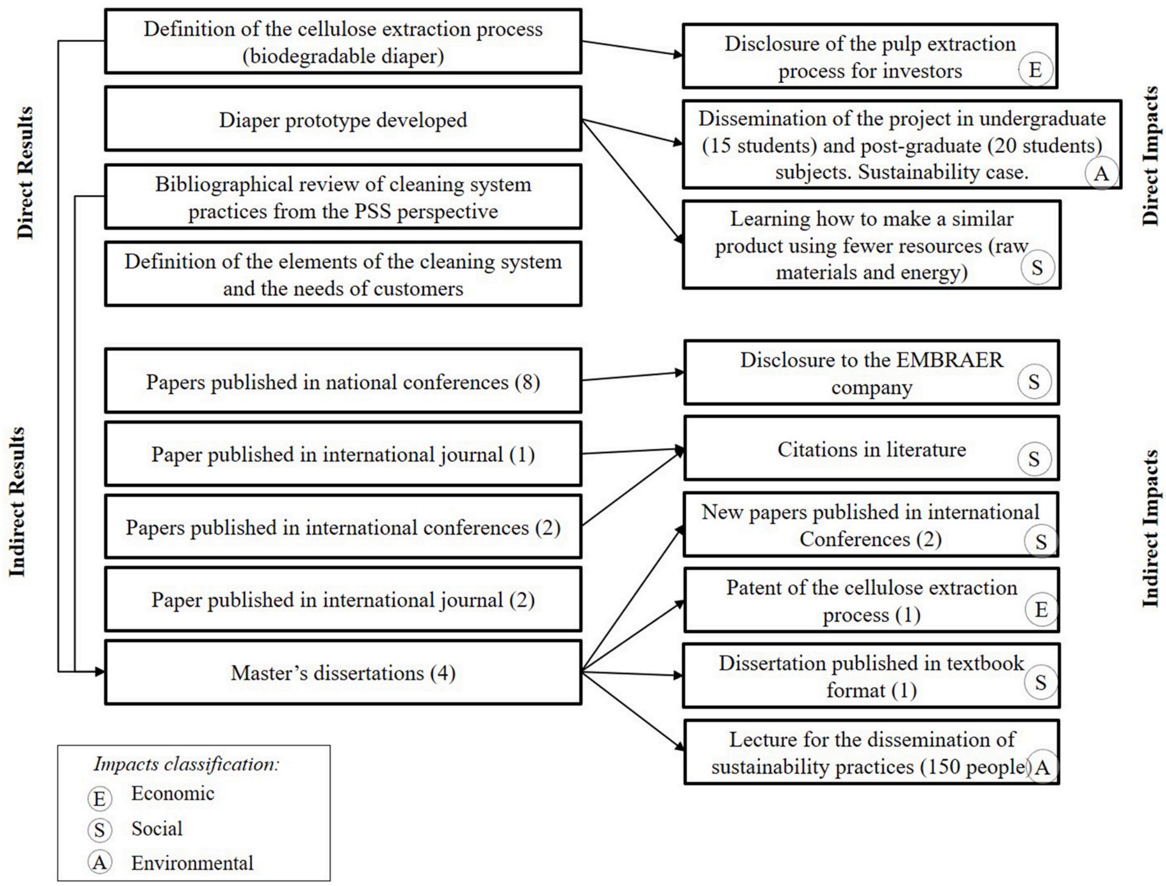

Fig. 2. Project A: Primary results and impacts.

company. A company representative contacted the researchers and asked for the presentation to be shared with the company employees.

Regarding indirect environmental impacts, the project reached approximately 150 people at a scientific conference on sustainability held in the city of Santa Maria in Brazil. The indirect economic impact consisted of the registration of a patent for the process of extracting cellulose, thus making it feasible to develop the biodegradable diaper. The next section presents the results of the second case study used for the empirical validation of the method.

Table 3
Project B: Overall and specific objectives.

