Assessing the potential socio-economic impact of technology transfer: Towards developing a conceptual model

Sandeep Singhai[1,*], Ritika Singh [2], Harish Kumar Sardana[3], & Anuradha Madhukar [4]
[1]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India; CSIR-Advanced Materials and Processes Research Institute, Bhopal – 462026
[2]CSIR-Central Scientific Instruments Organisation, Sector 30 C, Chandigarh – 160030
[3] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India; CSIR-Central Scientific Instruments Organisation, Chandigarh– 160030
[4]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India; International Science &Technology Affairs Directorate, CSIR, New Delhi

Abstract

The field of impact evaluation of research from public funding is evolving to justify and accelerate investments. The urge to gauge a holistic impact on society is catching the researcher's attention and approach. However, due to the inherent characteristics of and issues in measuring the socio-economic impact of research, it is challenging to develop a uniform and simple measurement tool. In the context of public-funded academic research institutions, in a multi-stage research process, we first propose an initial framework model for estimating the potential socio-economic effects of technologies weighing on the scientific, technological, social, environmental, and cultural pillars. Further, we analyzed and tested the model using multi-case studies and develop a questionnaire. This questionnaire is tested empirically in a focus group. Finally, we develop a conceptual model that is a flexible and simple means to measure the potential socio-economic impact of technologies with 15 indicators. Applicable at various stages of the technology lifecycle, this model can serve the dual purpose of estimating expectations and analyzing effects.

Keywords : Technology management,Research evaluation, Socio-economic impact, Technology transfer, Small and medium enterprises

1.Introduction

The panorama of studies on knowledge generation and dissemination from the public investment in science & technology through public-funded Academic Research Institutions (pfARIs) is elaborate and circular. Since the 1990s, the policy changes in science and technology have evoked interest in transferring technology outcomes of the pfARIs to the industry and evaluating the impact. Research teams having diverse subject experts have studied the facets of this interaction, including the effectiveness, enablers& barriers, the role of actors and policies[1] ,and factors affecting its success[2]. An exciting area of curiosity is the measurement of the impacts. This field is evolving, and researchers are working to understand and formalize how to measure the effects in an objective, cost-effective and timely manner[3]

The pfARIs and industry engagement through a variety of formal and informal channels[4] both being

*Corresponding Author(Email: sandeeps@ampri.res.in)

complementary[5], have a dynamic, positive benefit for the innovation ecosystem[6]. Consequently, the contribution of these actors in innovation activities and society is a subject of interest and is evolving from being implicit to explicit.

In developing countries, the interaction between pfARIs and small and medium enterprises (SMEs) is vital for capacity building and manufacturing. The pfARIs are significant beneficiaries of government funding for research and constitute a considerable part of the national innovation system [7]. Further, SMEs have an essential role to play due to their vast influence on the economic and social landscape[8]. For innovation, internal resources are good to explore and strengthen[9], but strategic alliances [10] and open innovation practices have the advantage of time and complementary resources. The association, cooperation, and coalition between pfARIs and SMEs justify the societal investment in future technologies from an economic perspective [11].

The Council of Scientific & Industrial Research (CSIR) and the associated Academy of Scientific & Innovative Research (AcSIR) are the largest pfARI with a pan-India presence [12], working primarily in the area of sustainable industrial technologies [13 - 17]. There is no doubt regarding the scientific impact of CSIR and AcSIR in terms of publications, citations, and intellectual property, but the industry linkage seems to be weak [18]. It is a matter of concern, and there are efforts to reinforce and strengthen it through policy and strategic measures. In India, SMEs constitute almost 95% of the total industry employing about 40% of the workforce and adapting to new technology areas[19] due to their inherent characteristics. The pandemic has further provided an opportunity and environment for both the actors to develop innovative products combating the coronavirus.

The significance of science and technology deduce that it delivers broader socio-economic impacts [20]. It requires sustained policy support [21] due to capacity issues, spill-over effects, and a host of such reasons. Traditionally, the impactof science and technology was presumed, and the policymakers did not felt the need for aseparate evaluation of these socio-economic effects. However, in the last decade of the 20th century, the scope of research evaluation began expanding[22]. Schot et al. highlighted the need for prioritizing a transformative innovation policy with origins in the localized socio-economic context for achieving sustainable development goals[23]. Accordingly, the evaluation landscape of research impact is also evolving, and the impetus on socio-economic considerations is widening.The criteria now encompass evaluating outputs and outcomes in scientific, social, economic, environmental,and cultural terms [24]. This approach envisages clarity about traditional metrics of judging science and the presumed impacts.

Therefore, it would be fruitful to study the potential socio-economic impact of the technologies developed by the pfARIs and translated into innovative products by SMEs.However, as the literature suggests the scarcity of objective metrics and the uniqueness of the technologies in terms of broader impacts, it is difficult to have a generic recipe. The reasons are complexities in establishing the exact causality, spill-over effects of research, long time lag between intervention and effect, issues in attribution, lack of interest by scientists, cultural differences between experts of evaluation, generality issues, and the possibility of negative impacts[24]. Therefore, a practical approach is to complement with case analyses of the socio-economic implications of diffused technologies. Case studies have been in ample use to assess the impact of research with in-depth insight and a better understanding of the processes [25]. In combination with follow-up expert opinion, it allows sensible judgments about the impact [26]. This paper is a contribution to this literature. We will formulate a framework for potential socio-economic impact assessment and study the selectedcase studies of technology transfer and effective commercialization from a pfARI leading towards socio-economic impacts. Basis the case studies and literature, the understanding would be formulated as a questionnaire and tested using qualitative and quantitative research with a focus group. The focus group study would culminate in a concurrence index for the potential socio-economic impacts of the selected case studies. The literature review, focus group study, and the concurrence results would help develop a framework for the potential socio-economic impact assessment of technology projects. The framework is helpful as a flexible tool for assessing socio-economic impacts at various stages of the project lifecycle.

