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FOREWORD

The International Journal on Optimization and Applications (IJOA) is an open access, double blind peer-reviewed online journal aiming at publishing high-quality research in all areas of : Applied mathematics, Engineering science, Artificial intelligence, Numerical Methods, Embedded Systems, Electric, Electronic engineering, Telecommunication Engineering... the IJOA begins its publication from 2021. This journal is enriched by very important special manuscripts that deal with problems using the latest methods of optimization. It aims to develop new ideas and collaborations, to be aware of the latest search trends in the optimization techniques and their applications in the various fields..

Finally, I would like to thank all participants who have contributed to the achievement of this journal and in particular the authors who have greatly enriched it with their performing articles.

Prof. Dr. Hanaa HACHIMI Editor in Chief

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Cloud and shadow IT: the flip side of digital costs

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***Abstract*— The phenomenon of shadow IT (SIT), also known as parallel or phantom computing, is constantly expanding, particularly as the use of cloud-based tools becomes increasingly widespread. This paper, based on qualitative research and a case study focused on reducing IT costs within a public transportation company, aims to explore in depth the method for identifying and assessing the hidden costs associated with cloud-based SIT.**

An innovative approach is presented in this paper, highlighting the possibility of identifying this type of shadow IT not only through technical solutions, but also by leveraging financial account data and analytical information available in financial tools. This innovative approach paves the way for a better understanding of the financial implications of cloud-based shadow IT and underscores the importance of considering these hidden costs in organizations' financial and strategic analyses.

***Keywords*—** *Shadow IT; IT management control ; hidden costs; cloud*

I. INTRODUCTION

Since the COVID-19 pandemic, remote work has grown considerably, changing traditional work methods. Employees now have the option of using their own IT equipment from home, and this development has led to the rise of Shadow IT (SIT) (Abbas & Alghail, 2023). Shadow IT is defined as the use of digital technologies, particularly cloud-based solutions, by employees without the formal approval of the Information Systems Department (ISD). Shadow IT is also called "parallel IT" or "phantom IT," and encompasses all the tools and software used by employees in their professional activities but which escape the control of IT teams (Meiller, 2020). Consequently, these unapproved technologies can pose significant risks to businesses, particularly in terms of security, compliance, and cost management.

According to Mell & Grance (2011), cloud computing is characterized by access to shared, configurable resources such as networks, servers, applications, and services that can be updated and accessed on demand. This situation is exacerbated by the proliferation of cloud computing, a technology that allows access to computing resources via the internet. While this technology is extremely beneficial for business flexibility, it also facilitates the use of cloud services without the knowledge or involvement of IT departments. This practice, uncontrolled by CIOs, constitutes a form of Shadow IT, making cost and risk control increasingly difficult for businesses. The public cloud represents fertile ground for the development of Shadow IT. Indeed, in a public cloud environment, data and applications are hosted by a third-party provider, which is a major contrast to traditional IT where the organization controls all resources (Satyanarayana, 2012). Software-as-a-Service (SaaS) cloud services are particularly affected by this phenomenon. In this model, companies are responsible for securing their data and managing user access. Employees, seeking quick and convenient solutions, resort to widespread data management tools or collaboration platforms without adhering to IT department validation protocols. Consequently, these tools escape all control in terms of security, compliance, and cost monitoring.

Shadow IT can be divided into several categories, including Greynet, which refers to network applications installed by end users to circumvent IT restrictions; content applications used to create and access data; and utilities used for system optimization or device cleanup (Vankayalapati, 2025). While these applications may meet immediate employee needs, they pose a significant risk of data leaks or security policy violations because they operate outside the control of IT teams.

This phenomenon has significant implications for IT governance within organizations. Shadow IT erodes the authority of the IT department and compromises the effectiveness of information systems management (Khalil & Samhan, 2025). Indeed, the IT department, traditionally responsible for aligning IT strategy with organizational objectives, sees its power diminish as employees act autonomously to adopt unapproved tools and services. This user autonomy, coupled with the rise of cloud computing and remote work, has transformed IT into a decentralized activity, escaping the traditional control of IT departments (Li et al., 2018). This loss of control leads to security problems, unforeseen costs, and non-compliance with applicable regulations, such as the GDPR, exposing companies to legal and financial penalties.

