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Risk Analysis under a Circular Economy Context Using a Systems Thinking Approach

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Abstract: Applying the circular economy (CE) concept is crucial for achieving sustainable development goals. A transition towards a CE requires new tools to clarify the interdependency among systems and assist policy-makers in their decisions, particularly in the risk assessment field. This paper analyzes the systemic effects and interdependencies of several risks in the context of a CE. The developed tool helps adopt proactive strategies that consider the four aspects of sustainability (economic, environmental, social, and technological). The adopted tool improves strategic thinking for a circular economy concept and supports organizations with respect to assessing risks. This paper aims to provide a comprehensive and novel model to quantify the priority weights of the sustainability risk indicators to provide guidelines for supporting the policy formulation process for decision-makers. In this paper, the taxonomy of various risk indicators has been proposed, and we have identified and adopted 40 risk indicators for the CE. This paper focuses on understanding how risks can be constructed and how they affect the performance of power plants over time in terms of availability, efficiency, and operational and maintenance cost. The causal loop diagram (CLD) model is built by deploying various risk quantifications, and the adopted tool was tested and validated to assess the CE risks relevant to the environmental perspective in power plants in the Middle East. The risk indicators under the concept of the CE model and the system thinking approach can help policy-makers in their strategic and operational decision-making process for achieving a better understanding of the risk assessment process. The taxonomy of risk categories and its linking with the system thinking approach will help in the successful and effective implementation of a CE in the energy sector in the long-term. The proposed model offers a tool for policy-makers to design policies when planning a CE.

Keywords: circular economy (CE); system dynamic (CD); risk taxonomy; causal loop diagram (CLD); risk assessment

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1. Introduction

The life expectancy of large companies will shrink to 14 years in 2026, which has decreased from 61 years in 1958 according to the S&P 500 index; currently, it is 18 years nowadays [1]. Thus, these companies will not be sustainable in the long-term. To be sustainable in the long-term, the circular economy methodology is applied. To improve the implementation of the CE approach, decision-makers need comprehensive and systematic frameworks. In the last decades, the circular economy has been gaining attention and traction with policy-makers, business leaders academics, and industries due to the increasing awareness of social and environmental problems. Furthermore, CE is a crucial tool for achieving the United Nations' sustainable development goals [2–6]. Sustainability is used for describing the conditions of a society, the environment, and an economy [7]. Achieving the three pillars of sustainability can be considered an important issue; hence, the three pillars (economic, social, and environmental) should be incorporated into all stages and levels of organizations [8]. Decision-makers and business leaders consider the CE approach as an innovative and sustainable model [9]. Although research has examined the need for organizations to incorporate the circular economy principle into their strategies, quantitative studies have shown that the influences of risks are still not available [10].

The energy sector plays a significant role in creating a sustainable economic system. Additionally, it enables other industries to build a CE. In the energy sector, a CE is supported through cooperation between companies and industries to decrease energy consumption [11]. In the same context, the oil and gas industry has a successful practice of the CE concept in some developed countries. High risks in oil and energy companies have led China to implement CE strategies in the upstream, downstream, and in links with the production chain [12]. This paper proposes a model to assess risks under the context of a CE and their effects on power plant performance in Jordan.

The energy sector is vital to the Jordanian economy, which depends on imported energy. This dependence leads to different risks [13]. The energy sector is a significant player in creating a sustainable economic system [11]. Energy plays a vital role in CEs where the CE could accelerate the transition towards renewable energy [14]. The circular economy in the energy sector is a crucial strategy for producing electricity by efficient usage of available resources and by avoiding waste and environmental issues. However, the energy market is based on quantitative tools for risk modeling [15]. Disruptions and risks along electricity production may have negative impacts on the performance of power plants. Managing these risks is a critical factor for sustainability in the long-term. Different risks may have negative effects on the energy sector; these risks are interrelated and can have serious social, economic, or other organizational impacts. However, identifying risks is an integral part of decisions to ensure better and more effective decisions that achieve sustainability goals [7,9,16]. However, sustainability performance may not be achieved without an extensive and comprehensive risk assessment process [7].

Organizations tend to integrate sustainability risk with the organization strategy (CE must be integrated with sustainable development) [6]. Considering risks as part of an organization's strategy is needed to control and optimize the risk management process and improve strategy implementation [17]. The implementation of a CE is a complex process and requires consecutive changes from policy-makers [6]. Moreover, decisions and policy-makers need tools to deal with complexity in their systems.

The system thinking approach is well-recognized as a tool for modeling the behavior of complex systems by focusing on policy analysis and design. To build a CE model, the correlation between the system parameters should be better reflected [18]. System thinking modeling will help capture the complexity within the economy, environment, society, and resource subsystems. Understanding the interdependencies and correlations in the system (e.g., the relations between operational, economic, social, and environmental aspects, etc.) plays a key role in building an effective and holistic CE module and in helping policy-makers in their decision [19]. System dynamics modeling facilitates dealing with complex sources [20]. Using risk indicators as an assessment method can play a crucial role in establishing a deep understanding and suitable integration of the CE system [21]. To align risks with the strategy, these risks should be measured and translated as organizational objectives. The management of sustainability risk should be executed at different levels [22]. Due to the dynamic nature of the sustainability risk impact on organizational performance, integrating these risks with the organization's strategy can achieve organizational goals [23].

