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Corporate environmental commitment facing the ecological risks of Industry 4.0: Building a sustainable future through government commitment

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Abstract

Industry 4.0 often requires increased consumption of energy and rare metals, and increases the waste of depreciated equipment, as well as the quantity of electrical and electronic waste. In this context, it is imperative that governments recognize the need to put in place policies, initiatives and incentives to foster the environmental commitment of industrial companies.

Indeed, Tunisia illustrates the case of a developing country where government involvement has encouraged companies to implement CSR practices helping to reduce the sustainability risks in the new digital age.

Based on a quantitative approach, we explore this relationship with 106 managers who participated in the questionnaire. The results confirmed, firstly, the negative impact generated by the integration of 4.0 technologies on corporate environmental commitment. Secondly, the results show that government involvement in the form of coercive and normative pressure plays a decisive role in reducing the risks of digital technologies in terms of sustainability.

This research has relevant implications for public policy and scientific research.

Keywords: Corporate Environmental Commitment, Government Commitment, Industry 4.0, Sustainability

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1. INTRODUCTION

For many years, the effects of industrialization on the environment were ignored. Industrial companies focused on optimizing production without considering the pollution they generated or the exhaustion of natural resources. With the emergence of Industry 4.0, environmental issues are becoming increasingly important. This concept refers to the fourth industrial revolution and is based on the integration of technologies such as cyber-physical networks, big data analysis, and the Industrial Internet of Things (IIoT) to optimize the production process (Shinde et al., 2021). In general, the digitization of industry provides solutions that promote corporate social responsibility (CSR). Indeed, it offers several advantages such as reduced inventory and lead times, resolution of social issues, the analysis of product life cycles, and manufacturing that is responsive to market changes. (Stock et al., 2018; Potočan et al., 2021; Shinde et al., 2021). However, the latter includes concerns about ecological risks that need special attention due to their negative impact on companies' environmental commitments. (Waibel, 2017; Dieste et al., 2023). These often require increased consumption of energy and rare metals, increase waste from depreciated equipment, and increase the amount of electrical and electronic waste. (Soltovski et al., 2020; Birkel et al., 2019; Dieste et al., 2023).

The existing literature (Labelle et al., 2017; Bousselmi et al., 2019; M'hissen et al., 2020; Usmany, 2024) shows that government policies, namely the introduction of clear and strict regulations, the granting of financial and tax incentives, and the

facilitation and support of responsible practices, promote CSR practices in terms of environmental protection. However, few studies have been conducted on government engagement as a regulatory and facilitating mechanism to mitigate the risks associated with industry sustainability in this new digital era, in contexts where development is still limited. This work therefore provides a new perspective on this little-explored aspect.

Although Tunisia has introduced several initiatives and implemented policies and incentives to support CSR practices (Bousselmi et al., 2019; M'hissen et al., 2020), this emerging country needs to continue and strengthen its actions to stimulate environmentally friendly approaches faced with the sustainability risks related to industry 4.0. This leads to ask the question: To what extent can government commitment reduce the negative impact of sustainability risks posed by Industry 4.0 on companies' environmental commitment?

This study aims first to analyze the risks generated by Industry 4.0 in terms of sustainability and their impact on companies' environmental commitment. Next, we will refer to the theory of resource dependence (Souleymane, 2024) and stakeholder theory (Williamson et al., 2006; Benaicha, 2017; M'hissen et al., 2020) to illuminate the influence of government commitment on promoting CSR practices that support environmental preservation. Finally, this study will examine the moderating role of government commitment in mitigating the risks associated with Industry 4.0 in terms of sustainability, which encourages companies to adopt responsible practices. Neo-institutional theory has been used to highlight the importance of government commitment in both coercive and normative terms. (Schuman, 1995).

Our article is structured as follows: we first present our theoretical framework, from which our research hypotheses are formulated. Finally, we present and interpret the results of the empirical study.

2. Literature review and hypotheses development

2.1. Determinants of corporate environmental commitment

Over the past half-century, numerous researchers have conducted studies on CSR and made significant contributions. (Bowen, 1953; Clarkson, 1995; Daudé and Noël, 2006; Bousselmi et al., 2019; Santiago et al., 2025).