The organization of the rest of this paper is as follows. First, we present a literature reviewof the socio-economic impact studies,especially research related to methodologies for assessment. Next, we discuss the multi-stage methodology adopted in the study and the research design. In the final section, we present the framework model for potential socio-economic impact, selected case studies, findings, contributions, implications, and limitations.

Evaluation serves the twin purposes of justifying the investments and gauging the progress[27]. Chronologically, public-funded science and technology evaluation has navigated from sole peer review to economic scrutiny and the recent inclusion of public scrutiny [21]. The regulatory changes in the 1980s regarding IP rights of federally funded research and scarcity of public funds were primarily responsible for initiating economic scrutiny. In addition, the evolving policies, globalization, and sustainable development goals (SDGs) may have contributed to the inclusion of the public scrutiny aspect[28]. The quest for sustainability in science leads to the hunt for broader evaluation measures, and socio-economic parameters provide this landscape in the current literature[29]. Though the centrality of societal impact in research evaluation is increasing steadily [26], measuring it with simple, reliable indicators with precision is a topic of recent deliberation[30].

The first systematic effort to encompass the socio-economic impact was conducted in the health sciences sector to justify the public investment in the UK [31]. Buxton and Hanney developed the Payback framework in 1996, incorporating the academic outputs and broader socio-economic impacts in the health sector[32]. The framework granulates the research and dissemination process into specific components, and a classification schema for research impacts is developed[33]. Spaapen et al. studied the interactions between the actors in the system from communication, collaboration, and contract perspectives. They suggested that these interactions help develop indicators that are helpful to measure socio-economic impacts [34]. However, it lacks to meet the specific requirements of impact assessment in some cases [35].

The ill-fated Australian research quality framework (RQF) is a comprehensive tool holistically covering the socio-economic impact of public-funded research[22]. It uses a case study-based approach with a follow-up by expert verification. Subsequently, the UK research excellence framework (REF) adapted the RQF. It added degrees of research impact and spread among users as criteria for evaluation. Passani et al. proposed a self-assessment methodology for socio-economic impact in information communication technologies and software as a service. They stressed the need for stakeholder integration in project execution for the best results [36].

The literature discusses the anticipations from future REF [37], the responsible metrics. Sivertsen discusses the individual and institutional units in assessments and the scope of mutual learning among the countries [38]. Though there are trade-offs and dilemmas in the suitability of available methodological approaches for evaluating societal impact [30], the case study methodology seems promising. It can analyze complex situations and synthesize in-depth understanding [39].

A literature stream related to the balanced scorecard (BSC) approach for assessing the corporate performanceas per the corporation's strategic objectives also seems exciting and helpful in our context. Initially proposed by Kaplan et al. [40] this approach tries to balance corporate performance assessment with additional parameters. Further, researchers have tried to extend this approach to R&D performance management in a corporate setup [41-43]. However, applying the criteria in the performance and potential assessment of technological innovations from public-funded R&D institutions is unexplored.

We propose that it is possible to develop and deploy technologies with potential socio-economic impacts in terms of scientific, economic, social, environmental, and cultural returns in the context of a pfARIin terms of corresponding indicators. We will develop a conceptual model for assessing potential socio-economic impact at different stages of the project lifecycle.

2.Methodology

In this work, we use an exploratory research design. Usingthe qualitative and quantitative methodology, we develop a conceptual model to assess the potential socio-economic impact of translated technologies from pfARI laboratories ina multi-stage research process.

In the first stage, we explore the available information on the impact assessment in CSIR laboratories through public means and consultation with the business development units of the CSIR laboratories. Then, triangulating these inputs with the literature, we came up with an initial classification framework of the factors contributing to the overall socio-economic impacts.

In the second stage, we used a purposive sampling of cases to understand the best practices and identify the indicators for socio-economic impacts.Purposive sampling is a non-probability sampling technique used frequently when the optimum selection criteria are known[44].

We selected holistically impactful technologies from the pfARIwith variance in terms of technological complexity, academic collaboration, industrial collaboration, type of intellectual property, and stakeholder engagement. It allowed us to have a balance in the salient features of the various technologies under consideration.

In the third stage, we used the focus group to test the framework for potential socio-economic impacts using qualitative measures. We chose a focus group with expertise in technology and management of technology to validate the proposed framework and evaluate the technologies' socio-economic performance. The focus group, comprising principal investigators of the research projects, members of the business development team, authors, and team members of the projects, were approached and involved in validating the proposed framework for evaluating the socio-economic performance of the technologies. Focus groupsare used frequently for the assessment of impact[45]. They are also helpful in gaining a comprehensive understanding of participants' experiences [46].

Finally, based on the results of the focus group study, available literature, and the author's understanding of the subject, we propose a conceptual model for potential socio-economic impact assessment.

2.1. Stage 1: Initial Development of criteria and framework

We studied the technology transfer mechanisms in place, guidelines, and the criteria for assessing the impact of technology transfer in 37 laboratories of a prominent pfARI in India. In addition, we analyzed the public data, annual reports, publications, patents literature, social and print media articles related to the pfARI technologies for gaining insight into their broader impacts. We also contacted the Business development heads of the laboratories to understand the process and best practices. We requested them to communicate the available technologies for commercialization, transferred technologies, and general best practices documents for impact assessments of their laboratories.

A general understanding that emerged at this stage was that the pfARI envisages measuring economic impacts, scientific & technological achievements, environmental impacts, social impacts, and cultural effects. The parameters of technological achievements could be technologies developed and deployed, economic impact generated, royalty earned. The scientific contribution can be measured using metrics like IP-generated, publications, and citations(www.csir.res.in). It is broadly in conformance with the available literature for assessing the socio-economic impact of research(Bornmann 2013). The previous literature identifies many variables of importance in evaluating the socio-economic impact of research from pfARI. With the inputs available to us, we further identified several specific indicators of importance.As a result of this exercise, we develop an initial framework for socio-economic impacts with a classification of five types of impact.

