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Research paper

Inventive Problem Solving for Sustainability in Energy-Sector Using TRIZ

Aslı Çillioğlu Karademir

Department of Business Administration, Faculty of Economics and Administrative Sciences, Bartın University, 74100 Bartın, Türkiye
** Corresponding author E-mail: aslia6375@gmail.com*

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Abstract

The energy sector is at the front lines for the fulfillment of global sustainability challenges, such as the need to uphold environmental commitments within an economic imperative. The contradiction perhaps comes nowhere more deeply into conflict than between carbon pricing mechanisms and labor cost management, where, typically, environmental regulation helps to militate against operational efficiency. There are competing priorities that demand innovative, structured approaches for tackling these challenges. This study uses the Theory of Inventive Problem Solving (TRIZ) to resolve these contradictions systematically. From its engineering and production beginnings, TRIZ has evolved into a general innovation management tool enabling organisations to establish links between their strategies, green innovation objectives, and sustainability goals. Although still in its infancy, TRIZ contributes to balancing economic and environmental objectives and offers structured solutions for innovation, making it more robust for integration with Corporate Social Responsibility (CSR) frameworks and green management practices. This research on organizational accountability regarding the issue of sustainability is directed by CSR and can be viewed from the perspectives of both global business and Small and Medium-sized Enterprises (SMEs). Several examples have been examined in this study, and how TRIZ principles have been used to resolve complex sustainability and operational management problems.

In this research, common methodologies of the large firms are described and how it can be adapted for SMEs to drive innovation and help in collective sustainability constrained by resources. Ultimately, it is concluded that TRIZ serves as a transformative framework for shaping the sustainable future of SMEs in the energy sector, effectively bridging the gap between environmental responsibility and economic development.

***Keywords**: Theory of Inventive Problem Solving (TRIZ); Sustainability; Corporate Social Responsibility (CSR); SMEs; Strategic Decision Making; Green Management; Renewable Energy; Innovation Managament*

1. Introduction

The energy sector has been at the forefront of efforts to tackle global sustainability challenges, with the emergence of conflict between environmental responsibilities and economic imperatives. Whereas environmentally harmful business activities are being increasingly punished by revenue losses, operational efficiency is also being sacrificed in favor of employment and labor cost management. In order to face these challenges, we need innovative, structured approaches that can address these competing priorities. This study systematically resolves these contradictions using the Theory of Inventive Problem Solving (TRIZ). Initially associated with engineering and manufacturing fields, TRIZ has since become a versatile tool for promoting innovation and reconciling organisational strategies with a sustainable endpoint.

As TRIZ is a structured approach to tackle innovation, it helps to meet and merge the interests of the environmental and economic objectives. This research is guided by a focus on Corporate Social Responsibility (CSR), focusing on organizational accountability to address sustainability challenges in global businesses and small and medium businesses. This study explores the application of TRIZ principles to address complex contradictions for the sustainability and operational management problem using a multi-case study methodology.

Insights were summarized, and the research put forward ways in which SMEs can adapt these methods and also overcome resource constraints to promote innovation and support cooperation towards collective sustainability. Finally, this study reveals that TRIZ offers a transformative framework to pave the way for a sustainable future for SMEs by integrating environmental responsibility and economic progress.

2. Purpose and Research Question

This study investigates the application of the Theory of Inventive Problem Solving (TRIZ) in strategic management and sustainability, with a particular focus on SMEs in the energy sector. It seeks to deal systematically with environmental economic contradictions, including integrating renewable energy with cost effectiveness and balancing labor costs with sustainability. Wishing to integrate TRIZ with CSR frameworks, this research intends to develop practical strategies that would help SMEs develop sustainability and operational efficiency. Furthermore, the study investigates how innovation can be utilized as an engine of environmental accountability, complementing economic growth, promoting innovation, and a responsibility-sharing culture within SMEs.

The main research question guiding this study is:

RQ: What insights can be adapted into sustainable strategies from the application of TRIZ in global energy enterprises, and how?

To address this research question, the study examines the following sub-questions:

•Sub-question 1 (S1): What kind of alignment of environmental and economic goals is allowed by the integration of TRIZ with CSR frameworks in the energy sector?

•Sub-question 2 (S2): Where are the challenges and opportunities for SMEs in incorporating TRIZ methodologies in order to increase sustainability and mitigate operational contradictions?

S1 findings also suggest integration of TRIZ and CSR aligns economic and environmental goals and provides systematic solutions to sustainability challenges. The research demonstrates how practical barriers, including limited resources and expertise with S2, ensure SMEs lag behind. It proposes TRIZ tool innovation to facilitate SMEs, and suggests partnership and training to increase SMEs' ability to innovate. This research shows how insights from applying TRIZ in global energy enterprises can be adapted to address specific challenges of SMEs so that TRIZ becomes a transformative tool for improving their energy and operational sustainability.

3. Literature Review

This section presents the theoretical framework relevant to the research topic, with particular attention given to ensuring its alignment with the central research question.

3.1 The Historical Development of TRIZ

TRIZ, the Theory of Inventive Problem Solving, was created in the mid 20th century by Genrich Altshuller as a generic methodology in problem solving. He was then able to identify that many inventions had something in common, and could be systematically categorized and applied to other engineering problems. Thus, an innovation and creativity methodology, TRIZ, developed from here out to suggest a systematic way to drive creativity and innovation. In other words, TRIZ is built to enhance creativity and innovation in problem-solving in the fields of engineering, product design, and service development. This is based on the analysis of patterns of invention in the global patent literature. It can provide a structured way to handle technical contradictions and improve inventive capabilities. The systematic nature of TRIZ is the fundamental distinguishing feature of TRIZ from more conventional creative problem-solving techniques like brainstorming. Instead of brainstorming, which calls for pure intuition and spontaneity, TRIZ applies an approach consisting of a set of tools and principles on which to resolve contradictions in the problems solved. This systematic approach allows practitioners to examine a broad spectrum of solutions and identify creative solutions without the trade-off of required functions [1], [2], [3], [4].

Another reason why TRIZ is so remarkable is that it is also based on patent analysis and analysis of patterns of invention from different science and technology areas. Because the knowledge to create TRIZ is developed using analysis of millions of patents, it has great knowledge and proven ideas for innovation [5], [6]. In contrast to other methodologies that offer either no theory or are based on subjective creativity, this represents a well-grounded theory. This is only possible by using historical data and innovative patterns, making TRIZ a reliable, evidence-based problem-solving [7], [8]. The acquisition and application, however, are complicated and include underlying organizational and cultural issues within the firm [9].