This paper proposes the integration of circular economy risks using four pillars (economic, social, environmental, and technological) and with their effects on the performance of power plants. In this study, a system thinking approach was developed to evaluate the impacts of several sustainability risks on the performance of power plants. System thinking is a suitable tool for analyzing complex systems.

This paper is structured as follows: Section 2 provides a brief review of the circular economy, risk assessment, and system thinking concepts. Section 3 introduces the research methodology approach. Section 4 discusses the conclusions, recommendations, and main limitations of executing the research. Finally, Section 5 presents the implications of the research.

2. Literature Review

2.1. On Circular Economy

The concept of a CE was first presented by scientists in China in 1998. A CE is considered a strategic component of the national development strategy [2,9,24]. The principle of a CE is a circular/closed flow of materials and the use of raw materials and energy through different stages [25]. The "3R" principles have been described as the reduction, reuse, and recycling of energy and materials. A CE is a regenerative system where the input, emission, waste, and leakage energy are reduced by narrowing material and energy loops in the long-term [26], focusing on what is in use along the life cycle stages of a product [19]. Hence, a CE is a continuous process that applies a constant monitoring of social, environmental, and economic impacts [27]. A sharing economy is conceptualized as a subset of a circular economy; a sharing economy has a strong consumer focus, while a CE addresses rebound effects [28]. More CE practices are required to support practitioners, decision-makers, and policy-makers [21]; however, the movement towards more circular economic practices has many challenges [29]. Several barriers have been identified in the movement towards a more CE. These barriers could be summarized as governmental regulations and social, cultural, technological, infrastructural, and economic barriers [29].

Three levels are required for CE implementation: the micro or individual organization level, the meso level, and the macro level. The efforts at these levels include the enhancement and development of the resources enterprise [21,30]. For the successful implementation of the CE approach, CE indicators are needed. These indicators help policy-makers make appropriate policies and plan decisions [27]. However, the literature shows that there is a lack of CE assessment and CE indicators to support CE goals [31–34].

A CE as a business model helps companies capture additional value from their materials and reduce risks. CE indicators include material circularity indicators and commentary indicators, where these indicators will be used as a decision-making tool for designers, procurement decisions, internal reporting, and the evaluation of companies. Examples of material risk indicators are material supply chain risks, price variation, and toxicity; complementary impact indicators are water usage, energy usage, and CO_2 emissions [35]. Up to this point, it is plausible to confirm that the implementation of CE strategies can achieve sustainable environmental and economic development. Sustainability focuses on the dynamic interactions between social and environmental parts [36]. Sustainability development meets present needs without compromising future needs [37,38]. The development will be suitable if human needs and long-term ecological sustainability are taken into account [39]. The crucial part of the sustainable development paradigm is energy. As the use of energy increases, the impact on the environment will increase [37]. CE strategies can achieve sustainable environmental and economic development [40], and CE aims to keep the value of the resource in the economy as long as possible while reducing the generated waste [41]. Thus, a CE will help in reducing the consumed energy and gas emissions [42]. Furthermore, a CE aims to find a consistent, coherent, and systematic way for the society, environment, and economy to achieve the desired benefits [43]. Additionally, a CE can offer solutions to mitigate various types of risks [44]. A CE strategy can reduce the pressure on environmental nature; similarly, it may reduce materials consumption by 53% by 2050. Furthermore, applying the CE concept can eliminate 100 million tons of waste in the next 5 years [19]. Moreover, a CE can enhance people's lives by resolving the unemployment issue in the long-term [27]. Thus, a CE may increase economic growth by providing new job opportunities and new business, by reusing materials' cost, by alleviating environmental pressure, and by reducing price volatility. According to these points, in the UK, the benefits of a CE can be summed up by the potential generation of 50,000 new jobs and EUR 12 billion of investment. In the Netherlands, a CE can generate 54,000 jobs, enhance the environment, and may amount to EUR 7.3 billion a year in market values [25]. On the other hand, implementing CE strategies in power plants is very important, particularly for the environmental perspective (emission reduction and energy saving) [45]. A CE is a systematic approach to economic development that helps improve the business economy, society, and the environment [46]. A CLD is a part of system dynamics modeling, and it is used to visualize the relationships between a sharing economy and a sustainability pillar [47]. The PESTLE analysis and CLD model are adopted in the insurance industry to address the effects of sharing economy activities [48].

The CE principle provides a crucial way to improve resource efficiency [9]. In the last years, the international community has attempted to move from a linear to a circular economy paradigm. This step helps increase sustainability in the long-term [32]. Furthermore, a transition to a circular economy will change corporate risks, cash flows, and customer relations for businesses. However, the transition has many challenges and difficulties to overcome [49]. Hence, a CE is a powerful tool to solve the conflict between social sustainability and economic growth [43]. A CE provides new strategies to reuse resources. The complexity of the CE and the lack of a quantitative model for CEs lead to many challenges in a logical and systematic approach to the decision-making process [43,50]. Policy-makers and leaders should study, understand, and analyze the interaction among obstacles to identify barriers and challenges and to transition to more efficient CE strategies [29]. The success of the circular economy start-up is severely linked with risks, which may include environmental, feedstock, technological, supply chain risks, etc. [4]. Due to the complexity and challenges of a CE, a risk assessment should be adapted to tackle the complexities of a circular economy [49]. The current literature shows that there are a lack of indicators in the context of CEs [21]. A structured risk assessment is vital to understanding the interrelationship among several risks [7]. Accordingly, a system thinking approach would be beneficial for dealing with sustainability risks (environmental, economic, and social) in the context of a circular economy. To evaluate and manage these risks, a systematic approach is essential [7]. Risk management is a crucial factor in an organization's stability and long-term growth [16]. The risk management process has great attention from practitioners and researchers [17]. This process starts with the identification step; then, analysis uncertainty in investment decision-making can be mitigated or accepted.