Many definitions of the term "CSR" reflect a new vision based on the "Triple Bottom Line," according to which CSR is a response to the requirements of the three pillars of sustainable development: economic, social, and environmental. (Jenkins, 2009; Asselot, 2011; Gagné, 2018; Chiadmi, 2022). CSR therefore consists of integrating economic, social, and environmental concerns into management models to ensure the sustainability of the company (Jenkins, 2009). Considering the objective of this study, we will focus on the third pillar of CSR, namely the company's environmental commitment. This concept is defined as the desire of companies to consider the impact of their actions on themselves and on others (Capron and Quairel-Lanoizelée, 2007) and to satisfy the needs expressed by stakeholders. (M'hissen et al., 2020; Souleymane, 2024). Based on the study by Gagné et al. (2022), we present the determinants of environmental practices that are often adopted by companies. These practices have been supported by other previous studies.

Table 1: Sustainable practices adopted within companies (Gagné et al., 2022)

Environmental practices introduced by companies	Previous research work
Protection of biodiversity	Bos-Brouwers (2010); Randrianarison (2010); Wolff et al. (2016).
Reduction of air pollution emissions	Bos-Brouwers (2010); Kassé, A (2020); Tawiah et al. (2021); De Giovanni (2012)
Reduction of waste materials	De Giovanni (2012); Battisti and Perry (2011); Bos-Brouwers (2010).
Minimization of resource consumption	Bos-Brouwers (2010); De Giovanni (2012); Kassé, A(2020).
Reduction of the environmental impact of products	Ambec and Lanoie (2009); Bos-Brouwers (2010); Kassé, A (2020); De Giovanni (2012).

2.2. Understanding Industry 4.0 and its sustainability risks: What impact will this have on companies' environmental commitments?

The concept of Industry 4.0 consists of introducing digital technologies into the industrial sector by creating a digital value chain (Gölzer and Fritzsche, 2017; Yaqub and Alsabban, 2023). It is based on cyber-physical systems that facilitate data transfer between people and objects. (Müller et al, 2018, Birkel et al., 2019). It can also be defined as the intelligent, horizontal, and vertical networking of people, machines, and information and communication systems, in order to control complex systems dynamically. (Müller et al., 2018). Cloud computing, blockchain, and big data analysis are all examples of technologies that contribute to the implementation of Industry 4.0. (Shinde et al., 2021). The benefits of these technologies for CSR from an industrial perspective have been the subject of several previous studies. According to Shinde et al. (2021), they help companies respond effectively to market demands and promise considerable opportunities for value creation. Chen et al. (2021) have shown that the digitization of industrial processes promotes more efficient use of energy and materials and leads to the adoption of renewable energies in emerging countries.

However, the implementation of these technologies raises serious concerns given the risks related to their adoption (Birkel et al., 2019; Soltovski et al., 2020), which may impede environmental practices. Firstly, the introduction of blockchain, big data, and cloud computing into the supply chain often increases energy consumption. (Stock et al., 2018; Biswas et al., 2022). Ford and Despeisse (2016) argued that innovative manufacturing processes require particularly high energy consumption compared to traditional production methods. They therefore still fail in terms of energy efficiency. (Stock et al., 2018). On the other hand, the increasing quantity of electrical and electronic waste has become a growing issue due to the hazardous substances it contains. (Garrido-Hidalgo et al., 2020; Chiarini, 2021; Alblooshi et al., 2022). Although efforts to recycle this waste have been made, some countries face the problem of limited equipment to process it. (Leklou, 2022). In addition, the depreciation of old equipment increases the waste of hazardous materials (Müller et al., 2018; Birkel et al., 2019). Di Carlo et al., (2021) indicate that depreciated devices are often sent to waste sites. Finally, industrial automation systems have a negative impact on natural ecosystems because of the increased consumption of rare metals and other natural resources required for technological progress (Stock et al., 2018; Birkel et al., 2019; Chiarini, 2021). Based on these theoretical foundations, we propose the following initial hypothesis:

H1. The sustainability risks related to Industry 4.0 can be a barrier to companies' environmental commitment.

2.3. The role of government in promoting corporate environmental practices

To emphasize the importance of the government's role in strengthening corporate environmental commitment, we drew on the foundations of two theories: resource dependence theory (Pfeffer and Salancik, 1978) and stakeholder theory. (Freeman, 1984).