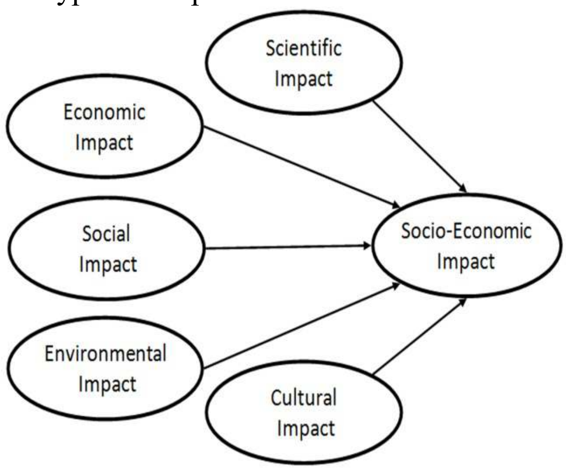

Fig. 1: Initial framework for potential socio-economic impact of technologies

As shown in figure 2, we structure the potential socio-economic impact as a comprehensive indicator that encompasses the scientific, economic, social, cultural, and environmental returns in terms of outputs and outcomes of the research at pfARIs. It is known by various nomenclature as third-stream activities, societal benefits, public value, and societal relevance in the literature [3]. The trend is to blend the traditional metrics of evaluation with metrics of societal relevance for clarity in the benefits of public investment in science and technology. It seems to be a step in the right direction as experience suggests an overlap between these indicators, and the boundary is fuzzy.

Link et al. have discussed the benefits from the economic aspect and confirmed the results using case study methodology. The benefits of the technology from pfARIs to the industry are two-fold viz. direct to the industry in terms of improved profit & indirect in terms of the lower price that society pays for the products offered by the industry due to lower development cost. However, the transference takes time and requires a long-term commitment by the pfARIs. Further, the policy support in such cases is a significant enabler. Therefore, the role of pfARIs management in ensuring the success of the TT effort by providing resources, promoting the potential technologies, and supporting the TT culture in their laboratory is critical. Further, post-transfer collaboration can be a game-changer for the companies building upon transferred knowledge for a successful, marketable product[47].

Social, cultural, and environmental impacts are additions of the research to thenation's social, cultural, and natural capital [3]. Interaction of science with society through technology has peer, upstream, midstream, and downstream implications regarding understanding, behavior, approach, and equity in society. The cultural impacts relate to the overall prevalence of scientific conduct, recognition for the creative work, and motivation for the people to engage through coverage in popular and social media, awards, and fellowships. Environmental impacts related to the sustainability of the technological intervention in reducing, reuse, and recycling. Since these impacts are broad and have a varied timescale, their measurement needs sustained effort and is a long-term phenomenon [48].

We will use this five-factor structure to assess the potential socio-economic impact of CSIR technologies.

2.2. Stage 2: Multi Case Studies

We worked on the database of technologies transferred by the pfARI in the last five years and tried to analyze and categorize them based on deployment status, sector, and characteristics such as academic collaboration in technology development, industry engagement, intellectual property rights, and stakeholder involvement. It gave us insights regarding the deployed technologies. From this universe, we selected the deployed technologies of the health and environment safety sector. We map the technologies in terms of the initial framework. Finally, wedecided on three case studies with perceived high potential socio-economic impact based on our experience for detailed assessments.

We discuss threedetailed case studies in the health and environment safety sector with potential socio-economic impacts in the following sections selected based on the age of technologies, technological complexity, engagement of industrial partner, and type of IPR. The technologies are electrostatic disinfection system (EDS), AutoCEPH, and UVC Air Duct Disinfection System. We had consultations with the scientists, SMEs, other stakeholders, and end-users and have depictedthe narrative effects and issuesthat emerged during the discussion. The chosen technologies' brief characteristics are shown in Table 1: Brief characteristics of selected case studies.

.

Table 1: Brief characteristics of selected case studies

	EDS	**AutoCEPH**	**UVC Air Duct Disinfection System**
COVID related	Yes	No	Yes
IPR	Yes (Patent)	Yes (Copyright)	Yes (Design)
Technology Complexity	Medium	High	Low
Academic Collaboration	No	Yes	No
Deployment Age	1 year	3 Year	3 Month
Industrial Partner	Yes (3)	No (0)	Yes (30)
Commercialization Strategy	TT through conventional mode	SaaS	TT through Expression of Interest in Media
Current Market Penetration	Medium	High	Medium

The first case we consider is an Electrostatic Disinfection system (EDS) for decontaminating the surroundings by offering the enhanced ability of substance exposure over the target surface and reducing run-off. The second technology, AutoCEPH, is a 2-D cephalometric analysis software. It assists orthodontic and maxillofacial surgeons in performing analyses for their patients. Finally, we consider the UVC Air Duct Disinfection System for improving indoor air quality. It is a retrofittable unit into existing HVAC air ducts using customizable sliding mechanisms. In the following sections, we compare these technologies and discuss their essential characteristics and issues considering the socio-economic impacts. Given in Table 2 Detailed comparison of selected technologies depicts the features of the three selected technologies in terms of considered pillars of scientific, economic, social, environmental, and cultural impacts.

CSIR developed the technology for electrostatic disinfection, which has been absorbed by an SME based in India, leading to new product development (NPD)(2021). The technology transfer happened during the COVID lockdown period. Interestingly the regional distance does not seem to have an impact on absorption. The reason appears to be the inculcation of intellectual proximity due to virtual communication between source and recipient. After that, the industry entered into a consultancy and training agreement with CSIR to enhance its internal R&D capabilities. This engagement helped the SME strengthen its R&D base and vouch for endowment funding from the US-India Science and Technology Endowment Fund for advancements in technology, with CSIR as a development partner. The journey is quite exciting and seems prospective, eyeing several opportunities by the collaborating ARI and SME.

AutoCEPH is a 2-D cephalometric analysis software. It assists orthodontic and maxillofacial surgeons in performing analyses for their patients. CSIR-Central Scientific Instruments Organisation, Chandigarh, India, has developed the software in collaboration with the Centre for Dental Education and Research (CDER), AIIMS, New Delhi, India. The software was developed and benchmarked with the available commercial software and manual tracing. After being judged comparable, the software was launched and promoted under the software as a service model (SaaS). To date, more than 1200 orthodontic surgeons have logged the software with a trans-national span. In addition, doctors have performed more than 6000 cephalometric analyses. With continual research and clinical inputs, the software is further evolving to include state-of-the-art features.