For the first 50 years, its application was limited to engineering and manufacturing. Also, it has proved effective in the inspiration of innovation, which has led to its adoption in fields outside its original ostensible home, such as service industries and management contexts. Specifically, described ways in which TRIZ can be used to improve service quality and innovation, in a variety of sectors, e.g., in healthcare and education [10], [16]. The versatility of TRIZ principles to a broad variety of problem-solving case studies can be underscored.

TRIZ, later, became popular in many fields like education and business [11]. Students trained in TRIZ achieve substantially higher problem-solving abilities than students in traditional engineering courses. By teaching formal heuristics and problem representation tools, TRIZ improves the self-efficacy of problem solving among students and increases the abilities of innovation management [12], [13]. Although challenges persist in effectively teaching TRIZ concepts, particularly for novices who may struggle to apply the methodology in practice, studies indicate that students trained in TRIZ principles are better able to handle complex problems and generate innovative ideas [14], [15]. As organizations and educational institutions explore TRIZ's potential, its integration with other methodologies and its application in diverse contexts will likely have a significant impact on future innovation practices.

3.2 Core Principles of TRIZ

The fundamental principles of TRIZ are at heart and become guidelines to overcome contradictions and to invent. Examination of many patents and inventions results in the derivation of these principles on which TRIZ provides a systematic approach to innovation, which includes 40 Inventive Principles, a contradiction matrix, and technological evolution patterns. These consist of ways to divide an object into parts that are independent (segmentation), taking out a disturbing part or property (taking out), etc. The principles address the part of the design process for which there are specific types of contradictions to address. For instance, the principle of "merging" suggests that both similar objects should be merged subject to increasing functionality and reducing complexity [19], [18], [17].

The Contradiction Matrix is an important tool in TRIZ, which is used to identify and resolve conflicts that exist between competing parameters in a design or process. These parameters are cross-referenced, enabling the user to identify inventive principles and generate solutions. The problem matrix provides the principles that have been successful in similar circumstances and makes problem-solving easier by giving access to them quickly [18], [20]. Users can identify and solve conflicts that exist between multiple parameters on a design or process. For instance, inventive principles are given by TRIZ to solve contradictions such as increasing material strength while at the same time increasing weight [19]. Users of TRIZ are guided toward creative solutions through introducing them to a new way of thinking about

problems [21], [22]. Particularly in fields such as engineering and product design, where contradictions are commonly found [23], [24], the proposition is valuable since it provides a path to enhance alternative design endeavours.
Along with the 40 Inventive Principles and Contradiction Matrix, TRIZ also means to stress the Ideal Final Result (IFR). This concept of IFR is related to looking at the best possible solution for the designer with no constraints, no limitations. It is an idealization which inspires innovative thinking and which supports in achieving more effective solutions. The manner in which thinking is shaped by constraints and requirements in the creative design process is how it is defined; with overconstrained and underconstrained problems needing to be addressed separately [101], [25], [26]. An emphasis on the ideal encourages practitioners to think beyond the boundaries that they may normally utilize when creating problem solutions, but to consider new or different ways of providing resolutions. Specifically, Ideality is the drive for the ideal, where a system conveys its goals with the lowest input and minimum undesirable side effects [101], [27].
In addition, TRIZ also includes Substance–Field Analysis, a method of modeling systems and identifying interactions among the system components. This analysis can help understand how substances (materials) and fields (forces) work together within systems, and so discover where the opportunities are for innovation [28]. By analyzing how interactions work, designers are able to see how to improve these or innovate upon them beyond initially obvious approaches.
Also, TRIZ has been integrated with other methodologies for enriching the innovation process, like Quality Function Deployment (QFD) and Lean Six Sigma. By extending these methodologies together, organizations will produce more robust solutions to mitigate technical, operational, and customer requirements [29], [30], [31]. The result is that innovation processes are streamlined and connected to customer needs and organizational goals.

3.3 Comparison of TRIZ and Other Problem-Solving Approaches

Research has revealed that TRIZ, Lean Six Sigma (LSS), and Design Thinking (DT) have distinct benefits and complement each other to assist in innovation and Corporate Social Responsibility (CSR) projects [102], [103]. Whereas Lean Six Sigma focuses on systematic process control, efficiency, and incremental improvements, TRIZ offers systematic methods of technical contradiction resolution and creativity [104], [105]. Design Thinking is very good in empathy with stakeholders, framing of problems, and developing solutions centered on users, but it is also accused of subjectivity, psychological inertia, and lack of systematic solutions towards problems [103]. On the whole, there is no best methodology that stands out; hybrid methodologies, blending the structural creativity of TRIZ with the operational discipline of LSS and empathy-driven design of DT, are best suited to the challenges of sustainability and CSR.
The empirical research shows that the combination of these approaches makes the company more sustainable and profitable. As an example, Green Lean Six Sigma and TRIZ have been integrated, resulting in more industrial waste being recycled [106]. This demonstrates that the combination of TRIZ and Green Lean Six Sigma helps in the efficiency of processes. It also fulfills more global green management goals, such as waste reduction and resource circularity [107], [108]. Likewise, Lean-TRIZ practices result in the removal of non-value-added waste in production [29], whereas in the banking sector, the adoption of TRIZ into LSS frameworks has led to customer satisfaction, cost reduction, and green management practices [110], [111].
Design Thinking helps TRIZ overcome the limits of technical thinking about problems by introducing empathy aspects for idea generation, while TRIZ's systematic tools give structured analytical frameworks for idea generation to DT processes. The use of DT and TRIZ together in an experimental application with undergraduate students has demonstrated that it is possible to generate numerous socially relevant ideas, suggesting potential for CSR problem solving [112], [113].
Comparative studies highlight the fact that no single methodology is dominant in sustainability-oriented innovation. TRIZ focuses on the improvement of problem-solving and creative processes, Lean Six Sigma on process efficiency, and Design Thinking focuses on the solution around the users, while in line with the requirements of all stakeholders. The integration of these methodologies drives organizations to simultaneously attain operational excellence, innovative performance, and social responsibility-focused outcomes [102], [114]. In practice, this integrated approach has been taken successfully in diverse domains, both in manufacturing and in service sectors, demonstrating reciprocal strength, and underpinned the unique value of TRIZ in multi-method innovation frameworks.
Moreover, these studies suggest the synergies between TRIZ, Lean Six Sigma, and Design Thinking as a methodology, which helps not only to raise technical and process innovations, but also improves CSR outcomes. Through the approach of systematically resolving technical contradictions with TRIZ [102], [106], process optimization with LSS [110], [104], and prioritization of stakeholder and societal needs with DT [103], [115], organizations can create solutions that are balanced in economic, environmental, and social terms. This combined approach integrates companies' innovation activities with ethical production and use of resources, stakeholder inclusiveness, sustainability, and green management practices [116], [112].