Resource dependency theory has provided a relevant analytical framework for several studies on corporate environmental commitment. It analyzes the relationships of dependency and power that exist between an organization and its social actors. Pfeffer and Salanick (1978), consider that organizations depend on the resources present in their environment for their survival. As a result, managers make strategic decisions while conforming to constraints (Child, 1972; Pfeffer and Salanick, 1978). Such theory can be used to address the obstacles to corporate environmental engagement. This can be inhibited by the lack of legal mechanisms, financial support programs, and knowledge (M'hissen et al., 2020; Souleymane, 2024). Companies are therefore seeking an institutional framework conducive to the implementation of CSR, which supports the importance of government commitment to resolving the social and environmental issues faced by organizations (Schneiberg and Clemens, 2006; Jamali et al., 2015; M'hissen et al., 2020).

From another perspective, stakeholder theory analyzes the relationships of dependency and interdependence between a company and its stakeholders. These relationships are conditioned by power and legitimacy issues. According to Mitchell et al. (1997), power is defined as an actor's ability to control or influence the actions of others. Past studies (Quairel and Auberger, 2005; Williamson et al., 2006; Souleymane, 2024) have shown that governments are an important stakeholder with the

power to impose obligations on companies to act responsibly. According to Maxfield and Schneider (1997) countries with strong governments based on respect for the law, offer a business environment that is distinct from countries with weak authority. For its part, legitimacy refers to the recognition by other stakeholders that the actions of the principal actor are perceived as justified according to socially established systems of norms and values (Suchman, 1995). The implementation of sustainable practices is thus judged legitimate in response to institutional pressures. (DiMaggio and Powell, 1983; M'hissen et al., 2020; Souleymane, 2024). As a result, the company takes into account the legitimacy of stakeholder interests without seeking profit and with a view to complying with ethical practices. (Benaicha, 2017). Weaver et al. (1999) justify the adoption of CSR by looking for social legitimacy, which is determined by institutional factors like government power and certification agencies. These theoretical foundations lead us to the second hypothesis, which is:

H2. Government commitment has a direct positive impact on corporate environmental commitment.

From a historical perspective, companies operating in the industrial production sector were the first to conform to institutional pressures due to their negative externalities. They are therefore required to adopt a CSR approach (Cowen et al., 1987; Adams et al., 1998; Bampoky, 2015). According to the study of Labelle et al. (2017) the creation of a restrictive regulatory framework to control certain activities, the granting of financial and tax incentives, and the support and facilitation of responsible initiatives are the main government initiatives in the area of CSR. In this sense, neo-institutional theory can be mobilized as it focuses on analyzing the factors that contribute to improving the legitimacy of corporate environmental practices (DiMaggio and Powell, 1983; Le Borgne-Larivière et al., 2009; Aamara and Mouhsine, 2025). Through this theory, Suchman (1995) identified coercive pressures and normative pressures. Coercive pressures emerge from the power that organizations have to constrain other entities through laws, regulations, and sanctions. Normative pressures, on the other hand, are primarily related to professionalization and the development of methods governing the performance of work. They refer to standards, labels, etc.

Furthermore, coercive pressures are driving companies to integrate environmental concerns into their activities (Quairel and Auberger, 2005; Williamson et al., 2006; Bousselmi et al., 2019; Souleymane, 2024). The adoption of sustainable digital technologies will therefore be mainly influenced by regulations and control mechanisms. (M'hissen et al., 2020). On the one hand, the introduction of a carbon tax is a relevant fiscal measure that encourages companies to reduce air pollutant emissions. (Sarabdeen, 2024). In addition, the implementation of strict laws promotes an equitable and sustainable distribution of natural resources while taking into account the needs of society. (Sarabdeen, 2024). Regulatory motivations for integrating CSR are also linked to the risk of environmental sanctions. (Quairel and Auberger, 2005). The South Korean authorities, for example, have introduced strict restrictions on the management of waste electrical and electronic equipment. (Liu et al., 2023). With regard to the normative aspect of institutional theory, it assumes that companies will integrate environmental concerns into their activities thanks to government commitment to introducing financial supporting policies and facilitating measures (Labelle et al., 2017; M'hissen et al., 2020). Due to public incentives and favorable taxation, companies will be encouraged to invest in the renewable energy sector, which contributes to reducing energy consumption and stimulating sustainable innovation (Alrashed and Asif, 2015; Sarabdeen, 2024). Finally, companies are encouraged to reduce the negative impacts of products on ecosystems by adopting environmentally friendly innovations such as eco-labels (Costa, 2021; Riskos et al., 2021). In fact, ecolabelling is considered an eco-innovation process that encourages the design of new eco-friendly products (Prieto-Sandoval et al., 2016). According to international organizations, engaging in certain ecolabels is voluntary (cited by Ahmed and Vij, 2022). As part of this certification, the implementation of appropriate programs and the creation of a service responsible for supporting companies and aligning them with green perspectives can also offer new approaches to promoting Industry 4.0 in a sustainable manner (Ahmed and Vij, 2022). These theoretical assumptions support the third hypothesis, which states that:

H3. Government commitment acts as a moderating factor by reducing the negative impact posed by sustainability risks related to Industry 4.0 on companies' environmental commitment.

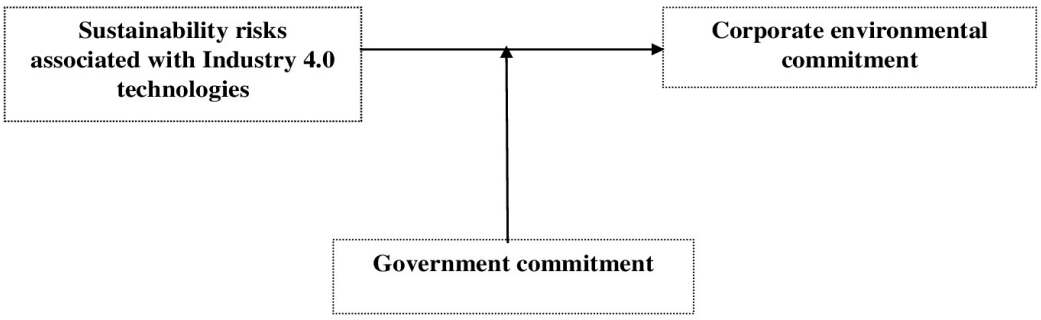

Figure 1 . Research model

3. Materials and Methods

3.1. Data collection and presentation of the sample

Based on the characteristics and objectives of our research, we adopted a quantitative research methodology. Data was collected using a questionnaire including 15 items. The questionnaire was administered by email and direct contact.

Given the constraints related to access, information, and respondent availability, we limited our sample to 106 industrial companies based in Tunisia. The survey population consists of managers from various sectors of activity, such as the electrical and electronics industry, the automotive industry, the wood industry, and the agri-food industry. It is composed of 35.8% women and 64.2% men. The majority of respondents are between 30 and 45 years old. The distribution of socio-professional categories is as follows: CEO (7.5%), Technical Director (6.6%), Quality, Health, Safety and Environment Manager (44.3%), Human Resources Manager (7.5%) and other employees (34.0%).

3.2. Measurements of Model Variables

Corporate environmental commitment represents the dependent variable. We adopted the measurement scale developed by Gagné et al. (2022). We used a 5-point Likert scale to measure the main determinants of corporate environmental commitment. (Ranging from "1 = Strongly disagree" to "5 = Strongly agree") (Table 2).

Table 2: Operationalization of the independent variable

Variable	Source	Items
Corporate environmental commitment	Gagné et al. (2022)	• I believe that my company protects biodiversity. • I believe that my company minimizes its consumption of resources (raw materials, water, and energy). • I believe that my company minimizes its polluting emissions in the air. • I believe that my company minimizes its waste material. • I believe that my company minimizes the environmental impact of its products.

Sustainability risks associated with 4.0 technologies represent the independent variable. Based on the study by Dieste et al. (2023), we used a 5-point Likert scale to allow respondents to identify the main negative effects of 4.0 technologies on corporate environmental commitment. (Ranging from "1 = Strongly disagree" to "5 = Strongly agree") (Table 3).