Sustainability risks affect the sustainable development of organizations and impact the long-term social, economic, and environmental perspectives. Thus, a sustainability risk assessment should align with the three pillars of sustainability (environmental, social, and economic risks) [7]. Similarly, researchers have noted that the risk management process can change organizational behavior and practices [23]. In the CE model, three dimensions should be considered, including environmental, economic, and social aspects. To successfully develop the CE paradigm, a system of indicators is required. These indicators help decision-makers develop an effective policy [51]. As a result, this paper aims to analyze various sustainability risks and their impacts on the sustainability of power plants under the context of a circular economy using a system thinking approach.

Due to increasing volatility, there is an urgent need to review risk management practices and build a foundation for a truly effective resilience framework for the risk management process. This can be achieved through enhanced coordination with stakeholders, industry partners, and the international community. However, this plan may help translate this strategic vision into action [52]. Electricity generation plays a crucial role in the economic and social development of countries. The environmental pollution problems of power plants are one of the major issues faced; hence, there is a need to build a sustainable system to deal with this issue. A CE is an efficient tool for dealing with environmental pollution. The CE concept is one of the most key sustainable systems for overcoming drawbacks and economic challenges (supply risk, problematic ownership structures, and deregulated markets) and for solving the economic instabilities of companies. Power plants are one of the main resources of pollution. Thus, the implementation of the CE concept is essential for protecting the environment and conserving resources and energy which, in turn, improve the long-term sustainability of the enterprise.

Modeling a CE is a hard job for practitioners and researchers due to the lack of suitable quantitative approaches. The complexity of CEs emerges from developing a systematic decision-making process of a useful CE system [43]. A CE includes behavioral and deterministic systems with feedback [19]. Although the potential revenue may result from applying the CE, the main challenge of CE implementation is the economic part [21]. To improve the implementation of the CE approach, decision-makers need comprehensive and systematic frameworks to assess the impact of CE scenarios. In this paper, a system thinking approach is utilized to assess CE risks.

The power plant case studies in this research are involved to define the decision variables (risk factors) for the four defined sustainability categories, which builds the model, formulates the interrelationships among several risks, and articulates the policy. The results of the adopted tool have been discussed and analyzed with policy-makers in their decision-making processes; however, few studies have explained the sustainability risks that are present [23]. Due to the complexity of the CE approach, the system thinking approach can appropriately simulate different scenarios that dynamically capture the complex relationships within and among society, economy, environment, and resource subsystems. System thinking is a methodological approach that takes into account all impacted dimensions of a problem on the system. This approach aims to enhance the understanding of how a company's performance is linked to the internal structure [53] and how components affect each other. This approach is a problem-solving approach, where the problem is considered a part of the overall system [54]. When the challenges of the organizations and communities are understood, the system thinking approach helps people understand the social system [55] and gives them the chance to build a learning organization [56]. The use of system dynamics helps in the understanding of the importance of a complex system, underlines the interactions among several management areas, and helps in preventing critical events [57].

Policy-makers and researchers have extensively used system thinking methods in management and social systems [58]. The main challenge for decision-makers is how an effective and efficient energy policy subject to socio-technical constraints could be designed [59]. However, the design of an effective energy policy is a complex process.

2.2. Risk Assessment

Risk management is based on risk identification, which helps prevent risks and helps establish safety and protection through companies [60]. The risk assessment process is a systematic process to evaluate risks [61]. Thus, in this step, the probability of the risk event and the severity of this event can be quantitatively assessed [62,63]. The risk assessment process is a crucial part of risk management, and it should be applied at the strategic, tactical, and operational levels [7]. Thus, risk assessment is vital for sustainability, long-term success, and a CE. This process is a very difficult step due to many challenges (e.g., lack of data for deriving or assigning the probability by experts, risk occurrence is correlated, etc.) [63]. To evaluate the importance and impact of various risks, the knowledge, experience, and awareness of experts will be used. These are crucial factors that affect the decisions of managers with respect to risk assessment [64]. The outputs of this process help policy-makers prioritize risks; thus, risk mitigation and control plans can be developed. According to these points, risk assessment is an integral and essential part of the decision-making process [65]. More precisely, the outputs of the risk assessment process can be utilized for decision structures and economic models in order to achieve balance through different plans of risk mitigation [62]. A conceptual model for risk assessment in a home environment was adopted to understand how variables affect each other and evolve over time [57].

However, due to the complexity of the interrelationships among economic, environmental, and social risks, the risk assessment process has several issues [66]. Although the risk assessment process has several challenges, practitioners and researchers have paid attention to it. Risks may cause revenue losses, operation disruption, and reduced reliability, which affects the long-term level of organizations [67]. The CE strategy is a key approach to sustainable development due to its efficient use of resources and reduction of waste and emissions [68]. Due to the complexity of sustainable development, particularly the relationship between organizations and their environments [69], implementing the CE strategy needs to be supported in practices, policies, and decision-making tools.