Improving indoor air quality is an area of interest in the pandemic era with long-term applications. The UVC Air Duct Disinfection System is a retrofit unit into existing HVAC air ducts using customizable sliding mechanisms. It consists of a slide mechanism, a regulated UV light source, and sensors. The device is used as a retrofit attachment to any existing air duct by minor modifications (cut, slot, and fitting) into it. The precise optimization of the intensity of UVC light ensures the proper dosage to the given airflow to inactivate any virus & bacteria present. In addition, the mechanical setup allows the user to position the light source quickly and easily removeit when maintenance or cleaning is required.

Table 2: Detailed comparison of selected technologies

	EDS	Auto CEPH	UVC Air Duct Disinfection System
Scientific Impact	• Quick technology development and rapid absorption	• Deployed as Software as a Service • High Impact	• New Product developed and launched by more than two dozen industrial

	• Timely Market Launch • IP protection of the core technology • High impact publications in the technology stream	Publications • Protected by Software copyright	partners • The IP protection is in the form of design registration
Economic Impact	• Licensing income generated to the institute • Royalty income • Follow on funding for incremental product development received jointly with industry	• Follow on funding for development of advanced features received • Massive potential for Licensing and royalty but is unexplored in search of marketing partner	• Licensing Income from Industrial Partners • Expect Royalty income with commercialization • Follow-on funding received for spin-off applications
Social Impact	• Interaction among policymakers, researchers, industries, users, and media • Improved internal R&D capability of the SME • Human capital generation in the specialized field of electrostatic spraying • Sterilized public places and hospitals will encourage economic activity	• Mass penetration among the prospective user base • Constructive stakeholder engagement leading to improved linkage and Product evolution • Academic collaborator leading the promotion and made its presence felt on all platforms • Robust human capital generation	• Industry connect with the help of print media • Management championing the project • System calibration and testing completed • Common communication platform for industrial partners • Prospective collaboration between the entities for economies of scale and market advantage
Environmental Impact	• Reduced material usage • Better surface coverage • Virucidal remedy for public health and safety	• Reduced paper usage for manual tracing • Positive impact on public health and safety	• Improvement in indoor air quality • Safer public spaces • Handling technology waste needs to be proper
Cultural Impact	• Widespread media attention • Technology display to policymakers and media • The scientist and team have won accolades for their exemplary work and are evolving as a research group	• Garnering end-user attention • Fellowships and Studentships. • International user base highlighting cross-cultural interaction	• Elaborate media coverage and attention • pfARI has released comprehensive guidelines on ventilation of residential and office buildings (www.csir.res.in 2021a)

Issues

The significance of reducing exposure-related health risks to the public and environment is primary [49]. The EDS case study focuses on disinfection which is very important in the current scenario. In particular electrostatic disinfection is garnering attention due to rapid decontamination and reduced footprint [50].

Developing countries like India rank low on hygiene parameters globally. However, the country's leadership has felt the urge, and India launched the Swachh Bharat Abhiyaan[51] in 2014 to create awareness for personal and public hygiene. Although the program has brought in a marked shift in the thought process of the citizens [52], it requires more rigorous efforts. Moreover, the covid pandemic has further enhanced the urge for solutions.

The concept of mass disinfection is relatively new for the country and needs to be supported by regulatory mechanisms. The standardization of the processes and certification of the products is also a significant issue. Guidelines regarding scheduled use of disinfection of the buildings and public spaces are required. The indigenous manufacturers need support and handholding in this direction. It requires the championing support and leadership of standards organisations, pollution control boards, licensing, and controlling authorities at a sustained level.

In the case of AutoCEPH, the pfARI is currently maintaining the software on its server. The software is with a free license, and customer support is not proper. The developer scientist usually provides customer support as there is no dedicated team for handling these issues. An industrial partner with an appropriate business model and execution team is ideally required to take care of these aspects.

The development is at the cusp of an exponential launch, and an industrial partner could help in this regard. The pfARI needs to chalk out an appropriate strategy to engage the prospective partners. The untapped economic potential is high and is achievable by introducing features like 3D cephalometry and AI-based automation and engagement of a marketing and support partner.

Finally, in the UVC Air Duct Disinfection System case, the need for standards is imminent. The regulator in India should develop a comprehensive standard for UV In-duct systems in HVAC. Further, since UV lamps contain toxic materials, it is essential to ensure their safe handling after service life. Improper disposal is an environmental hazard. Mass scale implementation can make it a big issue, and regulations in this regard would be vital.

Insights

The successful transfer and adoption of technology[53] have multifaceted implications for SMEs (Min et al. 2020) and the innovation ecosystem [54]. First, it leads to NPD, improving the business performance of the SME (Park and Ryu 2015). Further, it infuses the R&D culture among the employees at the micro-level, SMEs at the meso level, and the economy as a whole at the macro level leading to social gain [47].

The absorption capacity of the SMEs, which is critical to NPD success [56], is improved, enabling them to attract investment [57]. Mutual trust improves at all levels leading to greater engagement. Further, with the endowment funding[58] available for sustainable technology development, the proximity can lead to further collaboration and technology development. The technology has reduced environmental footprint and is socially relevant. The developed technology has a substantial potential socio-economic impact. However, to fully leverage the potential, handling issues like systematic policy, guidelines regarding disinfection, and regulatory support for certifications need attention.

In AutoCEPH software, the project has generated excellent results in all aspects barring the engagement of an industrial partner. The product is mature in its current form. However, with the implementation of 3D features and automation, it is expected that the outcome would be able to cross the threshold for financial impact. Good matchmaking by the technology transfer office can help the technology break this barrier, and then the sky is the limit. We suggest that the opportunities in the start-up or spin-off domains may be explored by looking into the asset-light model of the development.