Table 3: Operationalization of the independent variable

Variable	Source	Items
Sustainability risks associated with 4.0 technologies	Dieste et al. (2023)	• The adoption of 4.0 technologies can lead to higher levels of energy consumption. • The adoption of 4.0 technologies can lead to obsolescence and waste material. • The adoption of 4.0 technologies may increase the production of electrical and electronic waste. • The adoption of technological devices and equipment may lead to increased exploitation of natural resources. • The adoption of 4.0 technologies may result in higher energy consumption than traditional manufacturing.

Government commitment in sustainability represents the moderating variable. We applied the measurement scale developed by Sarabdeen (2024). We used a 5-point Likert scale, allowing respondents to evaluate the role of government in strengthening corporate environmental commitment. (Ranging from "1 = Strongly disagree" to "5 = Strongly agree") (Table 4).

Table 4: Operationalization of the independent variable

Variable	Source	Items
Government commitment in sustainability	Sarabdeen (2024)	• The government was a key actor in implementing sustainability regulations. • The government was a key actor in controlling carbon emissions and introducing a carbon tax. • The government was a key actor in reducing energy costs. • The government was a key actor in promoting sustainable innovation. • The government was a key actor in financing sustainable innovation.

4. Results

4.1. Convergent validity

Table 5: Characteristics of measurement scales

Measured variables	Scaleused	Number of items	Cronbach's alpha	Rho_A	Composite reliability	Average Variance Extracted (AVE)
Corporate environmental commitment	Gagné et al. (2022)	5	α = 0,819	0,827	0,874	0,581
Government commitment in sustainability	Sarabdeen (2024)	5	α = 0,847	0,850	0,891	0,622
Sustainability risks associated with 4.0 technologies	Dieste et al. (2023)	5	α = 0,886	0,896	0,916	0,686

Source: Data obtained from SmartPLS

Convergent validity is verified for all indicators representing the same concept or construct. It should be noted that reliability is ensured when Cronbach's alpha (Fernandes, 2012, cited by Hannachi, 2015) and rho_A (Vinzi et al., 2009) values are higher than or equal to 0.7. Similarly, this applies to the values of "composite reliability." Whereas that of the average extracted variance (AVE) must exceed 0.5 (Fornell and Larcker, 1981). In our case, all criteria are met, as shown in the table.

4.2. Discriminant validity

To verify discriminant validity, Fornell and Larcker (1981) suggest using the Root Average Variance Extracted (AVE) index. In Table 6, the values in bold on the diagonal of the latent variable correlation matrix represent the square roots of the AVE values. These are higher than the values below the diagonal. This means that each concept shares more variance with its measures than other concepts, which makes it possible to discriminate between them. Consequently, the measurement indicators only explain the latent variables to which they were assigned. Thus, the discriminant validity of our constructs is validated.

Table 6: Discriminant validity

	Corporate environmental commitment	Government commitment in sustainability	Sustainability risks associated with 4.0 technologies
Corporate environmental commitment	**0,762**		
Government commitment in sustainability	0,709	**0,789**	
Sustainability risks associated with 4.0 technologies	-0,674	-0,559	**0,829**