3.4 TRIZ in Management: Bridging Innovation and Strategic Decision-Making

The TRIZ approach goes far beyond typical brainstorming by furnishing a systematic, knowledge-based guiding framework for addressing contradictions in complex innovation challenges. This compares to trial and error, where the compromise of some solutions is required [2], [4]. "Ideal Final Result (IFR)" creates room for innovation and simplicity for ironing out appropriate solutions [32]. On the other hand, TRIZ is different from incremental improvement methods in that it promotes transforming and breakthrough innovations, as stated by Rahim and Iqbal [33] and Abramov et al. [34].
Besides, training in TRIZ gives the staff systematic tools to solve the complex issues, improving their innovative capabilities. The innovation processes are greatly improved in organizations that employ TRIZ, producing very practical, incredibly innovative ideas [27]. While not traditional brainstorming, TRIZ brings to brainstorming consistency, focus, and structure. Its proven applications include healthcare, manufacturing, and environmental sustainability [35], [36], [37], engineering, product design, and services.
TRIZ principles provide a structured methodology for achieving a compromise solution between carbon pricing mechanisms and labour cost controls by using innovative solutions that support the bridge between environmental and economic objectives. TRIZ strives for the solution of contradictions of technical, managerial, and business systems. Using functional analysis, the methodology makes shortcomings in the system visible and prepares the system models for subsequent analysis [38]. As TRIZ applies logical, knowledge-based frameworks, it categorizes contradictions in product development into eight types: basic structure, dynamic, and others: plus, minus, equal, and "anti" principles [39]. In this regard, the approach includes such tools as Root Conflict Analysis to display [40] contradictions in business processes.
When implementing TRIZ in an organization, it takes too much work to "Identify Problems" and "Contradictions". The 40 inventive and separation principles can be applied to analyze contradictions and generate innovative solutions on the basis of a contradiction matrix [41], [38]. For instance, TRIZ has been combined with Quality Function Deployment (QFD) for design processes [42]. Techniques such as QFD

and Voice of the Customer (VOC) analysis can be used on the team, once trained, to identify specific problems in relation to stakeholder needs and expectations [43].

TRIZ finds innovative solutions and ideas, but without any exact calculation. The feasibility of these ideas is normally evaluated by technical or economic calculations performed by engineers or analysts. Qualitative understanding of future scenarios is made possible through TRIZ instruments [44]. As an example of analyzing how carbon prices would affect labor costs, consider: calculating carbon emissions, understanding how carbon would impact energy costs, and then seeing the changes in labor costs. The indirect effect of carbon pricing on labour costs is clarified by these calculations [45]. This shows that TRIZ can be not just a technical tool for solving problems but also a managerial tool for strategic decision-making under the constraints of the environment. In this regard, information from the green management literature is especially applicable. Schiederig et al. [117] clarify basic distinctions of concepts in green innovation, while Adams et al. [118] explain sustainability-oriented innovation as organized changes of philosophy, values, and practices in the organization. Charkaoui [119] stresses the inclusion of green innovation in sustainable business models as the managerial imperative of our time. Based on this concept, overlapping TRIZ with green management strategies can enhance the capacity for sustainable management of SMEs by balancing innovation, competitiveness, and sustainability.

However, though essential for strategic decision making, analyses generally relate to engineering cost or economic impact analyses rather than TRIZ components. It was found that they could still be combined with TRIZ solutions to make a practical and comprehensive strategy. It can be summarised as a problem situation that formulates technical contradictions and innovation opportunities. Even though it doesn't solve problems directly and allow for innovations, it serves as a beacon of light for designers, pointing to the most promising solutions [46]. For instance:

- Problem: Increased labor costs are increasing due to rising carbon prices. What can we do to minimize this cost increase?
- TRIZ Solutions:

i. Innovative Principles: TRIZ contains the principle of minimizing the energy intensity of processes or optimizing the use of resources as the carbon price rises [47].
ii. Contradiction Matrix: Suggestions for reducing carbon emissions in production processes are provided along with improving efficiency.
iii. 76 Standard Solutions: Start looking at alternative energy sources, or start to look at what process improvement techniques can help you increase production without increasing cost. A TRIZ solution promotes the use of alternative energy sources and makes processes better. Technological change in the energy sector can reduce emissions and make carbon pricing easier [48].

TRIZ-driven approaches, therefore, are capable of minimizing energy consumption pursuant to the "Segmentation" principle or enhancing production based on the use of innovative materials [49].

4. Theoretical Framework: CSR, TRIZ, and Sustainability

The role of TRIZ methodology in advancing sustainability and TRIZ application in the organizational context within SMEs is considered in this section.

4.1 Role and Applications of TRIZ & CSR in Sustainability

CSR promotes the collective responsibility on the part of businesses to face environmental and economic challenges, to highlight the role of small and big businesses towards sustainability. Fostering sustainable development through CSR practices is important, as these practices instigate organizations to add social, environmental, and economic aspects to their operations [50], [51]. More specifically, literature also suggests that although small-scale SMEs have an essential part to play in the economy [52], [53], and if given the right level of support, can contribute substantively to sustainable practice.

Thus, the TRIZ method turns into a universal tool helping to close this gap. TRIZ has been incorporated into CSR initiatives for both SMEs and large corporations to identify sustainable practices and facilitate their effective implementation through their common responsibility [54]. In addition, reading from the literature, the adoption of innovative technologies and practices is among the ways through which SMEs can strengthen their competitive advantage towards the fulfilment of broader sustainability objectives [55]. The contribution of this is twofold: by combining CSR theory with innovative tools such as TRIZ, it underscores the need for SMEs to collaborate with global companies to develop sustainability solutions. This group approach facilitates improvement of SMEs' capabilities and is in line with large corporations' strategic goals for a more balanced economic environment [56].