Overall objectives	Specific objectives	Objective attained?
Creation of the Mobile Technology School (EMTEC)	a) Design and assembly of the production laboratory of Production of Didactic Prototypes	Yes
	b) Conception and production of didactic prototypes	Yes
	c) Conception and assembly of the mobile unit	Yes
	d) Preparation of didactic activities	Yes
	e) EMTEC activity at the pilot school	Yes
	f) Optimization of didactic activities	Yes
	g) EMTEC activity at the schools	Yes
	h) Transfer of project outcomes	Yes

4.2. *Case study B*

Selecting the project. Project B consisted of the creation of the "Mobile Technology School (EMTEC)" and a bus equipped with didactic prototypes developed to demonstrate the applicability and importance of the engineering profession. The bus-school had a small video room where audiovisuals could be shown to small audiences. This project was funded by the Funding Authority for Studies and Projects (FINEP), a prestigious Brazilian scientific funding organization. The project was led by an experienced professor and researcher and executed at the Integrated Colleges of Taquara. This innovative technological project aimed to demonstrate to high school students and their teachers the importance of Engineering professionals for the development of new products and processes that improve the quality of life of society. This project had a duration of four years. It was found that its objectives were well defined and fully documented with evidence of attainment.

Identifying the stakeholders. The stakeholders of this project were the private educational institution where the project was developed, the funding body (FINEP), the researchers, the educational institution where the first product presentation (pilot) was held, the high school students and teachers (customers) and society, which benefits from the students' and professors' motivation and the consequent increase the number of students interested in the technology areas. This could contribute directly to the country's technological development.

Identifying project objectives. The proposal objectives of Project B are shown in Table 3, which also shows that all the project objectives were attained.

Analyzing the evidence of achievement of objectives. The following items were verified as evidence of achieving the objectives: the final project report, the project documentation for the bus, the documentation of prototypes and

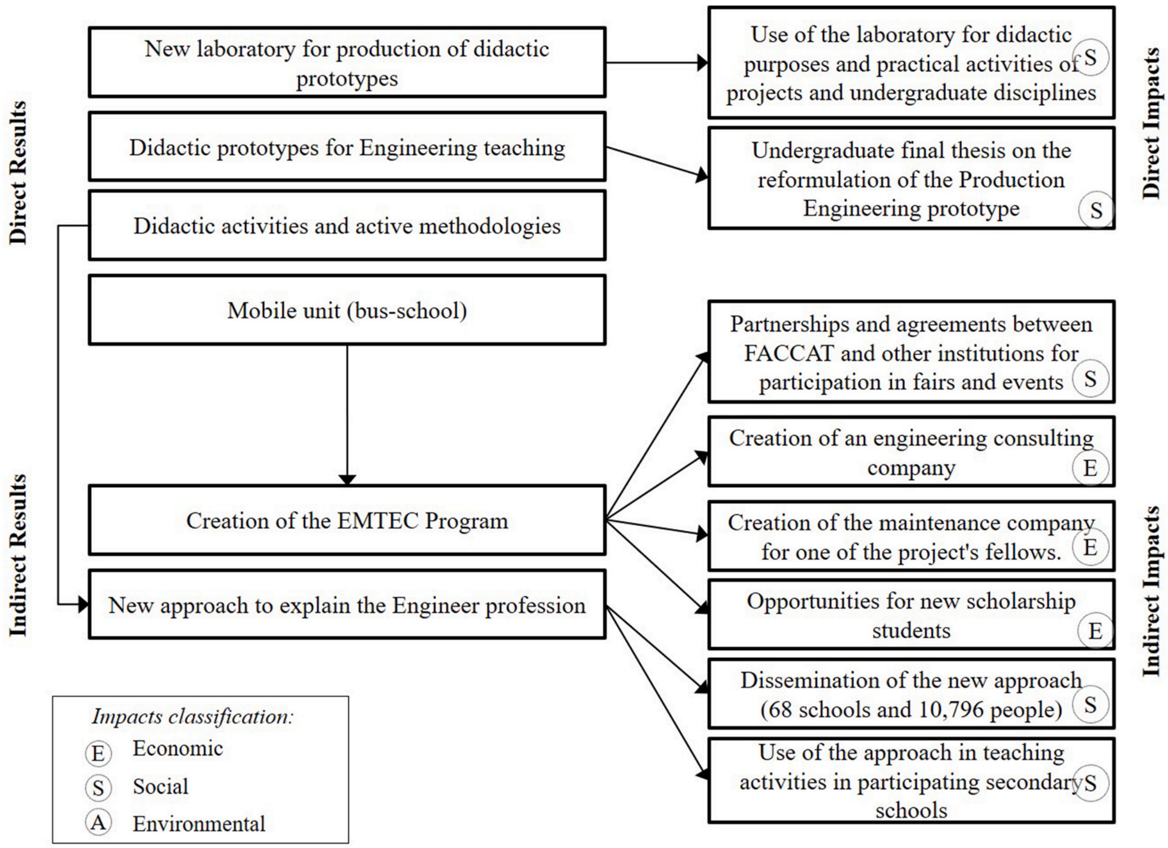

Fig. 3. Project B: Primary results and impacts.

benches, communication materials with the schools, and official documents sent to FINEP. The following actions were performed: interviews with the project leader and the scholarships students, the program leader generated by the project, the scientific curricula of the supervisors/professors and the main scholarships students. Last, the visitor's list of attendance for students impacted by the project was checked.