Furthermore, Shadow IT generates hidden costs that escape the notice of finance managers. These costs include unforeseen expenses related to securing data on unvalidated platforms, costs of non-compliance with regulatory standards, and indirect costs associated with managing tools used by employees without IT department involvement (Silic et al., 2025).

One of the most problematic aspects of Shadow IT lies in the invisibility of the tools used, which makes them difficult for IT managers to track and control. This invisibility complicates the management of associated costs and risks. Indeed, although many employees use these tools to improve their productivity, they often believe that the benefits of using them outweigh the potential risks. Employees consider their increased productivity as compensation for potential security breaches. This behavior is often reinforced by a theory of insufficient deterrence: sanctions or the guilt employees feel for violating security policies are not enough to deter their use of unauthorized tools. This situation demonstrates that managing Shadow IT requires more than sanctions; it requires a comprehensive IT governance strategy that includes clear processes, detection tools, and ongoing communication with employees (Silic et al., 2017).

To address the challenges posed by Shadow IT, companies must develop clear governance strategies and defined processes to better control the tools used by their employees. Implementing technical detection solutions is essential to identify unapproved applications and monitor the use of cloud services. Access management tools, application monitoring systems, and strict tool approval policies must be established to reduce the impact of Shadow IT on security and costs. Furthermore, raising employee awareness of IT security and the importance of adhering to company policies is crucial. Companies must also work in an interdisciplinary manner, involving both CFOs and CIOs, to understand the financial implications of Shadow IT and better control the hidden costs associated with this phenomenon (Ilesanmi, K. D. (2025)). The hidden costs generated by Shadow IT can be compared to those used in finance, where companies often underestimate expenses related to unvalidated services, leading to long-term financial losses (Alkousheh et al., 2025). To address the Shadow IT problem, companies must adopt a comprehensive approach that includes validation processes, detection tools, and a clear communication policy between the various departments within the company. Improved IT governance and the integration of security and compliance practices from the tool selection phase will help limit the impact of Shadow IT on IT resource management.

Overall, Shadow IT is a complex phenomenon that requires a strategic response and strengthened IT governance to mitigate its risks. By adopting a proactive approach that combines technical tools, clear governance and constant communication with employees, companies can better manage cloud infrastructure and reduce the risks associated with the uncontrolled use of cloud services

II. LITERATURE REVIEW

A. The Rise of Cloud Computing Practices and Their Impact on Organization and the Roles of Stakeholders

Chin et al. (2025) highlight that two opposing forces characterize the evolution of shadow IT. On the one hand, users adopt unofficial or informal technologies in response to internal information systems deemed inadequate to meet operational needs. This dynamic contributes to weakening the IT department's decision-making power, while reducing process standardization and compliance with security standards. On the other hand, a recentralization process is underway, aiming to deactivate parallel technologies and re-establish centralized control over information systems.

The various definitions of shadow IT agree that this practice is primarily initiated by employees themselves (Rakovic et al., 2020). These individuals choose unauthorized IT tools when IT department guidelines fail to meet their expectations, are perceived as too costly, or are simply not communicated effectively. A blurred line between professional and personal use can also lead to the misuse of existing tools, resulting in non-compliant technology manipulation.

Gonzalez et al. (2025) link the concepts of shadow IT and business-managed IT, reflecting a loss of IT department control over technology choices. According to these authors, the absence of internal restrictions from the IT department or management facilitates the proliferation of shadow IT. In the context of SaaS solutions, this situation is exacerbated by the behavior of vendors who often bypass purchasing departments or the IT department, concluding contracts directly with business units without prior consultation with IT managers (Scalabrin Bianchi et al., 2022). Akinade et al. (2025) note, however, that although cloud solution vendors seek to maximize their revenue, they ensure transparent and fair billing for their customers. This direct contracting method between business units and cloud service providers reduces implementation times, which are often constrained by internal IT processes. However, Akinade et al. (2025) highlight that cloud adoption goes beyond a simple technological choice; it represents a genuine evolution in management practices. This change requires a tripartite dialogue involving the IT department, business units, and decision-making bodies (such as the executive committee) to define and regulate the use of cloud solutions. within the organization. In this configuration, the IT department becomes a central player in technology governance, intervening both strategically and operationally to guide the use of cloud technologies, now required by management, functional departments and end users (Daniel et al., 2025).