While Feniser et al. [41] looked at the application of TRIZ to SMEs for sustainability-driven innovation, and demonstrated that TRIZ tools can be used to help develop "fast and efficient processes, products and sustainable services". These applications are still limited, indicating a major gap in the literature. Similar conclusions were made by Teplov [120], who found the potential of TRIZ to be innovative and eco-design within SMEs, but without focusing on its deployment in the energy sector. In contrast, CSR-related literature in the energy domain has investigated drivers of sustainability and responsibility adoption, but mostly in large-scale organizations with little consideration of SMEs [121]. Korsakienė and Raišienė [122] noted that "there is a dearth of research on SMEs" about sustainability drivers, and more broadly, Oduro et al. [123] pointed out unresolved questions about CSR in SMEs. These studies collectively show the lack of research about TRIZ adoption in SMEs within the energy sector, particularly regarding how it interacts with CSR and sustainability practices.

TRIZ goes beyond technical problem-solving in SMEs and supports strategic decision-making processes under environmental and sustainability constraints. Research on sustainability-oriented innovation and green management provides valuable insights into linking innovation with organizational practices [118], [124]. On the other hand, most TRIZ solutions are targeted to large-scale optimization and can be problematic for SMEs from a financial perspective. This calls for specific training programmes and collaborative pilot projects to increase the uptake in SME contexts. Such practices may enable SMEs to implement them in a manner compatible with CSR frameworks. Green human resource management, CSR integration, and green supply chain practices are proven to result in better environmental performance even if they also enhance competitiveness and long-term sustainability [125], [126].

In this context, the integration of TRIZ into eco-innovation processes is an important TRIZ application in sustainability. As an instance, TRIZ tools can be applied to specific production or energy use processes, providing a systematic method for identifying and addressing eco-innovation problems. This structured method identifies additional necessary innovation at different system levels as well as stresses a problem hierarchy model, which augments the innovation process [57]. This is equivalent to the application of TRIZ towards the acceleration of eco-innovation design, in which it improves interactions between the product and service function of an energy system towards sustainable operation [59].

The Separation Principle and other key TRIZ principles allow for resource-efficient solutions when solutions can be adjusted in time, space, or conditions. The application of this principle helps to significantly increase SME processes and services in terms of sustainability [58]. A 'Resource Utilization Principle' encourages sustainable innovation, alongside the consumption of fewer resources [60]. Businesses are guided by the TRIZ Contradiction Matrix and Ideal Final Result (IFR) when dealing with sustainability challenges regarding innovative and efficient methods [61].

Finally, we demonstrate that TRIZ can be applied successfully to SME real–world problems and brings traditional businesses and practices to a sustainable form, similar to how TRIZ can turn impossibility into possibility. Case studies show that TRIZ can improve operational efficiency and promote eco-innovation [41]. As an example, it has been shown that a combination of TRIZ with the Kano Model and Quality Function Deployment (QFD) in the development of sustainable products is useful [62]. Sustainable practices are promoted by TRIZ applications in manufacturing by process optimization and reduction in costs [63].

In Sustainability Oriented Innovation (SOI), the TRIZ role is to associate the economic, social, and environmental responsibility, aiming to constantly adapt to changing standards [64]. Simultaneous application of TRIZ and Life Cycle Assessment allows SMEs to deal with possible contradictions in eco design, thus reducing the risk of an inefficient eco design [65]. Moreover, TRIZ's approach is structured and facilitates SMEs to solve their complex problems effectively without the need for large technical skills, which creates an enabling environment in the firm for innovation [3].

SME teams need to be trained and empowered in TRIZ methodologies for long-term sustainability. Teams can use TRIZ tools and techniques in a rigorous program that helps teams address challenging issues [66]. This approach results in enhanced problem-solving capabilities in SME's, and constrained problem-solving capabilities within the organization to innovate, acquire a competitive edge, and sustainable growth [58].

4.2 SMEs in the Energy Sector: Contributions, Challenges, and TRIZ-Based Strategies

The energy sector needs complementarity of large-scale energy corporations and a range of innovations provided by small and medium enterprises. They contribute to innovation, to regional development, and to collaboration. An overview of SMEs' role in the energy sector, including some examples, is presented in Table 1, which is based on a dataset compiled by the author from EMEC [67], SELCO India [68], Kirubi et al. [69], Debor [70], Singer [71], Zambrano [72], Ya [73].

As seen in Table 1, the energy sector is not heavily monopolized as it has traditionally been; both large corporations and SME's have a responsibility and an active role in the energy sector. SMEs carve out niches, often by specialization and innovation, and provide a significant contribution to sector development. They usually concentrate on the cutting-edge zones like renewable energy technologies, energy storage, energy efficiency, and digital solutions. For instance, in the UK, Sustainable Marine has developed a new technology for tidal stream turbines as a means of extracting renewable energy from near-shore and coastal locations. These developments have led to an increase in energy efficiency of 15%-20% [67], as a reflection of trends in green management practices seen in SMEs [127]. Also, by targeting markets that larger companies do not reach: local and regional markets, SMEs prosper.

The Mpeketoni Electricity Project, for example, delivers a community-based diesel-powered microgrid system in rural areas in Kenya, substantially increasing productivity and income in the local community. The outcome is a market segment that is guided by optimized purchasing agents, and which allows SMEs to serve niche markets such as wind turbine maintenance, biomass energy projects, or energy efficiency consultancy, and compete with other players that require specialized expertise.

In terms of local economic development, the Mpeketoni Electricity Project increased local income in rural areas by 20% [69]. SELCO India is another example that provides a last-mile renewable solution, especially through photovoltaic systems, for underserved communities. Regarding supply chain integration, SELCO India optimized its supply chain to provide energy to 50,000 households [68]. In implementations of TRIZ, energy efficiency increased 15% in SME energy efficiency improvement projects [106], indicating the role that guided innovations play in green management practices [128].

Table 1: The Role of SMEs in the Energy Sector with Examples

Category	Example	Details
Offering Innovative Solutions	Sustainable Marine (UK)	Develops coastal and nearshore renewable energy solutions, aiming to power island and coastal communities using sustainable energy generation.
Local and Regional Focus	Mpeketoni Electricity Project (Kenya)	A community-based diesel-powered microgrid system in rural Kenya, significantly boosting local productivity and income.
Specialization and Niche Markets	SELCO India	Provides tailored energy solutions across customer segments, sectors, and geographies, focusing on last-mile sustainable energy solutions that improve quality of life and socio-economic development for the underserved.
Collaboration and Partnerships	La Esperanza Hydroelectric Project (Honduras)	A 13.5MW run-of-river hydro project in Intibucá, Honduras, supplying power to over 10,000 households.
Leveraging Policies and Incentives	Renewable Energy Cooperatives (Germany)	Since 2006, 862 cooperatives have been established, significantly contributing to Germany's renewable energy capacity.
Energy Trading and Microgrids	Île d'Yeu Microgrid Project (France)	Pilot project interconnecting 23 houses with a microgrid, utilizing solar panels and a battery storage for smart energy management.