The risk assessment step is challenging due to the complexity and dynamic nature of systems over time. The available risk assessment tools cannot consider the interdependency through risks, which means that the behavior of the system cannot be predicted [70]. The system thinking approach is crucial in a CE due to the required and needed comprehensive understanding to design the systems. System thinking is a key part to the adoption of the CE system [21].

There are several techniques and tools to assess risks; the most common techniques are as follows: preliminary hazard analysis, scenario analysis, brainstorming, failure modes, effects analysis, fault tree analysis, and event tree analysis [7]. According to [71] the success of risk management is based on the effectiveness of the developed framework. In the decision-making process, risk identification is very crucial. A CE seeks to better the management of resources within the system life cycle [27]. To meet sustainable development goals, implementing the CE concept is highly recommended [21]. However, there is no research study on the CE indicators that are related to risks. Thus, this paper pays attention to the developing CE risk indicators, particularly in the energy sector. Sustainability risks can be mitigated by several approaches [23], such as reducing gas emissions and improving government policies and regulations.

Rather than looking at the three perspectives of sustainability risks for circularity, this research aims to analyze and understand the dynamics of the exit. This paper aims to enhance the understating of sustainability risks. The model's feasibility is verified by using data from the literature and from power plants in Jordan. This paper provides a comprehensive system and a decision support tool for policy-makers and stakeholders.

3. Research Methodology

The proposed framework categorizes the risks under the circular economy concept in thermal power plants, with data drawn from the literature, executed interviews, and questionnaires, into several risks. Sustainability risks include risk of safety and poor quality of operations, risk of noncompliance with regulations, reputation risk, and risk of investing in unsustainable projects [23]. This categorization helps policy-makers focus on the main risks affecting the performance of power plants and the implementation of the circular economy. However, this paper highlights the importance of analyzing the endogenous and exogenous variables that affect the performance of organizations. Endogenous and exogenous variables have been highlighted as the most common approach to the categorization of sustainability risks. This paper classifies endogenous and exogenous factors into four sub-categories: environmental, economic, social, and technological risks. The adopted network model in this paper is illustrated in Figure 1. The figure shows that the risk assessment model can be adopted by identifying the different risks, and it shows how these risks affect the performance of power plants, which can be measured through three perspectives (availability, efficiency, and operational and maintenance cost). These risks are categorized into four pillars: economic, environmental, social, and technological. Each category covers several risk indicators.

In this study, a system thinking approach was adopted to evaluate the impacts of several sustainability risks on the performance of power plants. System thinking is a suitable tool for analyzing complex systems. A CLD model was built to evaluate the impacts of several sustainability risks on the performance of power plants. System thinking is a suitable tool for analyzing complex systems. System thinking has been utilized in several CE applications, including closed-loop supply chains [72,73], food supply chains [74], and remanufacturing [75].

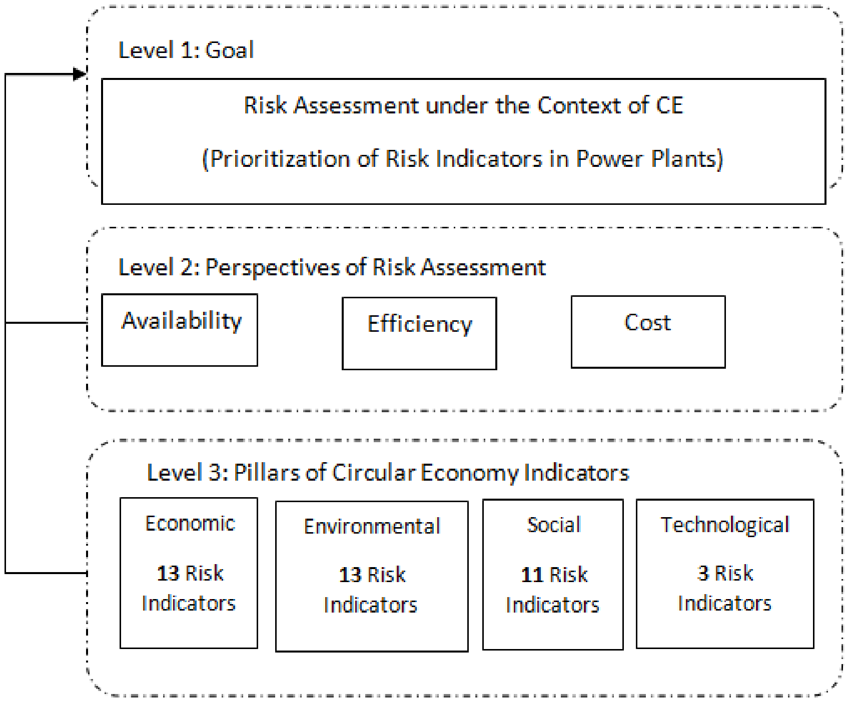

Figure 1. The adopted network model in this paper.

The proposed model has been applied in power plants in Jordan to deal with its complexity and forecast the performance of power plants. This research aimed to assess sustainability risks using a system thinking approach, which helps in the decision-making process. This paper builds based on the system thinking approach to capture the complex and systemic nature of the three suitability risks pillars. The data collection step was established using structured questionnaires and focus group interviews. Likert scale questions and open-ended questions were included to evaluate several risks and build the interdependencies among them.