Considering the UVCair duct disinfection system, offering a research product with calibration and testing certifications attracts the immediate attention of the market. Further, if the management of the research institution champions the efforts in identifying the market and promotion, the market penetration is swift. Sustaining momentum through communication and handholding would enhance the probability of successful commercialization. It also has a spiraling impact on the intensity of pfARI-industry interaction for future endeavors, as trust plays a vital role in engagement speed.

2.3.Stage 3: Validating the Framework for potential socio-economic impacts of the selected case studies

A focus group, consisting of principal investigators, members of the business development team, authors, and team members of the projects, were approached and involved in validating the proposed framework for evaluating the socio-economic performance of the technologies. It aligns with the literature regarding the importance of expert opinion in assessing the socio-economic impact [35]. Based on the literature review, inputs from CSIR laboratories, the cloverleaf model [59], the studied cases,and the experience in assessing the effects, we developed a questionnaire encompassing socio-economic impacts.

The questionnaires were presented to the focus group and ask them to record their quantitative and qualitative judgments. We record the responses for impacts of the technology on a five-point scale with values ranging from 1(very low impact) to 5(very high impact). Further, we ask the respondents to indicate their confidence in the response on a scale of 1 to 3, ranging from low to high confidence. We use the confidence level as a weighting variable. Finally, we compile the weighted sum for questions classified in our proposed model to have a qualitative understanding of the socio-economic impact of technologies. The value of indexes varies from 3 to 45 for each of the individual pillars, indicating a model with holistic balance. The range of scores for technology was from 15 to 225.

We recorded the response of the individual members of the focus group to the questionnaire. In follow-up, we organized a conference meeting to arrive at a consensus estimate values for potential socio-economic. The final values are as shown in Table 3Potential socio-economic impact score of technologies.

Table 3: Potential socio-economic impact score of technologies.

Technology	Scientific Index 3 to 45	Economic Index 3 to 45	Social Index 3 to 45	Environmental Index 3 to 45	Cultural Index 3 to 45	Total Score 15 to 225
EDS	39	39	42	36	42	198
AutoCEPH	42	36	40	30	30	178
UVC Air Duct Disinfection System	36	42	40	27	42	187

Table 3: Potential socio-economic impact score of technology summarizes the concurrence result for testing the model by the focus group indicating the importance and balance of considered factors in assessing socio-economic impacts. The high index values confirm our view that the purposively sampled technologies have

substantial potential socio-economic impacts.Therefore, this socio-economic index can be fruitful for analyzing the potential socio-economic impact of technologies.

2.4 The conceptual model for potential socio-economic impact assessment

The preceding discussion establishes our propositionthat it is possible to develop and deploy technologies with potential socio-economic impacts in terms of scientific, economic, social, environmental, and cultural returns in the context of a pfARI under various constraints.

Based on the case studies and relevant literature, we have devised a conceptual model, as shown in Fig. 2, assessment having 15 indicators across five dependent variables. We propose using the scientific, economic, social, environmental, and cultural indicators as dependent variables to gauge the socio-economic implications comprehensively.

The conceptual model depicts 15 indicators helpful in assessing the socio-economic impact of technology transfer projects: publications, new product development (NPD), intellectual property, licensing, royalty, research funding, collaborations, innovation culture, human capital, public health and safety, reduced footprint, environment-friendly, awards, fellowships, and media coverage. We group these observed indicators as scientific, economic, social, environmental, and cultural impacts. The conceptual model encompasses the vital factors and indicators for assessingthe potential socio-economic impact of translated/under translation technologies. Therefore, we can develop it as a customized tool for specific contexts and scenarios.

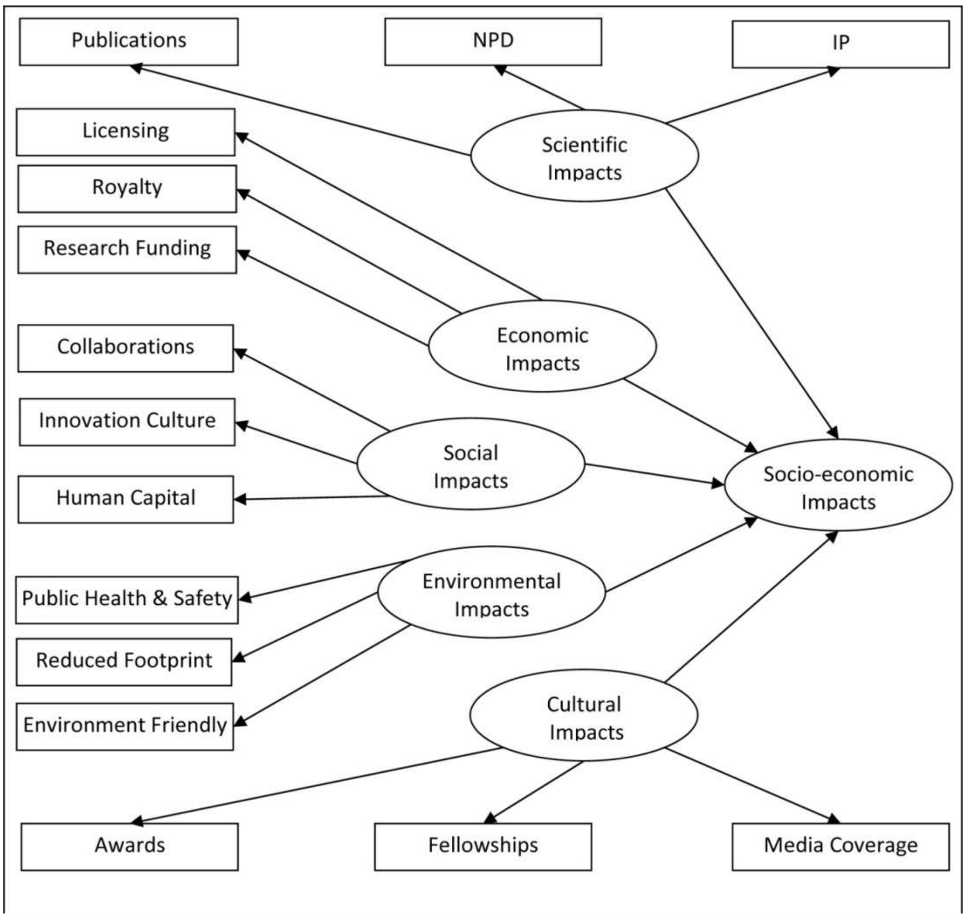

Fig. 2: Conceptual model of potential socio-economic impact assessment

3. Discussion

Nearly twenty years ago, the importance of socio-economic analysis of R&D was being discussed at high-level policy centres [60]. However, even to date, there is a dearth of valid techniques for such evaluation. The researchers are still arguing about strengthening the socio-economic impact assessment culture in science and technology. The research proposal review criteria should also judge the societal goals. [36].