SMEs' collaboration and partnerships partly reined in amplifying their impact. For instance, how SMEs work with bigger organizations in the La Esperanza Hydroelectric Project in Honduras to supply renewable energy to more than 10,000 households. Also, SMEs use government policies and incentives to realize renewable energy projects. In Germany, the growth of renewable energy cooperatives since 2006 (862 set up) is an example of how SMEs can take advantage of favorable regulation. Microgrid systems and energy trading are essential for SMEs. In the case of the Île d'Yeu Microgrid Project in France, 23 households were connected by solar panels and battery storage as part of a TRIZ-supported microgrid, which proved the potential for smart energy management [73].

In the energy sector, SMEs hold a vital function in leading innovation, sustainability, and local economic development. But with that comes a lot of challenges that prevent them from reaching their full potential. Key contributions and challenges of SMEs in this sector are summarized in Table 2, which was created by the author using sources from the International Energy Agency (IEA) [74], the European Commission [75], and the ECEEE [76]. Financial resource constraints are a significant obstacle; 50% of SMEs cannot access credit for energy efficiency projects, and, for instance, 60% of renewable energy cooperatives in Germany are implementing projects with government incentives [74]. The other important limitation is the technical know-how, as 40% of SMEs do not have the number of qualified personnel to implement energy efficiency measures [76]. In terms of regulatory compliance, 35% of SMEs fail to keep up with new energy regulations [75]. These difficulties flag up the opportunity for structured methods of solving problems, such as TRIZ, to simplify decision-making in SMEs. Organizations with TRIZ knowledge can achieve this faster by seeing technical and operational barriers and overcoming them. These numerical data support their contributions to innovation, sustainability, and local economic development in the energy sector, and empirical studies also confirm these benefits. For instance, Rahardjo et al. [106] claimed that the combination of Green Lean Six Sigma and TRIZ resulted in a rise in industrial efficiency of the plywood production from 92-93% to above 95%.

Table 2: Key Contributions and Challenges of SMEs in the Energy Sector

Contributions	Challenges
Innovation and Flexibility	Limited Financial Resources
Many times, SMEs are the drivers of innovation in energy-efficient technologies and sustainable practices that react quickly to changes in the market.	Often, SMEs have financial limitation that inhibits investment in energy efficiency measures.
Local Economic Development	Lack of Technical Expertise
The local economies of our communities depend on them for local job creation and the development of communities.	However, most SMEs have little relevant technical knowledge to enable the application of energy-efficient solutions.
Supply Chain Integration	Regulatory Compliance
The energy sector supply chain depends heavily on SMEs, which supply specialized products and services to larger enterprises.	It's quite difficult for SME to navigate environmental regulations.
Energy Efficiency Improvements	Limited Access to Financing
SMEs present significant potential for energy efficiency improvement within their operations and hence to the overall sector's sustainability.	For SMEs, accessing financing for energy efficiency projects is made complicated by stringent lending criteria.
Adoption of Renewable Energy Solutions	Awareness and Information Gaps
At the same time, renewable energy solutions are increasingly adopted by SMEs in the sector, diversifying the sources of energy.	SMEs are often unaware of the benefits and opportunities that accompany the adoption of renewable energy and energy efficiency.

These findings, supported by the examples in Table 2, demonstrate that SMEs' capacity to generate innovative solutions and increase energy efficiency has been demonstrated both sectorally and methodologically. Also, Purnomo [29] reported that the implementation of TRIZ-LSS to wood production has resulted in decreasing non-value-added wastes by 12%. Besides these micro-scale efficiency benefits, SMEs make macro-level contributions to the ecosystem of energy management. These results align with green management concepts that focus on waste reduction and resource efficiency [129].

Distributed generation, energy storage, and smart grids are vital in decentralized energy solutions, and SMEs have a major role in accomplishing this [77]. Through emission reduction, waste management, and the use of renewable energy, they advance environmental goals [78]. With their innovative approaches, they fill the void to meet those regional energy demands in regions often isolated and underserved by larger corporations unwilling or unable to fill the gap. However, SMEs still encounter many barriers that prevent them from adopting and fostering sustainable solutions, such as limited funding, complex regulations, and scarce skilled staff [79]. To address these challenges and increase competitiveness, simplified regulations, capacity building, and green financing are critical [80]. SMEs can take advantage of TRIZ-based methodologies and training programmes to overcome the contradictions between sustainability and resource limitations, with practical results based on energy efficiency improvement and eco-innovation solutions [37], [66]. Furthermore, the structured toolkit of TRIZ has been found to be able to reduce uncertainty and simplify decision-making processes in SMEs, and this helps to integrate sustainability-oriented innovations. This plays a role in the formation of innovation management practices [8], [65], [58]. Adopting sustainable technologies is accelerated by collaboration with larger firms and research institutions [82]. By integrating TRIZ-driven approaches, these collaborations enhance technology adoption and strengthen SMEs' role in regional sustainability transitions.

SMEs that have adopted TRIZ have many positives associated with being aligned with sustainable innovation objectives. SMEs streamline their processes, reduce material waste, and optimize resource expenditures, which yields huge cost savings using TRIZ methodologies [81]. Moreover, with TRIZ, companies can create an eco-friendly product as quickly as possible to follow the sustainable standard and to improve the competitive position within the market [83]. Besides following the global sustainability trends, this approach serves the environmentally aware consumers, enhancing market competitiveness [84], [37].

Though the benefits of TRIZ adoption are obvious, working them out in its own SMEs can be difficult. Organizational inertia is sometimes a reason why many SMEs are wary of changing established processes. Additional factors of hindrance include financial constraints and managerial resistance towards effective implementation [85]. In particular, small enterprises with limited resources and expertise face additional difficulties as a result of the complexity of TRIZ tools and techniques [9]. Furthermore, the CEO's failures to notice the benefits of TRIZ restrict its implementation [41].

In order to overcome these barriers, SMEs can follow some strategies. Certain training programs on TRIZ adoption are targeted at employees equipped with the proper skills [15]. An external expert or consultant collaboration can ease the shift, or rather give a guide specific to the industry [37]. Small-scale pilot projects have shown tangible benefits, promoting organizational confidence and a culture of innovation in TRIZ [86]. By strategically dealing with these challenges, SMEs can take full advantage of TRIZ for their aspects of sustainable development, operational efficiency, and competitiveness in the energy sector [43].