Identifying the results and indirect/direct impacts. Based on the actions carried out in the previous steps, the results and direct and indirect impacts were identified and summarized in a worksheet. Next, a diagram was developed for classifying and presenting the findings (Fig. 3.).

It was possible to observe that two direct social impacts were generated (use of the laboratory and a research thesis) and there were two main indirect results: a new technique to explain the engineering profession and the EMTEC program's creation. Due to the improvements implemented over the years, the project became an institutional program after its completion. Consequently, the University now maintains an ongoing funding program to reach more schools and students in the region with the mobile unit, in addition to those targeted initially by the project.

The dissemination of a new technique to promote an engineering career to 68 schools and over 10.796 people since the project completion was evidence regarding indirect impacts generated. Partnerships and agreements have been executed between the University and other institutions (national high schools, enterprises, city halls) which characterizes them as indirect social impacts. In addition to that, there were indirect economic impacts, such as opening new opportunities for scholarship students to participate in the program.

Moreover, a significant indirect impact was the awakening of entrepreneurship in two members of the project who have identified the opportunity to open their own companies. One enterprise in service maintenance was opened by one of the scholarship students, and one consulting enterprise in engineering was created by the project leader. These two companies were established solely because of the project, and they are in the city where the project was created. The following section will discuss the primary findings and implications observed.

5. Discussion

Research projects are a systematic search for the advancement of knowledge to solve problems or satisfying society desires; that way, advances in STI support the economic growth of nations and the well-being of citizens. Also, investments in scientific projects help advance science and technology [25]. Our results demonstrated that both projects investigated presented direct and indirect outcomes and, although not all the outcomes generated impacts, both projects presented direct and indirect effects (see Table 4). Findings indicate that under the circumstances and constraints defined in the present study, the proposed method tested contributes to systematize the identification process of impacts in STI projects.

The outcomes also demonstrated that the indirect results and impacts of STI projects were varied and might not match the initial intended project outcomes. This corroborates the statement made by Piric and Reeve [34;p.,51]: "Many of the most important outcomes of R&D investment, e.g., new knowledge, skills and experience, are intangible and unquantifiable, their benefits may not be realized for some years, and their impact may be felt in entirely unrelated areas".

Another important finding was to observe interconnections among direct results both inside and outside the STI project. In case study A, for example, the definition of the cellulose extraction process was the leading cause for the prototype of the biodegradable diaper to be obtained. Similarly, the definition of the pulp extraction process obtained allowed disclosure to investors. Another example is regarding the diaper prototype developed is correlated to learning on waste management,

Table 4
Comparison between case studies results.

#	Case study A	Case study B
Direct Results	• Development of a new pulp extraction process • Prototype of the developed product	• New didactic prototype production laboratory • Didactic mobile unit bus school (EMTEC)
Indirect Results	• Scientific publications (Conference (8), Journals (3) and Master dissertations (4))	• Institutionalization of the EMTEC Program at Higher Education Institution (HEI) until today • New interactive methodology to publicize the profession of Engineer
Direct impacts	• Disclosure of the pulp extraction process generated for investor groups • Creation of a case study on sustainability for undergraduate and graduate teaching • Development of a similar product with lower consumption of raw materials and energy	• Use of the laboratory for teaching purposes and practical activities using Project-Based Learning • A new research derived aiming to develop new prototypes on the Engineering profession demonstrates the importance of using Operational Research in Engineering
Indirect impacts	• Presentation of the project to Embraer company directors • Scientific publications (master's dissertation (1), textbook (1) and scientific articles (2)). • Registration of a patent for the cellulose extraction process • Dissemination of methodologies at various specialized events totalling 150 people impacted	• Partnerships and agreements between the Faculty and other institutions for participation in events • Opening of two companies (one for consulting in Industrial Engineering area and the other for maintenance services). • Generation of new opportunities for scholarship students • Dissemination to 68 primary and secondary schools totalling 10,796 students impacted • Use of the technique for other teaching activities in schools in the region
Lessons learned and Implications	• Generation of new knowledge on waste management, on the role of PSS actors and on cellulose extraction processes. • The project demonstrated that studies on waste reuse are feasible and bring possibilities for environmental impact.	• The prototypes developed must enable maximum interactivity with the people who visit the EMTEC • Although each prototype represents one of the Engineering areas, the prototypes must be flexible to demonstrate others that are not covered. • Students presenting prototypes must be students of Engineering courses, facilitating the solution that questions proposed by the visiting public. • The design and development of prototypes must take into account the familiarity of visiting students with the proposed system, facilitating correlation of the prototype to the professional profile of the Engineer who builds it in real life • The program manager being trained in Engineering at the institution. • Implication in marketing in decision making of prospects to study at HEI. Prospects who visited EMTEC may be more favourable to choose HEI. • Improved retention of current students