Source: Data obtained from SmartPLS

4.3. Evaluation of the measurement model

Tabel 7: Evaluation of the Structural Model

	R^2	R Square Adjusted
Corporate environmental commitment	0,723	0,715

Source: Data obtained from SmartPLS

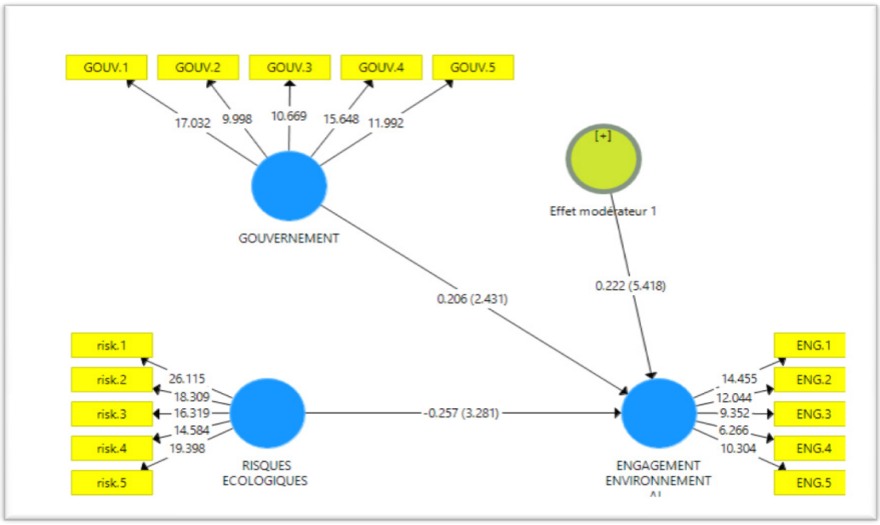

Figure 2. Estimation results for the theoretical model

4.4. Hypothesis Validation

Table 8 : Hypothesis Testing

Hypotheses	Initial sample (O)	Sample mean (M)	Standard deviation (STDEV)	t-value (| O/STDEV |)	p-values
Moderating effect 1 -> Corporate environmental commitment	0,222	0,219	0,041	5,418	**0,000**
Government commitment in sustainability -> Environmental commitment	0,206	0,212	0,085	2,431	**0,015**
Sustainability risks associated with 4.0 technologies -> Corporate Environmental commitment	-0,257	-0,260	0,078	3,281	**0,001**

Source: Data obtained from SmartPLS

First, based on our hypotheses, we examined the relationship between the two variables "Sustainability risks associated with 4.0 technologies" and "Corporate environmental commitment." Analysis of the results showed that there is a significant negative relationship between these two variables. (Y = -0.257, t = 3.281, p < 0.05). This result confirms what we found in the literature, which states that sustainability risks of digital technologies adopted in the industrial sector can impede companies' environmental practices. **Thus, H1 is validated**.

Secondly, we examined the effect of the variable "Government commitment" on "Corporate environmental commitment." We found that government commitment improves environmental practices. (Y = 0.206, t = 2.431, p < 0.05). **H2 is validated.**

Finally, we analyzed the effect of our moderating variable, "Government Commitment," on the relationship ("Sustainability Risks associated with 4.0 Technologies" – "Corporate Environmental Commitment"). By examining the positive and significant sign of the gamma coefficient (Y = 0.222, t = 5.418, 0.000 < 0.01), we confirmed that the negative effect of the independent variable "Sustainability risks associated with 4.0 technologies" on the dependent variable "Environmental commitment" is dependent on the level of government commitment to supporting responsible practices. This means that if the level of government commitment in sustainability is high, the negative effects of sustainability risks related to 4.0 technologies on the environmental commitment of companies is less. **H3 is therefore validated.**