5. Methodology

This section was dedicated to presenting a comprehensive overview of the methodological framework adopted in this study. The explanation was structured under specific subheadings to ensure clarity and coherence in outlining the research design, data collection techniques, analysis methods, and other relevant procedural elements.

5.1 Research Design

This study employs a multi-method qualitative research approach to investigate the use of the Theory of Inventive Problem Solving (or TRIZ) in the energy industry, specifically applied to sustainability and strategic management of Small and Medium-sized Enterprises (SMEs). The multi-case study methodology permits a more in-depth study of varied organizational contexts, identifying both similarities and dissimilarities among completely different firms' practices [135]. To address the main question and its subquestions, the research design combines three key components:

i. Systematic Review: A review of existing literature is conducted systematically to identify the theoretical basis of TRIZ in the context of its integration with Corporate Social Responsibility (CSR) and its relevance to Sustainable Energy (unproblematic energy) challenges faced by SMEs in the energy sector. In this phase, the first subquestion (S1) is addressed.

ii. Illustrative Problem-Solving: The Contradiction Matrix and 40 Inventive Principles from TRIZ tools are applied to show practical solutions for SMEs. This component addresses the second subquestion (S2) by demonstrating how TRIZ methodologies can be simplified and adapted to suit specific challenges of SME in resource-constrained environments.

iii. Multiple Case Study: Real-world examples of TRIZ applications are presented through case studies from global energy companies. TRIZ principles are demonstrated to be used in the balancing of the integration of renewable energy with cost efficiency in such cases. The main contribution of this phase is to address the main research question (RQ).

The multi-case study methodology permits a more in-depth study of varied organizational contexts, identifying both similarities and dissimilarities amongst completely different firms' use of TRIZ.

Case studies were selected based on the following criteria:

- Companies must do business in the energy sector.
- Publicly available data must demonstrate evidence of TRIZ-related practices or strategies.
- To enable broader application of the findings, organizations should consist of a variety of geographical and operational contexts.

Therefore, by combining these three components, a complete research methodology is derived, taking both theoretical and industrial aspects into account at the research question level. To ensure a robust comparative analysis, data from a range of sources, academic publications, corporate reports, publicly available documents, and official websites of the companies themselves are utilised. This also permits triangulations of the data sources to increase the reliability of findings. Through thematic coding and content analysis, contradictions were categorized, relevant TRIZ principles were applied, and the outcomes were carefully reported. The case studies and applied methodology were indicative of the potential to develop an adaptable strategy for SMEs. Finally, the study provides concrete guidance for SMEs in the energy sector to enhance their sustainability performance and strategic management practices.

5.2 Analysis

Using a systematic review of the academic and industry literature, this research derives the theoretical basis of TRIZ and its coupling with CSR frameworks. A literature review informs sub-question 1 (S1) and, more specifically, the review of TRIZ's ability to align environmental and economic objectives. Data sources for understanding TRIZ mechanisms and applications include peer-reviewed journals, technical reports, and industry analyses.

- To address S1, TRIZ methodologies were applied to a specific contradiction, with increasing carbon prices and labor costs as key factors.

Problem Identification: During the problem identification process, contradictions were systematically framed and coded through thematic coding and pattern recognition techniques in order to facilitate qualitative analysis. This made real-world operational issues that way more visible. Potential solutions were then investigated using TRIZ-based solutions. Ideas reflecting green innovation strategies that have aimed at reducing carbon emissions while meeting high levels of operation were analysed using the case study coding framework. This brought out some important barriers, results, and patterns. This way, consistency was ensured from case to case while also showing how TRIZ and green management practices could be combined to overcome energy-related challenges.

TRIZ Tools Application: The Contradiction Matrix, 40 Inventive Principles, and 76 Standard Solutions were used in proposing solutions with TRIZ tools. For instance:

I. Innovative Principles: SMEs implement energy-efficient processes and optimize resources to reduce costs [47].

II. Standard Solutions: Ideas for lowering carbon emissions but still maintaining a high level of operational performance.

Using the case-study coding system, the study enabled the capture of core barriers, outcomes, and patterns for ensuring coherence across the examples. This approach presents a number of practical examples showing how TRIZ can be used to deal with energy-related issues.

- To answer S2, the examples were contextualized for SMEs to produce insights. Using literature and case studies, challenges and opportunities were mapped systematically using a qualitative content analysis framework. The analysis identified recurring barriers such as a lack of technical expertise, limited financial resources, and regulatory complexities. Based on these patterns, a set of strategies was proposed through targeted training, external partnerships, and pilot projects.
- In addressing the RQ, eleven global energy enterprises were selected as case studies. Innovative use of TRIZ methodologies to resolve the sustainability challenges and operational contradictions of each enterprise was shown.

Selection Criteria: Data were collected from secondary sources, including the OECD Report [87], Eurostat Databases [88], the World Energy Council [89], the International Energy Agency [74], and official websites of sustainability reports.

Firms were identified based on their participation in renewable energy efforts, their measures to reduce emissions, and their adoption of novel approaches. Each case study was analyzed using a qualitative framework to assess TRIZ application outcomes, limitations, and scalability potential. The eleven selected global energy enterprises represent a variety of approaches to key issues that include integration of renewable energy, emission reductions, and cost management, as summarized in Table 3, which was compiled by the author.

Table 3 presents case studies in the energy sector to show how TRIZ can be used to resolve energy sector clashes, and offers insight into how these approaches might be applied to SMEs. For instance, Hydro-Québec could resolve the paradox of switching to renewable energy without putting pressure on hydroelectric costs by using the concepts of Dynamicity and Local Quality, and thus it cut emissions without harming hydropower. Enel (Italy) has used the Contradiction Matrix tool to improve energy storage integration whilst maintaining grid stability against renewable energy variability. Iberdrola (Spain) used Segmentation and Preliminary Action to overcome high upfront costs and increased investment in modular solar panels. Applying the parameter changes principle, Ørsted (Denmark) decreased offshore wind energy installation costs.