B. Opportunities and Risks Associated with Cloud Information Systems (CIS)

B.1. Opportunities

Cloud information systems (CIS) offer several significant opportunities and advantages. The integration of cloud services enables ubiquitous access to data, regardless of location, time, or access method (Gonul Kochan et al., 2026). These systems can be developed in-house or acquired from

external providers. Initially, CIS took various forms, often initiated by end users. Their development began in the late 1980s, a period during which end users were responsible for their implementation, although their management and integration into IT strategy remained the responsibility of the Information Systems Department (ISD). Today, the rise of mobile technologies allows employees to connect to applications via their smartphones, possessing the technical skills to install these tools independently, often without perceiving the risks associated with this autonomy (Rahman & Hossain, 2024).

Employee adoption of information systems (IS) fosters improved efficiency, speed, and creativity, and can stimulate innovation within organizations (Jaradat et al., 2026). Furthermore, these systems facilitate real-time communication and knowledge sharing, particularly in organizations spread across large geographical areas (Thompson, 2025). CIOs can play a key role in encouraging the use of IS, notably by training employees on the associated risks and raising awareness of information security best practices (Ammar, 2025). This approach can generate "reasoned deviant behavior" among employees, who take advantage of the benefits of IT systems, such as time optimization and ease of use of IT tools. However, this risk-taking is often accompanied by countermeasures, such as justifications based on "denial of harm" or the adoption of neutralization strategies through security measures. Cloud-based solutions offer advantages in terms of time savings, relying on turnkey offerings, and increased flexibility to cope with activity peaks thanks to external shared hosting (Huy & Phuc, 2025). They also offer cost-reduction advantages, allowing for the differentiation of capital expenditures (CAPEX) related to physical infrastructure from operating expenses (OPEX) related to non-amortizable external services (Mostefaoui et al., 2022). However, the authors emphasize that "the cloud has a recurring cost," which could weigh on companies' IT budgets in the long term. Indeed, unlike on-premises applications whose costs are absorbed after license amortization, cloud services generate ongoing costs throughout the usage period or contract.

According to Shen & Chen (2022), several hidden costs can be associated with cloud solutions, including over- or under-provisioning of resources, an increased number of administrators due to the use of multiple applications, storage costs, promises of free access below certain usage thresholds, contracting for unnecessary services, uncontrolled user adoption, service reversibility, contract exit fees, maintenance, network costs, and the risks associated with regulatory changes requiring updates to ensure compliance.

B.2. Risks Associated with Cloud Information Systems (CIS)

The adoption of cloud information systems (CIS) generates several significant risks, particularly regarding documentation and service management. Indeed, the lack of systematic documentation concerning outsourced data and processes is a major issue, which can lead to inefficient information management and organizational risks. This lack of documentation can result in situations where internal know-how is retained by employees, thus increasing the risks of duplication, inconsistent data (Foster, 2025), and, in some cases, data loss (Wuersch et al., 2023). The location of data in cloud environments also raises significant questions in the event of an incident, due to the potential difficulties in identifying the responsible party or the appropriate contact person to resolve the problems.

Another major risk lies in the increased vulnerability to attacks, such as viruses, which can compromise data integrity and security (Legros, 2022). In sectors such as healthcare, delays in digital transformation, often linked to a lack of resources, lead employees to adopt workarounds, thus exacerbating the risks associated with the use of IT systems (Singun, 2025). Firewall vulnerabilities, for example, allow the downloading of unsecured applications or the dissemination of sensitive data on private mobile devices. This situation also raises legal questions regarding data ownership: when an employee stores work-related information in the cloud, they may be considered the owner of that data, even if they are not authorized to act on behalf of the company.

From an organizational perspective, the cloud presents an additional risk due to long-term contractual commitments, sometimes making it difficult to terminate or revise contract terms. External financial auditors, tasked with verifying compliance with the Sarbanes-Oxley Act (SOX) and its Section 404 on the reliability of financial reporting for publicly traded companies, often identify user-developed systems (UDSs) as a major weakness in internal control. Indeed, these systems can facilitate the manipulation of non-compliant data (Akinsola, 2025).