demonstrated that studies on waste reuse are feasible and bring possibilities for environmental impact. These two examples illustrate a direct result that resulted in a direct impact. Already in project B, as an effect of the didactic prototypes developed, it was possible to implement didactic teaching activities at the graduation level. It is an example of a direct result that resulted in another direct result. Following the same rationale, the possibility of carrying out practical activities in undergraduate classes is a consequence of the development of the new didactic prototype laboratory. That is a direct result that led to a direct impact. Although initially unexpected, this finding suggests that the method identifies interlinked effects of different direct and indirect results that may occur inside or outside the project analyzed.

The inherent difficulty of forecasting and measuring benefits in STI projects is explained by the fact that indirect outcomes and impacts may emanate from the project and provoke changes in the long term. One example of this long-term impact was establishing two new enterprises identified in the results (case study B). Without the project, they would never have been created. These new enterprises originated essentially from the project and because some components of the project team perceived the business opportunities. These enterprises can generate new businesses opportunities in society, and they can survive and even change their strategy throughout their life cycle. As a result, they have an indirect economic impact reflected in generating revenues, taxes, and services to customers in the region.

Besides that, the research outcomes corroborate the statement of Furtado and Freitas [58] that, even though projects might not attain all their intended objectives, they may bring a set of gains to society. Therefore, the money invested in technological projects can be justified, even when the more significant objectives or gains are not totally achieved. For instance, in Project A, even though it did not achieve all its intended objectives, it did generate direct and indirect impacts on the economic, social, and environmental order. This finding corroborates the ideas of Coccia [25,65]who suggested that leading nations invest in scientific research to produce new technologies and achievements to seize important opportunities in markets or to deal with environmental threats and investments in STI projects help advance science and technology.

Comparing, for instance, the proposed artifact with the MDM approaches, considered as one of the most encompassing methods in the literature, our findings suggest that the proposed artifact presents the following main advantages: it identifies intangible impacts, it considers the opinions and impressions of stakeholders, it can be applied to diverse types of projects in different areas, it has a simple and economical application, and it does not limit the number or the types of impacts that can be identified. Therefore, the empirical findings in this study suggest that this work contributes to the existing body of knowledge about the methods for measuring the results and indirect impacts of STI projects by providing answers to some of the gaps in the literature.

Most importantly, to evaluate the rigor and the validity of the results, the performance of the method was measured according to the qualification criteria indicated by [74] to evaluate the performance of new artifacts, namely: ease of use, efficiency (getting the best yield with a minimum of errors), generality (amply comprehensive, it can be applied in a different context of technological projects), and operability (it can perform the intended task and it can be used effectively).

In this sense, the outcomes from the case studies analyzed suggest that the application process may be considered accessible to use when compared to other methodologies [9,13,35,41,42,44,59]. The method does not require complex modelling or a long quantitative survey, so it meets the criterion of ease of use. Moreover, the fact that the results and impacts are not measured makes the survey of information faster and it facilitates the application. Besides, the amplitude attributes suggest that the capture of intangible results of STI projects was possible with the artifact. Our findings address recent research gaps indicated by Rau, Goggins and Fahy [5; p., 275] who stated that "comprehensive approaches to impact assessment that are capable of capturing more intangible forms of impact, especially concerning possible shifts in opinion and practices among key policy and civil society actors, remain the exception."

This research project makes contributions to the understanding of indirect impacts and results in technological innovation projects [73]. Overall, it is possible to state that most other approaches seek to measure the results and effects and, therefore, do not comprehend essential intangible gains. Among the intangible benefits, it is possible to exemplify a company's increased technological capacity or its improved visibility, behavioral changes, and the understanding of new possibilities. Hence, it is possible to conclude that the novel method can be considered efficient, meeting that evaluation criterion [74].