NTPC (India) overcame the contradiction between fossil fuel dependency and renewable energy integration by achieving 30% of its energy mix through renewable sources by use of Segmentation and Parameter Changes. Hybrid energy systems were analyzed by Vattenfall

(Sweden) using the Contradiction Matrix to balance nuclear and renewable energies. The Universality Principle helped EDP (Portugal) strike a balance between market competition and green investments, leading to an increased share of the green energy market. When AGL Energy (Australia) changed from coal to renewable energy, it deployed Contradiction Matrix and Dynamicity principles for developing large-scale solar energy projects. RWE (Germany) achieved an increase in operational efficiency while reducing lignite use through Parameter Changes, increasing renewable energy capacity, and diversifying its energy portfolio.
In accordance with the Dynamicity principle, China Energy Investment Corp. (China) dropped the contradiction of high energy demand with low renewable infrastructure, leading to major growth in wind and solar energy production. NextEra Energy (USA) kept investment costs in check while scaling wind energy according to the Preliminary Action Principle, gained leadership in wind energy projects, and optimized efficiency. Taken together, these case studies demonstrate the practical benefits offered by TRIZ tools. Through thematic coding and content analysis, discrepancies were categorized, TRIZ principles were mapped, and results were systematically reported. This approach enables developing adaptable strategies for SMEs.

Table 3: TRIZ Applications in Global Energy Enterprises: Contradictions, Strategies, and Outcomes

Organization	Ref	Sector	Key Contradiction	TRIZ Principle(s)	Outcome/Impact
Hydro-Québec	[90]	Renewable Energy	Transition to renewable vs. hydro costs	Dynamicity, Local Quality	Expanded hydro capacity, reduced emissions
Enel (Italy)	[91]	Renewable Energy	Balancing grid stability with renewable energy variability	Contradiction Matrix	Improved energy storage integration
Iberdrola (Spain)	[92]	Renewable Energy	High upfront costs vs. long-term savings	Segmentation, Preliminary Action	Increased investment in modular solar panels
Ørsted (Denmark)	[93]	Offshore Wind Energy	Installation costs vs. scalability	Parameter Changes	Reduced costs through adaptive design
NTPC (India)	[94]	Power Generation	Coal dependency vs. renewable integration	Segmentation, Parameter Changes	Transitioned 30% to renewable energy mix
Vattenfall (Sweden)	[95]	Renewable Energy	Balancing nuclear and renewables	Contradiction Matrix	Enhanced hybrid systems combining nuclear and wind
EDP (Portugal)	[96]	Renewable Energy	Market competition vs. green investment	Principle of Universality	Expanded green energy market share
AGL Energy (Australia)	[97]	Renewable Energy	Transitioning from coal to renewables	Contradiction Matrix, Dynamicity	Developed large-scale solar projects
RWE (Germany)	[98]	Energy Transition	Reducing lignite use vs. operational efficiency	Parameter Changes	Increased renewable capacity and diversified energy portfolio
China Energy Investment Corp. (China)	[99]	Renewable Energy	High energy demand vs. low renewable energy infrastructure	Dynamicity	Expanded wind and solar energy generation
NextEra Energy (USA)	[100]	Renewable Energy	Scaling wind energy vs. fluctuating investment costs	Preliminary Action	Leading wind energy producer with increased efficiency in project delivery

6. Discussion

Sub-question 1 (S1) focused on TRIZ's ability to align environmental and economic objectives. Through a systematic review of peer-reviewed journals, technical reports, and industry analyses, TRIZ mechanisms and applications were examined to understand how they can inform sustainable innovation strategies in the energy sector. Building on this review, TRIZ was applied to a specific contradiction involving rising carbon prices and labor costs. The Contradiction Matrix facilitates resource optimization while maintaining operational efficiency. This is in line with the findings of Malik and Jasiska-Biliczak [54] and Dumitriu et al. [55], who emphasize the importance of TRIZ in the promotion of collaborative sustainability practices. Extending TRIZ within CSR frameworks can enhance strategic alignment and create synergies between innovation, sustainability, and long-term economic growth. This approach ensures consistency across examples and provides practical illustrations of how TRIZ and green management practices can effectively address energy-related issues. In practice, SMEs play an active role in the energy sector, contributing to niche markets such as wind turbine maintenance, biomass projects, and energy efficiency consulting. Their collaboration with larger organizations, participation in government policies and incentives, as demonstrated in Table 1, such as the Mpeketoni Electricity Project in Kenya or La Esperanza Hydroelectric Project in Honduras, has positively increased the reach and impact of renewable energy projects. These examples illustrate the ability of SMEs to employ various TRIZ-based strategies to help drive sustainability and solve energy challenges.
Sub-question 2 (S2) examined the contextual challenges SMEs face in implementing sustainable strategies. Using a qualitative content analysis framework, case studies were contextualized to generate insights into barriers and opportunities. SMEs encounter difficulties in applying TRIZ due to limited resources, lack of awareness, and technical complexity [41], [9]. This study, with information outlined in Table 2, found recurring difficulties which included lack of technical expertise, financial limitations, regulatory complexity, scalability issues, and cultural differences. Literature indicates that these obstacles can be addressed through interventions such as focused training programs, partnerships with external stakeholders, and small-scale pilot projects [14]. Based on these patterns, focused interventions—such as training, external collaborations, and pilot projects—are proposed to support SMEs. In this context, applying TRIZ proves effective, as integrating it into decision-making and structured frameworks enables SMEs to focus on green innovation and sustainability goals despite resource limitations.
To answer the research question (RQ), eleven global energy companies were chosen as the cases. Table 3 gives several examples of global energy companies' TRIZ-based approach towards contradiction solutions in the energy sector. For example, Hydro-Québec decreased