Furthermore, information generated by UDSs is often perceived as less credible by managers compared to information from traditional systems, such as Enterprise Resource Planning (ERP) systems, which limits its use in the decision-making process (Liutkevičienė et al., 2026). Consequently, managers seek to reduce the use of these unofficial systems (Washik et al., 2026).

C. Cloud-based Information Systems as a Generator of Hidden Costs

We argue that cloud-based information systems (ISS) generate costs that companies are unable to identify transparently. These costs, by their very nature difficult to measure, can be likened to the "hidden costs" encountered in finance. Hidden costs are defined as those not represented in a company's information systems, such as budgets, income statements, general ledger accounting, cost accounting, and dashboards (Zajac & Goranova, 2026). Conversely, a visible cost is defined as a clearly identified cost category within these information systems, and which has three main characteristics:

- A recognized name (e.g., personnel costs),
- A specific measurement (e.g., the amount of salaries and social security contributions),
- A monitoring system (e.g., monthly analysis of payroll trends, with targets for cost reduction).

Zajac & Goranova (2026) distinguish two categories of hidden costs: "historical costs" and "opportunity costs." The former are real costs, but diluted across the various cost lines of existing information systems, while the latter result indirectly from malfunctions, although they are not directly included in visible costs (Kude & Huber, 2025). Furthermore, Zhao et al. (2025) emphasize the importance of the procurement function in managing the total cost of ownership. This cost, which is frequently used in IT cost analysis, encompasses not only the acquisition cost but also the costs associated with malfunctions, such as those related to breakdowns or poor quality, which are, in themselves, hidden costs.

In the context of IT systems, some costs can be considered historical hidden costs. Indeed, these costs often escape the attention of the Information Systems Department (ISD), even though they are potentially present in the company's accounts. This phenomenon is partly linked to a lack of transparency regarding the use of cloud systems within organizations. This leads to the following research proposition, which we will examine in the third part of this article:

• Proposition 1: Cloud information systems can be considered as historical hidden costs.

D. Methods for Detecting and Controlling Cloud Information Systems (CIS)

Gërxhani & Cichocki (2023) point out that, due to their informal nature, shadow systems, or CIS, are rarely detected overtly. However, several technical solutions can be implemented to limit or control the use of CIS, such as establishing blacklists or whitelists to block access to certain sites (Kamjou et al., 2024). Furthermore, managing user authentication allows for restricting access to network resources and, consequently, to sensitive company data (Martseniuk et al., 2024). Other technical methods, such as analyzing support tickets, conducting employee surveys, or verifying the software installed on end-user devices, can also be used to detect the existence of CIS. Furthermore, the use of statistical methods and machine learning algorithms applied to security firewall logs can contribute to the identification of these systems (Aljabri et al., 2022).

A review of the literature reveals that the cloud plays a central role in the development of cloud information systems (LIS), which are primarily generated by individuals within organizations but can also originate from business units. The Information Systems Department (ISD) seeks to control this phenomenon due to the resulting security, risk, and quality issues. Initially, it is essential to identify LIS—a process currently reliant on manual and technical approaches—in order to better control it. This leads to the following research proposition, which we will explore in the third part of this article:

• Proposition 2: Technical solutions represent the most direct means of detecting cloud information systems (LIS).

It is worth noting that banning and monitoring strategies often prove ineffective, as most employees can circumvent these restrictions by using mobile applications that do not require administrative privileges to install (Liutkevičienė et al., 2014). Network management policies can offer simple solutions, such as centralizing management and maintenance of updates (Aljabri et al., 2022). However, according to Akinsola (2025), personal norms and potential sanctions do not exert significant pressure on the adoption of IT systems. In contrast, individual perceptions of informal and formal controls strongly influence the organizational climate and employee ethics. Chen et al. (2022) emphasize that an approach involving strict IT control—such as prohibiting business departments from installing IT tools—reduces risk while maximizing efficiency.