The stakeholders' opinions and impressions are an essential aspect of the proposed approach concerning the available literature in the area, since "the involvement of external scientists and stakeholders in the scenario development process can integrate different types of knowledge, perspectives and values" [48; p., 245]. This aspect is considered most clearly only by the MDM approach. At the same time, most of the other existent methodologies do not consider the impressions, interests or opinions of the stakeholders involved in the project. For this reason, the proposed approach advances knowledge by addressing relevant gaps in most current approaches.

Our method's structure added to the few prerequisites for utilization, making it possible to apply it to a range of project types and knowledge areas. Considering that it is not necessary to limit the method to a specific context or type of project, it can be used for projects in different areas of knowledge. This advantage makes it a comprehensive approach, meeting the generality criterion indicated by [74]to evaluate the performance of artifacts. In addition, the classification of impacts is performed at the end of the method. Consequently, there is no limit to the number of effects or types of implications that can be identified. This flexibility is possible because the questionnaire can be modified by customizing or adding questions to seek information about different types of impacts, in addition to those considered in this research.

To sum up, we can conclude that the method differs from others in the literature that do not measure the impacts they identify. Particularly in the application in developing economies, recognized by financial difficulties, it is essential to have an easy-to-use and assertive tool to identify results and indirect impacts of STI projects. This helps to ensure that some return will be delivered to society. Furthermore, if necessary, the method can be used to perform anticipatory analysis of ex-post projects by identifying whether it is worth investing in an in-depth assessment to measure results and impacts. Thus, it is possible to affirm that the artifact also meets the evaluation criterion of operability [74]. The method considered the results from the features of the artifact and its interaction with the environment. The proposed method was analyzed from the standpoint of the environment and of the actors involved (the organization that developed the project, government, enterprises or institutions, universities, technology development centers, R&D centers, and society). Managerial and policy implications are discussed in the following section.

6. Policy and managerial implications

This study extends the current body of knowledge on the challenges of measuring the indirect results and impacts of STI projects, particularly to the developing economies context. Relevant issues on technology in society [27] were addressed in our study. The indirect results identified in the validation process may bring competitive advantages to the organizations that developed the project. Having a dominating control over the products (predicted) and knowledge generated (not predicted) can lead an organization to develop new projects or change its structure to become more competitive. Already the project's indirect impacts may help firms and policymakers to assure society that the investment made with their taxes is well used. On top of that, the dissemination of the information related to real gains from the projects can lead society to give credibility to the government's actions to promote the advancement of science and technology.

From policymakers and the government's perspective, the proposed method is an artifact that enables identifying the benefits to society that originate from public investments in science and technology. It can also help justify the need for more investment and/or justify the continuity of innovation incentive programs and project funding facilitation programs. Governments may more easily demonstrate to the society or local community the effects of the public money invested in private projects. They can point out that the gains (social, environmental, and economic) do not accrue exclusively to the institution or enterprise that implements the project. The presentations to society of the results from using public money will contribute to making the public management more transparent. The scientific implications of the article in this context are relevant because notoriously investments in R&D projects generate new technologies that support companies and nations' competitive advantage and, as a consequence, economic growth. Besides, scientific advances and new technologies for nations are a source of socio-economic power in the international system [25].

For the enterprises and institutions interested in implementing technological projects, the proposed method helps to identify results and effects that were not initially predicted. The method may confirm the expected results or demonstrate other nuances of the finished project. In this way, companies can identify new business opportunities and better comprehend technological projects' impacts on society. Furthermore, the enterprises can map the results and indirect effects directly to the need for new investment or funding of new projects. Considering that innovative projects determine economic development, innovative projects must be carefully configured given the current competitive environment and disruptive technologies available [60].

Concerning the universities that use public funding to develop technological projects, the proposed method can be applied as an instrument to comprehend the real impact of the knowledge generated [76]. This benefit is particularly important because technological transfer decreases further away from the point of origin of the research, but within the economic environment, there are routes through which it is channeled [26,31]. With the data generated during the reproduction of the method, institutions will be able to connect indicators of results to their projects. This benefit can support the negotiation process with financing bodies and the development of partnerships with private companies. Using the proposed artifact, universities may benefit from a source of information to leverage academic gains (e.g., scientific production), and economic gains (e.g., patents, new products, new institutional agreements, startups) as a result of the projects carried out.