To develop and validate endogenous and exogenous variables in this paper, several steps were followed. All variables were adapted using related literature, case studies, and questionnaire surveys. A pilot study was conducted by researchers and practitioners. A pilot study is a crucial factor for a good study design. Furthermore, a pilot study increases the likelihood of study success. In addition, a pilot study provides a warning about the possibility of failing the main study and the potential issues in the related study . The study utilized a Likert scale (5 points) to evaluate the risks on the adapted survey. The model in this study was developed following an improved systematic approach. As shown in Figure 2, the required improved phases to develop the risk assessment model included four main stages, which were model conceptualization, model simulation, model validation, and model implementation. This paper will cover the CLD development, while the construction of the simulation model will be covered in a future paper.

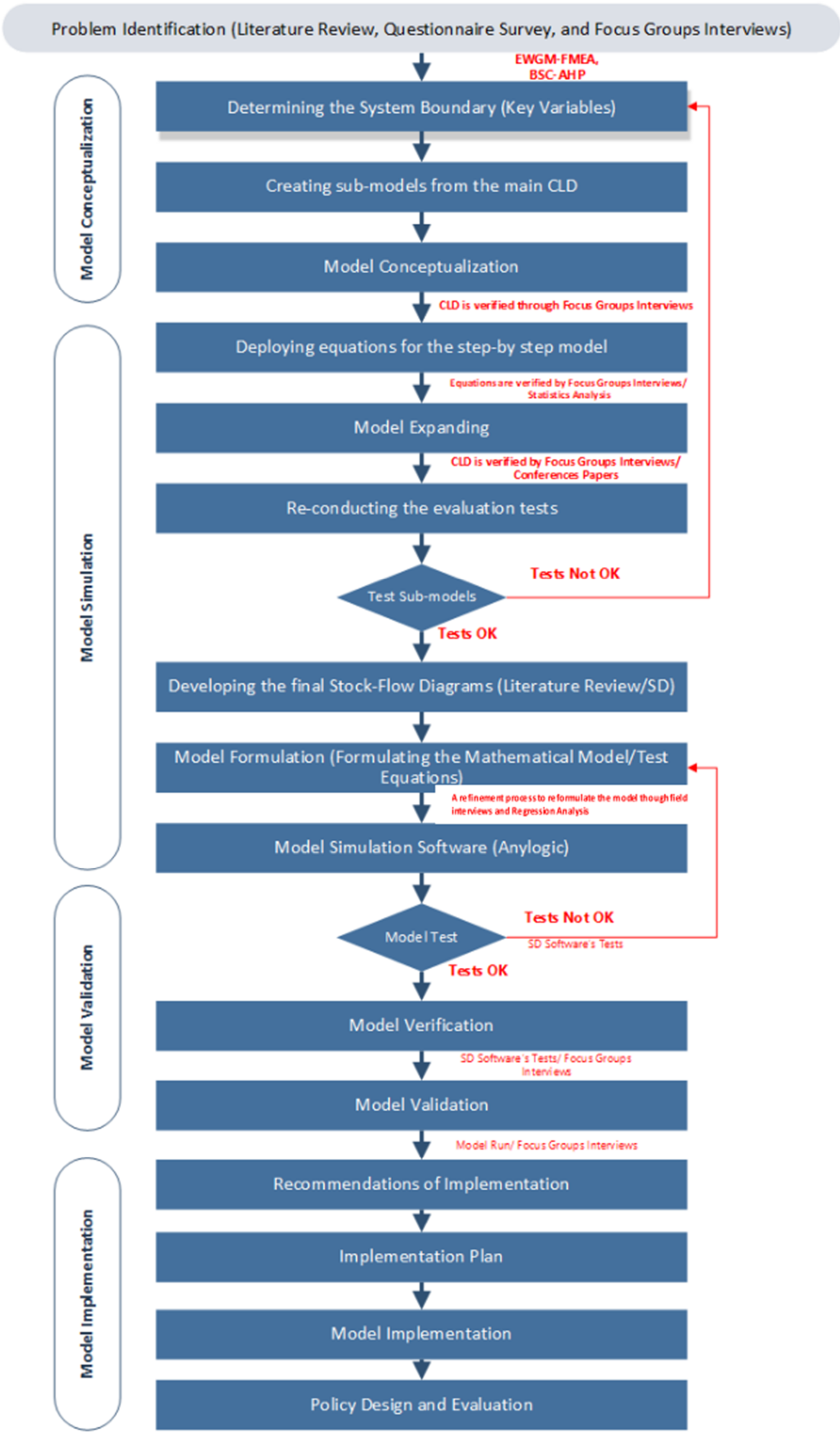

Figure 2. Model developing stages.

3.1. Data Collection

In the decision-making process, when designing policies, and when modeling processes, all information should be utilized. This information is available in the mental data from expert experience and observation. Model effectiveness is based on the effective use of information that arises from the presented system [76]. However, the sources of the required information to build a model are generated from three databases: numerical, mental, and written [55,76].

The structure of a system thinking model can be constructed from an expert's knowledge about decision-making [76]. For this paper, the building of a CE risk model and the interrelationships among risks have been validated through questionnaires and interviews in power plants. A questionnaire survey was utilized for risk identification and evaluation. The interdependencies among various types of risks and analyzing these interactions need practitioners' experience; thus, interviews were applied.

In this research, a pilot study was conducted before the main survey. Accordingly, the wording and the design structure of the questionnaire, as well as the suitable data collection strategies, were firstly tested by a small academic group, which identified the obscure questions. Finally, the needed time to complete the questionnaire was checked.