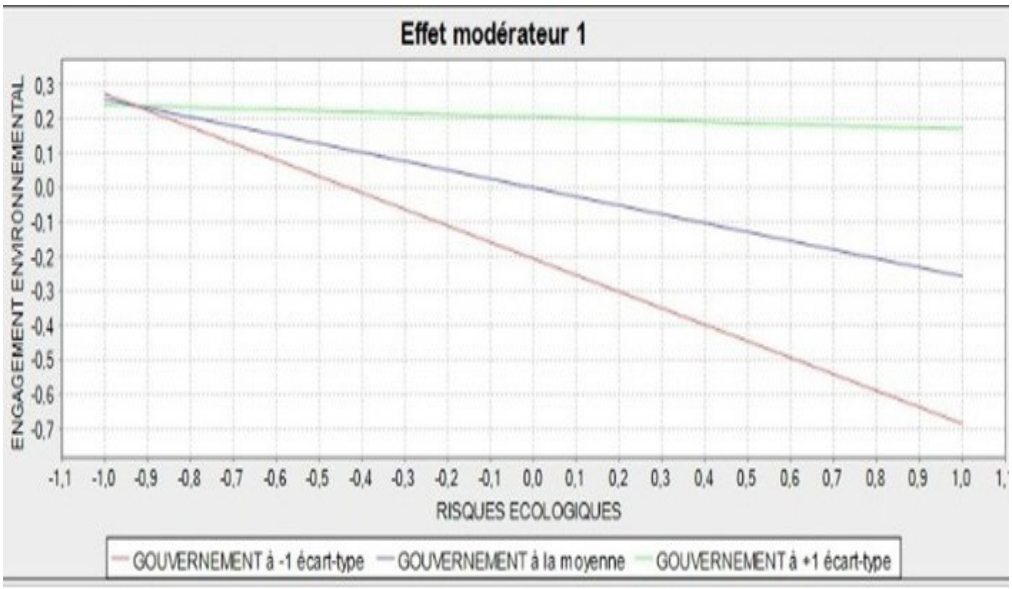

Figure 3. Analysis results of government commitment's moderating effect

5. Discussion

This research confirmed the starting assumption that corporate environmental commitment can be impeded by the adverse effects of Industry 4.0 in terms of sustainability, as demonstrated by several previous studies (Soltovski et al., 2020; El Baz et al., 2023), and that these effects can be mitigated through the central role of government interventions in promoting CSR practices, which is in line with the work of Moktadir et al. (2018) and Sarabdeen (2024).

The confirmation of the first hypothesis is supported by the contributions of researchers (Birkel et al. (2019) and Dieste et al. (2023)) demonstrating that the risks generated by the technologies adopted in industry can negatively impact companies' environmental commitment. Indeed, smart factories relying on technologies such as big data, the cloud, and blockchain can lead to increased energy consumption and higher use of natural resources (Waibel, 2017). They can also generate large amounts of electrical and electronic waste (Chiarini, 2021).

On the other hand, the results of the second hypothesis test, validated the existence of a positive relationship between government commitment and corporate environmental commitment, which corresponds to the finding obtained by M'hissen et al. (2020) and Souleymane (2024) according to whom the government facilitates access to the resources necessary for the adoption of eco-responsible approaches. Similarly, Williamson et al. (2006) and Benaicha (2017) consider that public authorities are a major stakeholder contributing to the creation of a favorable environment for CSR.

Finally, our results attest to the moderating role of government in reducing the negative effects of sustainability risks of industry 4.0, on corporate environmental commitment. From a coercive perspective, organizations adopt environmentally friendly behaviors by complying with regulations aimed at controlling carbon emissions, optimizing the use of natural resources, and better managing electrical and electronic waste. (Sarabdeen, 2024). From a normative perspective, promoting sustainable innovation is an attractive alternative in a digitized industrial environment, for example, supporting the energy transition and promoting eco-labels through tax and financial incentives (Sarabdeen, 2024). The study conducted by Alrashed and Asif (2015) showed that governments encourage the adoption of solar photovoltaic systems by offering reductions on energy products and short- and long-term loans.

6. Conclusion

In this article, we support the argument that industry 4.0 can have negative effects on companies' environmental commitment, highlighting the moderating role of government commitment on this dynamic.

According to the results of this study, respondents confirmed that the risks posed by I4.0 technologies in terms of sustainability, can impede companies' environmental practices. They are therefore required to ensure synergy between the integration of digital technologies into their manufacturing processes and their sustainability objectives. Respondents also confirmed that government policies and tools such as the control mechanisms, the establishment of a consistent regulatory framework for environmental protection as well as the promotion of sustainable innovation, play a crucial role in reducing these risks that supports and facilitates responsible practices.

Although policies and incentives to integrate sustainable technologies have been implemented in industrial sectors, Tunisian companies still face obstacles that must be considered by public authorities. Several actions can be proposed to public decision-makers, notably:

- The clarification of the Tunisian regulatory framework so that industrial companies can understand the environmental issues associated with 4.0 technologies.
- The establishment of a national platform enabling companies to report their emissions generated by the use of digital infrastructure. This will enable more efficient public policies to be targeted at the most polluting companies.
- The rehabilitation and development of certain closed landfill sites using environmentally friendly solutions and practices that prevent soil contamination. In this regard, the establishment of a logistical structure that trains and supports companies in managing electrical and electronic waste is an initiative that enables them to comply with environmental regulations.
- The simplification of administrative procedures and the establishment of clear conditions for access to financial incentives, to improve transparency and equity in awarding financial aid.
- The introduction of an eco-label that will be attributed to companies that reduce

their ecological impact while integrating Industry 4.0.

- The development of innovative approaches aimed at mitigating the negative impact of Industry 4.0 on sustainability such as the creation of collaborative platforms between companies and institutions (government agencies, universities and research centers, NGOs, etc.)

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