emissions yet increased hydro capacity, Orsted decreased installation costs, and NTPC increased the renewable share of its power supply to 30%. So when these strategies are modified for SMEs, they are applied as viable solutions for local sustainability goals.
Boavida et al. [58] and Russo & Serafini [65] provide empirical evidence of TRIZ's effectiveness and scalability as a tool for eco-innovation. Although the literature on TRIZ adoption is increasingly growing, studies focusing on energy-sector SMEs and examining measurable outcomes from training programs and pilot projects remain limited [37], [66]. Future research could explore ways to develop TRIZ training and collaboration models. Some of these could be pilot projects, digital platforms, and partnerships that fill these gaps. Such initiatives would assist SMEs to break down adoption barriers and enhance the capabilities for innovation, whilst at the same time delivering tangible outputs. The results also confirm the usefulness of TRIZ in the green management and innovation of SMEs [41], [130].
In addition, cases presented in this paper are shown to reveal that TRIZ analysis is performed within the context of thematic coding and content analysis, where conflicts are categorized and mapped systematically to TRIZ principles. This enables SMEs to create flexible solutions to the same conflicts in their own limited resources and technical capacities. TRIZ-supported microgrids, energy efficiency interventions, and solutions for renewable energy allow SMEs to engage in innovation in local markets [106], [41], [65]. Although there are great possibilities that TRIZ can offer to SMEs, there are some limitations. Significant constraints in the scale, resources, and training due to the shortage of trained personnel and sufficient R&D funds are identified [131], [41]. Future research could focus on the question of how TRIZ can be adapted for SMEs with limited technical expertise, especially in the energy sector. Such a study would not only fill a gap of missing information in the literature but would also contribute to designing effective training programs and sector-specific adaptations. Financial and human capital constraints make adoption of TRIZ more difficult and contribute significantly to limitations of small firms in their efforts at innovation [132], [133].
From a policy and practitioner perspective, the development of funding models and public-private partnerships to support the implementation of TRIZ training and implementation in SMEs could improve the capacity of SMEs for sustainable innovation. Such initiatives would help bridge technical skill gaps and enable energy-sector SMEs to adopt TRIZ more effectively. In addition, there can be restrictions to the implementation of TRIZ due to organizational and cultural factors. Since factors such as management styles, communication norms, and employee attitudes towards change vary in different countries and sectors, effective implementation of TRIZ in SMEs may require cultural adaptation [134], [109].
Literature has indicated that TRIZ contains large potential for SMEs for improving resource efficiency, developing sustainable innovation, and enhancing their problem-solving capability. The Separation Principle and the Resource Utilization Principle, for instance, increase the sustainability of processes and services through adaptable solutions [58], [60]. Combining TRIZ with tools such as the Kano Model, QFD, and Life Cycle Assessment reduces the risk of inefficiencies in eco-design and provides firms with a competitive advantage [62–65]. However, since most TRIZ implementation examples applied to the largest enterprises in the world are optimized for large-scale structures, SMEs may face scalability challenges due to limited resources and technical capacity [41], [65].

7. Conclusion

This work shows that TRIZ plays a critical role in closing the chasm between solution methodologists and strategic decision makers in energy problems. Considering the contradictions that are inherent in carbon pricing mechanisms coexisting with labor cost management, such as TRIZ empowers SMEs to strike a proper balance when optimizing resources to also achieve their sustainability goals. These challenges are shown to be typically managed using Inventive Principles and Contradiction Matrix as structured approaches in the analyzed case studies.
The relevance of TRIZ is further enhanced by integrating it into CSR frameworks that support the realization of CSR goals by creating linkages to business aims. Through TRIZ-driven innovations, small & medium-sized businesses can participate in the energy sector directly by solving complex issues for running such businesses, which may involve operational efficiency, cost management, and environmental compliance. Strategic alignment allows SMEs the capacity to contribute to global sustainability while improving their competitiveness.
The findings also show the versatility of TRIZ for building teams between SMEs, policy makers, and larger enterprises. Such partnerships enhance its impact on developing sustainable energy solutions and improve SMEs' ability to manage uncertainty and make better decisions.
This study contributes to the overall literature on innovation and sustainability by examining the barriers and benefits in SMEs' adoption of TRIZ. According to the findings, TRIZ can support eco-innovation and green management practices in SMEs despite resource constraints, resulting in improved environmental and economic performance. TRIZ deals with barriers such as resource limitations as well as technical complexity in order to make SMEs ready to provide long-term sustainability. In the end, this research confirms TRIZ's transformative role for the energy sector through its structure that fulfills the energy sector's organizational needs while also meeting the growing demand of the global sustainability imperatives.
The following practical implications are organized into a cohesive framework:

- Strategic Alignment: SMEs can use the tools of TRIZ to align their operation with global sustainability standards. These methodologies can be implemented into strategic planning processes in order to assist SME's improve their economic and environmental performance.
- Policy Support: The targeted incentive and financial assistance programmes should be launched by policymakers to support SMEs. The proposed measures would allow the adoption of methodologies using TRIZ while overcoming key barriers, for instance, limited resources.
- Collaborative Networks: Knowledge exchange, TRIZ benefits are maximized by encouraging partnerships between SMEs, large enterprises, and academic institutions. Collaborations like this can have a collective impact in efforts to become more sustainable within the energy industry.

8. Limitations and Future Directions

Despite its usefulness, the study has some limitations. While secondary data base case study research helps provide a rich source of qualitative data, its generalizability is limited. Since SME examples focused on the case studies are specific to certain sectors and geographical settings, the transferability of the findings to different sectors and cultural contexts may be limited. Therefore, future empirical research is required. The impacts of TRIZ innovation and sustainability practices in the energy sector can be more comprehensively assessed through studies conducted in different countries and with larger samples. Additionally, future studies should consider the importance of the impact of TRIZ practices in more detail on long-term sustainability results and integration with green management practices.
This study reveals the strengths and weaknesses of TRIZ adoption in SMEs. Implementation is limited by factors related to scalability, limited resource availability, including insufficient access to trained personnel, limited availability of funding for research and

development, and limited access to specific training programs. Subsequent research could investigate how TRIZ training and collaboration models could be developed into models that would be more effective, whether that is through pilot projects, digital platforms, or inter-firm alliances. Such work would be both theoretically and practically useful. They can help SMEs to overcome adoption barriers and boost innovation capacity.

In addition, financial and human resource restrictions still exist to scale TRIZ applications in larger organizations. This brings the importance of policies, support, and investments in public-private partnerships into focus. Further investigation should examine how TRIZ can be applied to SMEs that have low technical capabilities. Possible policies, such as structural funding mechanisms and models for partnerships, could be taken into account to enable TRIZ implementation and training.

Successful adoption of TRIZ in SMEs also demands that consideration is given to organizational and cultural factors. Leadership styles, communication practices, and the attitude of employees to change have an impact on adoption outcomes. Existing literature implies that TRIZ is a method that can be used to increase resource efficiency, sustainable innovation, and the ability to solve a problem. However, since most TRIZ applications are intended for use in larger enterprises, scalability has been a challenge. Therefore, technical and cultural adaptation strategies are necessary for the successful implementation in SMEs. Consequently, both technical and cultural adaptation strategies need to be developed and implemented to ensure the successful application of TRIZ in SMEs. Future research can focus on the following questions: (1) How does TRIZ need to be customized for SMEs with limited technical capacity? (2) Which funding models and partnership structures are best in facilitating the adoption of TRIZ and sustainable innovation in SMEs in the energy sector? Responding to these questions would yield both theoretical and practical lessons for policymakers and practitioners.

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