In this research, judgment sampling or subjective sampling was used. Consequently, 5 practitioners in power plants, 2 academic research staff, and 2 practitioners from another industry were selected for the pilot study; the practitioners were not included in the conducted case study. The respondents were asked to evaluate the questionnaire design, the questions, the meaning, and the required time to complete the questionnaire. Later, feedback from them was taken to improve the questionnaire and mitigate any issues. After the received feedback, the following issues have been reviewed and the questionnaires enhanced: the length of the questions, the needed time to complete the questionnaire, and the design structure of the assessment process for performance measures and risk indicators. This stage helps determine the suitable data collection method. Questionnaires and interviews have been applied as the principal methods for data collection. The questions were formatted based on the literature review and expert experience, and they were tested through the pilot study (over a small academic group).

The conducted interviews help set the equations and determine the proper cause-effect relations among risks. The relationship among variables can be determined through statistical studies, fieldwork, interviews, considerations of extreme conditions, and physical laws. A CLD model can never be comprehensive and final; it is always tentative [53].

The practitioners were asked to assess the CE risk indicators using a Likert scale. Score 1 indicates minimal or no effect risk, and score 5 indicates very high/severe importance. The details of this scale were also provided within the questionnaire to eliminate any issues. The rating scale reflects the importance of each factor measure and each risk indicator. The generated weight (priority) for each risk were utilized later as inputs for the simulation model. These values can be considered the initial values for the stocks or the parameters.

A questionnaire survey was directly conducted in power plants through 6 visits, and 18 practitioners were interviewed. The practitioners were selected based on their experience with power plants. Afterwards, interviews with the top management team were conducted for a better understanding of the impacts of various risks on the performance of power plants. Practitioners were asked to identify the CE risks in power plants for all categories.

In the conducted interviews, the importance of considering these risks and how these risks impact the organization's ability to be sustainable were explained in detail, and global examples were presented. A rich discussion among the group's team was consequently conducted, and useful data were collected. Afterward, the identified risks were classified according to various categories. Due to a lack of experience in what CE risks are and due to ignoring various risk types, the questionnaire surveys were distributed to the practitioners. The questionnaires included all CE risks addressed in the proper risk category. The groups were asked to assess these risks according to the impact on the performance (availability, efficiency, and operational and maintenance cost) of power plants using the Likert scale. This step helped in creating the CLD for the CE risk model.

When practitioners were asked, "how various risks can be quantified to build a robust model and, what is the appropriate risk assessment approach", they clarified that the risks were assessed based on their experience and using the risk map. There was a risk assessment committee that met every month to analyze the risks, but the management focused more on the technical and internal operational risks, which were related to the equipment and operation process.

However, from the conducted interviews and the survey, it can be noted that the management team in these power plants have good knowledge of risk assessment, but only focus on the technical part. Policy-makers struggle with determining what risks have a greater impact on the performance of the power plants. Furthermore, they do not have any idea about the CE principle or sustainability indicators.

3.2. Taxonomy of CE Risks

Good indicators are valuable metrics for evaluating the soundness of policy development and for providing guidelines for decision-makers to further develop effective policy instruments [51]. The CE concept has become an important implemented approach in many countries. To build a globally sustainable development goal [4], resource efficiency, offering substantial opportunities, cascading and optimizing the use of this resource, and reducing gas emissions [49] are necessary. The CE concept has gained importance on the agendas of policy-makers and is a significant field in academic research due to its valuable benefits [26]. To help practitioners and decision-makers select the most proper future circular business model and design strategies, researchers have developed taxonomies. In the current literature, indicators are classified into three dimensions of sustainability (environmental, economic, and social). These indicators will help monitor the progress towards a CE [21]. Indicators are quantitative or qualitative factors that measure achievement. Indicators help provide an effective tool for measuring performance and progress, reveal complex phenomena, and condense the complexity of the dynamic environment in a useful manner. Last but not least, an indicator is a policy-making tool that is used to define goals and track progress. After the risks were identified based on the available literature and the collected data from power plants, these risks were categorized into four different categories, as tabulated in Table 1.

Table 1. Risks taxonomy under the CE context within four categories.

Economic Risks
Competition risk
Interest rate risk
Exchange rate risk
Supplier price risk
Price of electricity risk
Credit risk
Investment risk
Debt collection risk
Operating revenue and expense risk
Procurement cost risk
Global economic recession risk
Asset depreciation risk
Market liquidity risk

Table 1. *Cont.*

Environmental Risks
GHG emissions (NOx, CO_2 and SO_2) risk
Environmental regulations
Industrial water reuse ratio risk
Recycling of treated water risk
Solid waste risk in thermal power plants
Waste handling risk
Lost time due to injuries risk
Accident fatalities per energy produced risk (Severe accidents risks)
Human toxicity potential expresses risk (ex. Polychlorinated Biphenyls (PCBs
Noise impact caused by energy system risk
Bad odors risk
Risk of mortality due to normal operation (reduced life expectancy in years of life lost/GWh)
Soil pollution risk
Social Risks
Lack of motivation for staff risk
Lack of innovation risk
Lack of organizational learning capability risk
Poor relationship between parties risk
Labor strikes risk
Social challenges risk (Poverty, substantial levels of inequalities, health challenge)
Behavioral aspect of employee's risk
Union/labor relations risk
Reputation risk (Negative Media Coverage)
Changing behavior risk (Change in human behavior)
Local community impacts risk
Technological Risks
Obsolescence risk
Improved combustion efficiency risk
Sustainable technology innovation risk

3.3. Causal Loop Diagram (CLD) Development

The adopted tool to assess CE risks includes various risk sub-systems: the environmental sub-model, the economic sub-model, the social sub-model, and the technological sub-model. In this paper, the environmental sub-model will be developed. System thinking modeling aims to improve the understanding process of complex systems. This complexity emerges from the interaction among various risk variables.