The researchers have stated the reasons for such a significant gap in research evaluation literature across various studies.The literature documents the lack of consensus about what data to use, frameworks, methods, or criteria for impact assessment [1,24,34,61].

However, in the Indian context, assessing the socio-economic impact of technologies is of prime importance as the offered solution will be catering to the sizeable poor and vulnerable population of the country [62].

Consistent with the literature, we undertookthe study. Amodel is proposed based on the studied literature, policy documents, case studies, and focus group discussions in the said context that gives a quick idea about the potential socio-economic impact of the developed technologies. However, basis the broader understanding of the socio-economic assessment, it was found that this model has limitations and needs comprehensive evaluation before being brought to practice.

3.1.Dynamism of the Model

The model has considered the social, economic, cultural, environmental, and scientific impact.However, this model can be expanded to include other factors such as strategic [63,64] , zoological [65] and geographical [66]. The addition or deletion of factors from the model can be contextualized to the technology domain under study.

3.2. Quantification of the model

The model has considered various criteria under the factors such as the scientific impact viz. New Product Development, Publication, and Intellectual Property. However, the scientific impact can be extended beyond these measurements, including the criterion such as the citation index [67,68]. Similarly, the economic impact has a vast span that can be extended beyond considered factors, like the impact on the firms' profitability can also be considered [69,70]. Additionally, for the social impact, the criteria can include the impact on inclusivity of the population.

3.3.Balancing of the model

In this study, the model uses equal weightage for all the parameters. However, this can be varied as the interplay of these factors, and the criteriathat need to be studied in the domain, and the expert assumptions about assigning weights need to be taken [71].

Although the scope of the study is significant for the stakeholders, with the above considerations, we can have a microscopic examination of the socio-economic impact of technologies. However, as illustrated in the literature, the higher resolution of the examination would lead to a context-specific and expertise-driven study that tends to be effective but may lack time and cost-efficiency.

The derived model is for the technologies developed but is a quick and straightforwardcalculation tool for assessing the socio-economic impact. If we consider the project lifecycle, studying the socio-economic impact of the resultant technology needs to fill the model gaps, as has been discussed here. However, at the initial stage, when the project proposal is formulated, a quick analysis of the impact can enhance the value of the proposal and benefit society at large. Moreover, the funding agencies must include such evaluation parameter criteria in their policy guidelines for project submission. It will ensure compliance to the socio-economic effect and raise the scientific community's awarenessof this.

4.Conclusion

Technology is a significant guide for how human life is proceeding, and there is a strong belief that it is beneficial for life on earth. However, many parallel concepts have evolved from umpteen dimensions and directions regarding the utility of investments in science and technology. Moreover, in the context of public-funded research, the growing competition for research funds leads to an enhanced quest for evaluation with a broadening scope. Our study contributes to the field by proposing a tool for evaluating technology transfer projects regarding their socio-economic impacts.

Socio-economic impacts of research are beneficial indicators for the evaluation of science and technology. It gives a broad spectrum of impacts having direct and indirect causality. Though the field is emerging, the justification of the need for such indicators is sound. This work would contribute to this promising field. However, the result is based on multi-case studiesfollowed by focus group discussion and has associated limitations of biasing.

We have proposed a conceptual model that can assess the potential and actual socio-economic impact of research projects. It can be modified and updated as per the contextual requirements. It provides a simple analysis method. An exciting adaptation can be to analyze the socio-economic impact of individuals, research groups, institutions, and other units of study at a point in time and longitudinally.Furthermore, the balancing of the proposed model with appropriate weights needs to be explored.

The development of the conceptual model considers the pfARI and SME context, but the basic idea can be helpful for other contexts and streams. Furthermore, the model can be further tested and validated in future studies.

Acknowledgment

We acknowledge the support extended by Director Prof. S Anantha Ramakrishna, Dr. Harry Garg&Dr. A K Shukla, Senior Principal Scientist, and Dr. Manoj Kumar Patel, Principal Scientist. We also thank Sh. Virendra Kumarand Ms. Priyanka Raghav, Senior Scientists at CSIR-Central Scientific Instruments Organisation Chandigarh, for their support. We extend our sincere gratitude to Dr Avanish Kumar Srivastava Director CSIR-AMPRI and Dr. J P Chaurasiya, Head PPD CSIR-AMPRI Bhopal.

References

[1] Bozeman, Barry, Rimes, Heather, and Youtie, Jan (2015), 'The evolving state-of-the-art in technology transfer research: Revisiting the contingent effectiveness model', Research Policy, 44 (1), 34-49.

[2] Singhai, Sandeep, et al. (2021), 'Analysis of Factors Influencing Technology Transfer: A Structural Equation Modeling Based Approach', Sustainability, 13 (10), 5600.

[3] Bornmann, Lutz (2013), 'What is societal impact of research and how can it be assessed? A literature survey', Journal of the American Society for information science and technology, 64 (2), 217-33.

[4] Vega-Gomez, Francisco I and Miranda-Gonzalez, Francisco J (2021), 'Choosing between Formal and Informal Technology Transfer Channels: Determining Factors among Spanish Academicians', Sustainability, 13 (5), 2476.

[5] Grimpe, Christoph and Hussinger, Katrin (2013), 'Formal and informal knowledge and technology transfer from academia to industry: Complementarity effects and innovation performance', Industry and innovation, 20 (8), 683-700.