Besides companies and universities [76], technological innovation centers can benefit from the proposed method to identify the results and indirect impacts of their projects or partnership-implemented projects [77]. Technology centers should be considered key organizations in the process of innovation [61]. Society, on the other hand, can be considered the stakeholder that might obtain the most benefit, although it might not use it directly. These favorable impacts include the generation of new businesses and the infusion of new skilled workers.

More investigations to examine how occur collaboration within innovation projects in developing countries are needed [11]. The empirical validation of the artifact through two case studies in a developing economy corroborates the hypothesis that it can identify results and direct and indirect impacts of STI projects considering the stakeholders involved. Nevertheless, the outcomes should be evaluated with parsimony because they represent the results and impacts substantiated by evidence and the intangible results and impacts identified. Furthermore, the identification of outcomes and impacts of each project represents the moment in which the method was applied. Other consequences could be identified later since many effects of the project "remain and intensify over time" [24; p., 8]. Our findings also offer important implications concerning data gathering used for evaluating the results of STI projects. In this regard, we advise that policymakers and practitioners, when applying the method in the field, should pay particular attention to indicators identified, the actions and the guiding questions posted in the stages of *Analyzing the evidence of objective accomplishment, Identifying the direct and indirect results*, and *Identifying the direct and indirect impacts.* By doing this, it is expected that project analysis obtained sufficient robustness and information validity.

In a nutshell, the findings support the efficacy of the proposed method [78]. They indicate that it is an alternative for identifying the results and indirect impacts of STI projects rather than measuring them, constituting an academic and practical contribution. The artifact facilitates the mapping of the most relevant elements for identifying the indirect impacts in a structured artifact. These implications are relevant because, although there is abundant research into STI in developed countries, these findings cannot be immediately replicated to the reality of the developing countries [11]. The following section describes the main conclusions and suggestions for future research in the area.

7. Conclusions

This article developed and tested a novel method for identifying the results and indirect impacts of technological innovation projects. Based on the theoretical framework, two basic premises were mapped. First, technological projects present direct and indirect outcomes. Second, the results can be identified through the project objectives achieved. The method was empirically validated by examining two projects. As a result, this study offers a methodology capable of detecting the results and impacts of public investment in science and technology on society.

Research findings make relevant contributions to the current literature, enhancing the understanding of this field. The investigation indicated that the proposed method contributes to filling several research gaps in the literature on ex-post methodologies used to evaluate the indirect outcomes of technological projects. One aspect that sets the proposed method apart is that it allows identifying a comprehensive range of categories of indirect impacts. To sum up, the primary academic and practical contribution is that the method is user-friendly, and it can be applied to analyze the results and the indirect impacts of technological projects in diverse areas of knowledge, technology, R&D, and science.

The findings in this paper also are subject to some limitations. First, the method was used to identify results and indirect impacts rather than to measure or rate them according to their importance to the stakeholders. Further work must be conducted to measure or estimate the results and indirect impacts. Exploring this aspect constitutes an opportunity for further research. The second limitation is regarding the analysis of information gathered from the interviews. Two types of data were considered: data that can be ascertained by documentation and data presented by the people involved in the project. The third limitation is that, because the projects had been completed, some outcomes or impacts might not have been presented.

Upon completing the case studies analysis, it was possible to sediment future developments and new interdisciplinary scientific work opportunities. The impacts on STI projects could be organized in a cause-effect logic, according to the order of occurrence, since one impact can generate another one. Another interesting avenue of research would be to apply the MDM method in case studies in parallel with our approach, then compare the outcomes found by both. This research opportunity intends to identify the non-measurable impacts determined by the proposed method that are not contemplated by the MDM approach. This exercise could demonstrate with more clarity the differentials of our artifact as well as opportunities for enhancement. The third research avenue refers to the validation that occurred with projects implemented by educational institutions. It would be interesting to apply the proposed method to industries and private companies or in partnership with universities. Thus, it would be possible to determine the outcomes and indirect impacts of projects that, as a rule, seek to develop new products or processes for the exclusive benefit of the enterprise. This study's primary contribution resulted in an accessible artifact that can analyze the results and indirect impacts of projects in diverse areas of STI.

Author contribution statement

Prof. Liliane de Almeida: Conceptualization, Methodology, Data curation, Writing – original draft and Writing - review & editing and Project administration. Prof. Diego Augusto de Jesus Pacheco: Methodology, Data curation, Validation, Writing – original draft and Writing - review & editing. Prof. Carla Schwengber ten Caten: Funding acquisition, Supervision and Project administration. Prof. Carlos Fernando Jung: Conceptualization, Supervision and Project administration.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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