The CLD was created and presented in Figure 3 for the environmental risks sub-model as part of the risk assessment model. Environmental risks are the risks to the environmental systems and the risks related to human health [77]. The environmental subsystem is dealt with by the environmental aspects of the electricity generation system [78]. The complexity of environmental issues and decision-making have many challenges for utilizing SD as a methodology for modeling environmental problems [79]. Energy production will produce pressures on the environment, which means that the environmental dimension is influenced by economic and social perspectives [80]. However, no integrated model can be found in the current literature that links the influence of the environment on sustainable energy policies [81]. To compare the effects of the decision-making process in policy design and business development plans in the electricity sector, several scenarios should be modeled; these scenarios should consider environmental policies [82]. Environmental, social, and internal and operational business process risks interact together. The impacts of various risks (lost time due to injuries risk, GHG emissions risk, solid waste risk, noise risk, soil pollution risk, and bad odor risk) on the performance of power plants can be observed. The interactions among solid waste risk, soil pollution risk, bad odor risk, lost time injuries, accident risk, and environmental uncertainties will produce environmental, health, and safety risks. These risks affect the availability, efficiency, and operational and maintenance cost risks.

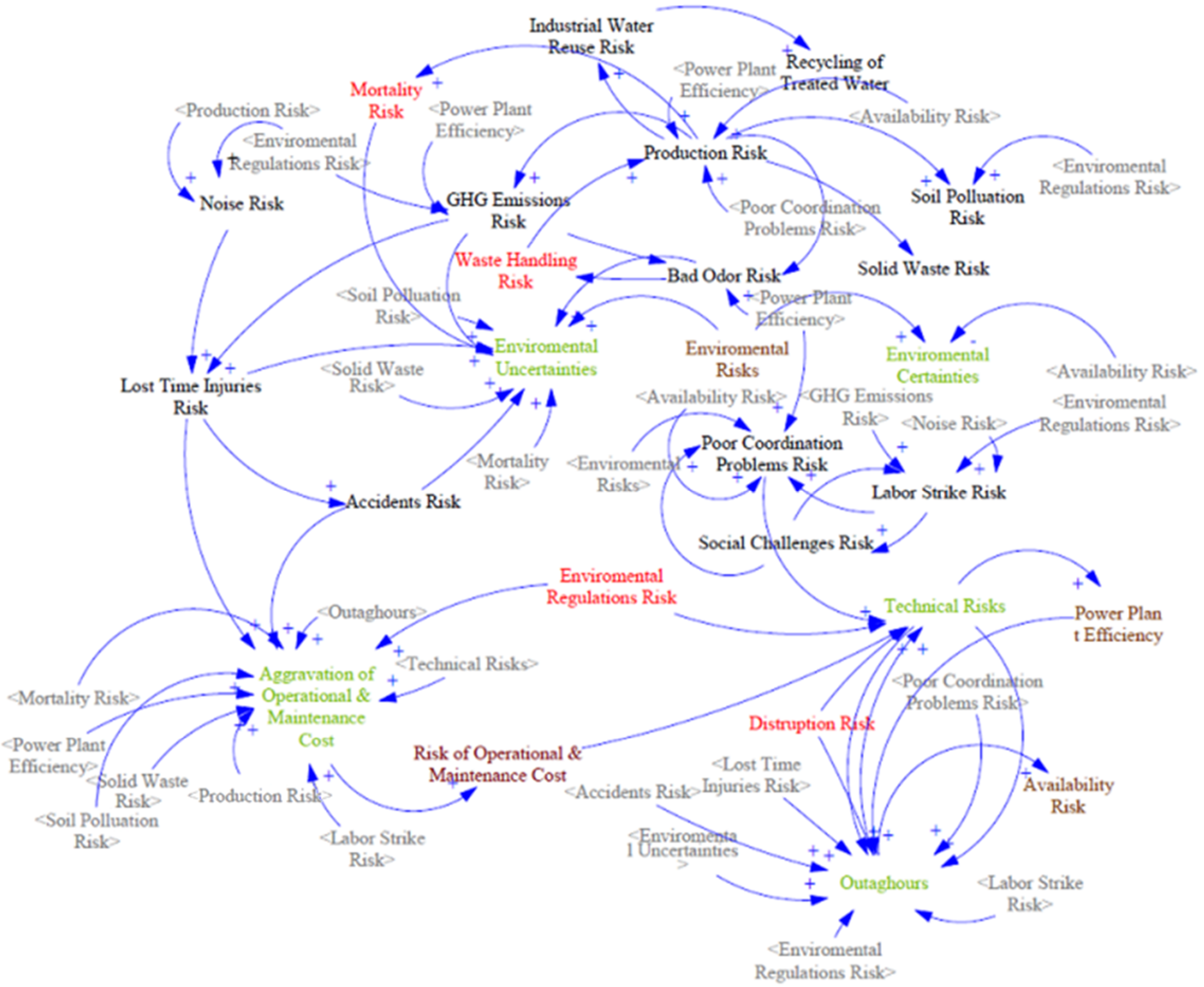

Figure 3. Causal loop diagram (CLD) for the environmental risks.