[6] Schaeffer, Véronique, Öcalan-Özel, Sıla, and Pénin, Julien (2020), 'The complementarities between formal and informal channels of university–industry knowledge transfer: a longitudinal approach', The Journal of technology transfer, 45 (1), 31-55.

[7] Watkins, Andrew, et al. (2015), 'National innovation systems and the intermediary role of industry associations in building institutional capacities for innovation in developing countries: A critical review of the literature', Research policy, 44 (8), 1407-18.

[8] Tambunan, Tulus Tahi Hamonangan (2009), SMEs in Asian developing countries (Springer).

[9] Deeds, David L and Hill, Charles WL (1996), 'Strategic alliances and the rate of new product development: An empirical study of entrepreneurial biotechnology firms', Journal of business venturing, 11 (1), 41-55.

[10] Inkpen, Andrew C (2005), 'Strategic alliances', The Blackwell handbook of strategic management, 403-27.

[11] Maroušek, Josef, Mysková, Kateřina, and Žák, Jaroslav (2015), 'Managing environmental innovation: Case study on biorefinery concept', Revista Técnica de la Facultad de Ingeniería Universidad del Zulia, 38, 216-20.

[12] www.csir.res.in 'CSIR Guidelines on Ventilation of Residential and Office Buildings for SARS-Cov-2 Virus | Council of Scientific & Industrial Research | CSIR | GoI', <https://www.csir.res.in/csir-guidelines-ventilation-residential-and-office-buildings-sars-cov-2-virus>, accessed 29/05/2021.
www.csir.res.in 'About CSIR | Council of Scientific & Industrial Research | CSIR | GoI', <https://www.csir.res.in/about-us/about-csir>, accessed 23/04/2021.

[13] Dutta, Tanushree, et al. (2016), 'Global demand for rare earth resources and strategies for green mining', Environmental Research, 150, 182-90.

[14] Jha, Manis Kumar, et al. (2013), 'Recovery of lithium and cobalt from waste lithium ion batteries of mobile phone', Waste management, 33 (9), 1890-97.

[15] Krishnamoorthy, G, et al. (2012), 'Green chemistry approaches to leather tanning process for making chrome-free leather by unnatural amino acids', Journal of hazardous materials, 215, 173-82.

[16] Kumar, Sunil, et al. (2017), 'Challenges and opportunities associated with waste management in India', Royal Society open science, 4 (3), 160764.

[17] Patel, Manoj Kumar (2016), 'Technological improvements in electrostatic spraying and its impact to agriculture during the last decade and future research perspectives–A review', Engineering in Agriculture, Environment and Food, 9 (1), 92-100.

[18] Arora, Parveen and Nath, Pradosh (2015), 'Innovation in Indian Industries: Insights from the First National Innovation Survey', Asian Journal of Innovation and Policy, 4 (3), 360-80.

[19] Rothwell, Roy and Zegveld, Walter (1982), 'Innovation and the small and medium sized firm', University of Illinois at Urbana-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship.

[20] Bush, Vannevar (1945), 'As we may think', The atlantic monthly, 176 (1), 101-08.

[21] Stephan, Paula E (2012), How economics shapes science (1: Harvard University Press Cambridge, MA).

[22] Donovan, Claire (2008), 'The Australian Research Quality Framework: A live experiment in capturing the social, economic, environmental, and cultural returns of publicly funded research', New directions for evaluation, 2008 (118), 47-60.

[23] Schot, Johan and Steinmueller, W Edward (2018), 'Three frames for innovation policy: R&D, systems of innovation and transformative change', Research policy, 47 (9), 1554-67.

[24] Bornmann, L., 2013. What is societal impact of research and how can it be assessed? A literature survey. Journal of the American Society forinformation science and technology, 64(2), pp.217-233.

[25] Rymer, Les (2011), 'Measuring the Impact of Research--The Context for Metric Development. Go8 Backgrounder 23', Group of Eight (NJ1).

[26] Hill, Steven (2016), 'Assessing (for) impact: Future assessment of the societal impact of research', Palgrave Communications, 2 (1), 1-7.

[27] Ahonen, Pertti (2015), 'Aspects of the institutionalization of evaluation in Finland: Basic, agency, process and change', Evaluation, 21 (3), 308-24.

[28] Gallopín, Gilberto C (2001), 'Science and technology, sustainability and sustainable development'.

[29] Molas-Gallart, Jordi, et al. (2016), 'Towards an alternative framework for the evaluation of translational research initiatives', Research Evaluation, 25 (3), 235-43.

[30] Lauronen, Juha-Pekka (2020), 'The dilemmas and uncertainties in assessing the societal impact of research', Science and Public Policy, 47 (2), 207-18.

[31] Grant, Jonathan (2006), 'Measuring the benefits from research', Policy Resource.

[32] Buxton, Martin and Hanney, Steve (1996), 'How can payback from health services research be assessed?', Journal of health services research & policy, 1 (1), 35-43.

[33] Hanney, Stephen R and González-Block, Miguel A (2011), 'Yes, research can inform health policy; but can we bridge the'Do-Knowing It's Been Done'gap?', (BioMed Central).

[34] Spaapen, Jack and Van Drooge, Leonie (2011), 'Introducing ‘productive interactions’

in social impact assessment', Research Evaluation, 20 (3), 211-18.

[35] Penfield, Teresa, et al. (2014), 'Assessment, evaluations, and definitions of research impact: A review', Research evaluation, 23 (1), 21-32.

[36] Passani, Antonella, et al. (2014), 'SEQUOIA: A methodology for the socio-economic impact assessment of Software-as-a-Service and Internet of Services research projects', Research Evaluation, 23 (2), 133-49.

[37] Wilsdon, James (2016), 'The metric tide: Independent review of the role of metrics in research assessment and management'. www.csir.res.in 'CSIR@80: Vision & Strategy 2022 2011', <https://www.csir.res.in/sites/default/files/CSIR80-final.pdf>, accessed 13/05/2021.