From Figure 3, it can be seen that the environmental risks in power plants emerge from various interconnected risks, and these risks affect the power plant performance (availability of power plants, the efficiency of a power plant, and the operational and maintenance cost). As shown in the CLD model, industrial water reuse directly affects the production risk, which increases human toxicity. GHG emissions, solid waste, bad odor risk, and soil pollution influence the environmental uncertainties, which directly increase the environmental risks. These risks affect the power plant's performance in the long-term. Thus, monitoring the adoption of CE risk indicators will reduce the environmental risks and reduce production risks, which directly helps in reducing the consumption of fuel. The interrelationships among various environmental, health, and safety risks that have impacted the performance of the power plants are described. The CLD is created and presented in Figure 3. Environmental, social and internal, and operational business process risks interact together. The influences of various risks (lost time due to injuries risk, GHG emissions risk, solid waste risk, noise risk, soil pollution risk, and bad odor risk) on the performance of power plants can be observed. The interactions among solid waste risk, soil pollution risk, bad odor risk, lost time due to injuries risk, accident risk, and environmental uncertainties will produce environmental, health, and safety risks. These risks affect the availability, efficiency, and operational and maintenance cost risks. the environmental risks are influenced by various risks through environmental uncertainties, such as accident risk, GHG emission risk, bad odor risk, mortality due to normal operation risk, lost time due to injuries risk, soil pollution risk, and solid waste risk. On the other hand, the availability of power plants is influenced by various environmental, internal, and operational business process risks, as well as by social risks such as disruption risk, labor strike risk, lost time injuries risk, poor coordination problems risk, technical risks, and environmental regulations risk.

4. Conclusion, Recommendation, and Limitation

This study used a system thinking approach for risk assessment under the concept of a CE. This model helps policy-makers monitor CE adoption. Accordingly, the taxonomy of CE risks enables companies to move towards a CE paradigm. Linking the CE indicators with the system thinking approach will help in the successful and effective implementation of the CE in the long-term. The proposed model offers a tool for policy-makers to draw policies when planning a CE, which when approved has various benefits in the long-term. The conducted interviews within the power plants reveal that the risk assessment approaches need to be adjusted to tackle the complexities of a CE. This paper serves as a guide for policies and for decision-makers. In response to the rising recognition of the importance of moving to a CE, particularly in the energy sector, the complex interdependencies among sustainability risks under the CE context were investigated. This helps in developing mitigation strategies. The results reveal that the developed tool provides a suitable tool for helping policy-makers in their decision-making process. The developed tool can be considered an appropriate risk assessment tool for capturing the system behavior over time, the impacts of various risks on the performance of power plants, and the potential changes in a power plant's performance. The developed tool provides a methodological approach for dealing with the causal interrelationships and feedback among various risks in power plants. Practitioners' knowledge, archived data, and literature reviews are utilized to address, identify, and assess various risks. The proposed model can be generalized and applied in other industries. The proposed model addresses the non-technical risks in power plants and helps in understanding the interrelationships among various risks. The results of this paper can support the management of organizations through circular economy practices and can overcome the risks faced by power plants to achieve high performance. This paper identifies the different risk factors that power plants face under the concept of a circular economy. The proposed model was developed to provide guidelines for management to prioritize several interrelated risks and support the implementation of a CE.

Accordingly, this study firstly recommends two strategies for the policy-makers: Top management can form a single organizational unit that takes direct responsibility for monitoring the risk management process; this unit is managed by risk managers in organizations. This step can build a successful risk management process. Furthermore, the responsibility management unit can develop a risk framework to measure risks and suggest policies. Thus, the policy-makers will have a clear view of the interrelationships among various risks and will make better decisions, building a comprehensive mitigation plan. Secondly, it is recommended to the top management of power plants to categorize the risks for various categories and then assign the impact of each risk category on the performance of power plants (efficiency, availability, and operational and maintenance cost).

Among the limitations, the proposed work has been applied in power plants. On the other hand, to increase the effectiveness of the proposed methodology, the continuous monitoring of risks is needed, and the risk evaluation may be adjusted. Furthermore, organizational culture, strategic priorities, company vision, and the educational and social background of the experts may alter the outcomes of this work, which appears as another limitation.

5. Implications of the Research

This paper provides a novel insight into analyzing the sustainability risks (environmental, economic, social, and technological risks) on the performance of power plants. The developed tool contributes to power plants' efficiency by analyzing how well several risks are interrelated and affect the performance. Thus, power plants can explore which area will mitigate these risks and their cost by investigating the power plants' performance using a system thinking approach. The sustainability risks not only focus on the financial performance of organizations but also seek to sustain the longer survival of the company.

From the managerial viewpoint, to achieve sustainability, organizations should consider several possible risks. The developed tool can be applied to different industries. In addition, considering social risks would be beneficial for organizations to reduce the negative effects.

On the other hand, organizations cannot achieve sustainable growth and continuous improvement without conducting a systematic risk management process; hence, the proposed model in this paper helps in that effort.

Future studies could apply the proposed methodology to other fields. A comparative analysis can be conducted through several companies. Furthermore, the scope of the proposed method can also be extended to cover technical risks. It is clear that further research can be conducted by integrating the developed SD model with artificial neural networks (ANN), genetic algorithms (GA), or knowledge base systems (KBS) to improve the developed risk assessment model.

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