[38] Sivertsen, Gunnar (2017), 'Unique, but still best practice? The Research Excellence Framework (REF) from an international perspective', Palgrave Communications, 3 (1), 1-6.

[39] Bell, Sarah, Shaw, Ben, and Boaz, Annette (2011), 'Real-world approaches to assessing the impact of environmental research on policy', Research Evaluation, 20 (3), 227-37.

[40] Kaplan, Robert S and Norton, David P (2005), 'The balanced scorecard: measures that drive performance', Harvard business review, 83 (7), 172.

[41] Amaratunga, D, et al. (2010), 'A balanced scorecard approach for R&D: evidence from a case study', Facilities.

[42] Bremser, Wayne G and Barsky, Noah P (2004), 'Utilizing the balanced scorecard for R&D performance measurement', R&d Management, 34 (3), 229-38.

[43] García-Valderrama, Teresa, Mulero-Mendigorri, Eva, and Revuelta-Bordoy, Daniel (2008), 'A balanced scorecard framework for R&D', European Journal of Innovation Management.

[44] Tongco, Ma Dolores C (2007), 'Purposive sampling as a tool for informant selection', Ethnobotany Research and applications, 5, 147-58.

[45] Bloor, Michael (2001), Focus groups in social research (Sage).

[46] Morgan, David L and Krueger, Richard A (1998), The focus group guidebook (Sage).

[47] Link, Albert N and Scott, John T (2019), 'The economic benefits of technology transfer from US federal laboratories', The Journal of technology transfer, 44 (5), 1416-26.

[48] Lähteenmäki-Smith, Kaisa, et al. (2006), 'Research with an impact: Evaluation practices in public research organisations'.

[49] Wang, Jiao, et al. (2020), 'Disinfection technology of hospital wastes and wastewater: Suggestions for disinfection strategy during coronavirus Disease 2019 (COVID-19) pandemic in China', Environmental pollution, 114665.

[50] Cadnum, Jennifer L, et al. (2020), 'Evaluation of an electrostatic spray disinfectant technology for rapid decontamination of portable equipment and large open areas in the era of SARS-CoV-2', American journal of infection control, 48 (8), 951-54.

[51] Vishwakarma, Devendra (2016), 'Swachh Bharat abhiyan clean India abhiyan', International Research Journal of Management, IT and Social Sciences, 3 (3), 48-52.

[52] Dandabathula, Giribabu, et al. (2019), 'Impact assessment of India's Swachh Bharat Mission–Clean India Campaign on acute diarrheal disease outbreaks: Yes, there is a positive change', Journal of family medicine and primary care, 8 (3), 1202.

[53] Fu, Yao, et al. (2018), 'Factors affecting sustainable process technology adoption: A systematic literature review', Journal of Cleaner Production, 205, 226-51.

[54] Yi, Ming, Fang, Xiaomeng, and Zhang, Yao (2019), 'The differentiated influence of technology absorption on regional economic growth in China', Sustainability, 11 (2), 450.

[55] Park, Taekyung and Ryu, Dongwoo (2015), 'Drivers of technology commercialization and performance in SMEs', Management Decision.

[56] Cooper, Robert G and Kleinschmidt, Elko J (2007), 'Winning businesses in product development: The critical success factors', Research-Technology Management, 50 (3), 52-66.

[57] Hsu, Chiung-Wen and Chang, Pao-Long (2013), 'Innovative evaluation model of emerging energy technology commercialization', Innovation, 15 (4), 476-83.

[58] Hall, Bronwyn H and Maffioli, Alessandro (2008), 'Evaluating the impact of technology development funds in emerging economies: evidence from Latin America', The European Journal of Development Research, 20 (2), 172-98.

[59] Heslop, Louise A, McGregor, Eileen, and Griffith, May (2001), 'Development of a technology readiness assessment measure: The cloverleaf model of technology transfer', The Journal of technology transfer, 26 (4), 369-84.

[60] Van Raan, A.F., 2000. R&D evaluation at the beginning of the new century. ressearch evaluation, 9(2), pp.81-86

[61] Poppy, G., 2015. Science must prepare for impact. Nature News, 526(7571), p.7.

[62] Tiwari, S., Tiwary, E. India: Assess social impact of technology. Nature **522,** 419 (2015). https://doi.org/10.1038/522419c

[63] Palvia, P.C., 1997. Developing a model of the global and strategic impact of information technology. Information & Management, 32(5), pp.229-244.

[64] Salazar, A., Hackney, R. and Howells, J., 2003. The strategic impact of internet technology in biotechnology and pharmaceutical firms: insights from a knowledge management perspective. Information Technology and Management, 4(2), pp.289-301.

[65] Allison, T.D., Diffendorfer, J.E., Baerwald, E.F., Beston, J.A., Drake, D., Hale, A.M., Hein, C.D., Huso, M.M., Loss, S.R., Lovich, J.E. and Strickland, M.D., 2019. Impacts to wildlife of wind energy siting and operation in the United States. Issues in Ecology, 21(1), pp.2-18.

[66] Gillespie, A. and Robins, K., 1989. Geographical inequalities: The spatial bias of the new communications technologies. Journal of communication, 39(3), pp.7-18.

[67] Smith, M.J., Weinberger, C., Bruna, E.M. and Allesina, S., 2014. The scientific impact of nations: Journal placement and citation performance. PloS one, 9(10), p.e109195.

[68] Wong, R., Allen, F.H. and Willett, P., 2010. The scientific impact of the Cambridge Structural Database: A citation-based study. Journal of Applied Crystallography, 43(4), pp.811-824.

[69] Mithas, S., Tafti, A., Bardhan, I. and Goh, J.M., 2012. Information technology and firm profitability: mechanisms and empirical evidence. Mis Quarterly, pp.205-224.

[70] Palmer, M. and Truong, Y., 2017. The impact of technological green new product introductions on firm profitability. Ecological Economics, 136, pp.86-93.

[71] Eilat, H., Golany, B. and Shtub, A., 2008. R&D project evaluation: An integrated DEA and balanced scorecard approach. Omega, 36(5), pp.895-912.