IT governance defines the rights and responsibilities for decision-making, thereby facilitating the appropriate use of IT resources and enabling the IT department to respond to risks associated with IT security. Behavioral, performance, and socialization controls must be adapted for managing the use of cloud- and internet-based digital technologies, taking into account their specific characteristics (Zhao et al., 2025). A prerequisite for the effective management of these systems lies in identifying the costs associated with IT security. These controls can be implemented, in particular, through the analysis of user development documentation. By identifying instances of IT security, the IT department can propose new working practices, require business units to use only IT-approved tools, coordinate actions, and centralize the registration of IT instances. A division of tasks between the IT department and business units then becomes essential. Thus, the IT department will handle generic activities common to several departments, while the business units will focus on specific developments to optimize transaction and production costs. This reflection leads to the following research proposition, which we will examine in the third part of the article:

• Proposition 3: Appropriate governance enables the detection and control of the SIT.

In the following section, we will compare our three research propositions within the framework of our field study and discuss their implications in the conclusion.

III. FIELD STUDY BASED ON A CASE STUDY IN THE INFORMATION SYSTEMS DEPARTMENTS (ISDS)

A. Case Study Presentation

This research is based on a field study conducted using the case study method, which allows for the analysis of specific situations and the testing of theoretical hypotheses. According to Yin (2018), each case study constitutes an independent research project, capable of either confirming or refuting a theoretical framework, while also offering the possibility of generating new elements and perspectives. The qualitative method adopted in this study allows for in-depth analysis, with detailed information gathered from various sources: interviews with key individuals, internal documents, and quantitative management data, thus serving to measure and illustrate the concepts studied.

The case study focuses on IT and telecommunications costs within a Moroccan construction group with over 2,000 employees. This group has six business line IT departments, each dedicated to a specific subsidiary, as well as a cross-functional IT department responsible for support functions,

and a Group IT department in charge of joint projects. Each business line IT department is responsible for its own costs, while the Group IT department oversees the harmonization of strategic decisions and ensures consistency of control and governance at the global level.

This group has launched an ambitious cost-saving plan, supported by working groups tasked with identifying processes, costs, risks, and problems encountered, with the aim of proposing an improvement plan. The IT cost reduction program comprises nine specific projects, illustrated in Figure 1 below.

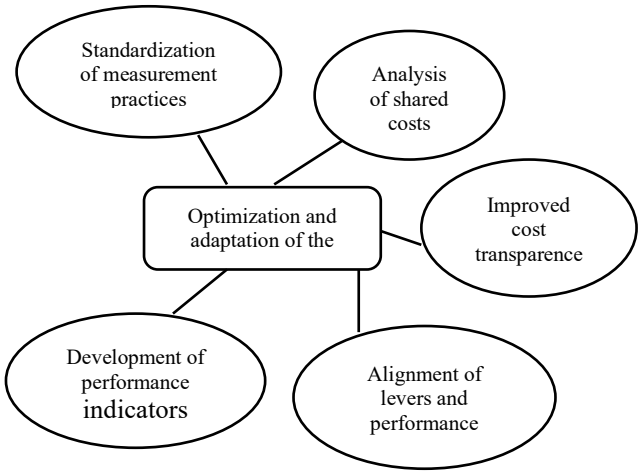
Figure 1: Presentation of the 9 projects in the cost reduction program

Number	Project
1	Governance of MOA/MOE responsibilities
2	Financial transparency and cost management
3	IT service outsourcing
4	IT Product and Service Acquisition Process
5	Centralized management of project portfolios and maintenance
6	Standardization of technologies and processes
7	Application streamlining and decommissioning
8	Application streamlining and decommissioning
9	Optimization of non-production environments

Source: by the author

Among these projects, the one related to finance was deemed particularly crucial, as it occupies the second position in the program. The specific objectives of this project are detailed in Figure 2 below.

Figure 2: Objectives of Project 2 - Financial Component



Source: by the author

B. Data Collection and Analysis Methods

The researcher was involved in a consulting engagement focused on the financial aspects, primarily concerning return on investment and cost optimization during 2022. The project was structured around four main sessions, which enabled the collection of data and information relevant to this research on shadow IT.

The researcher undertook a consulting engagement focused on the financial aspects, primarily concentrating on return on investment and cost optimization in 2022. The project took place over four main sessions, allowing for the collection of data and information relevant to this research on shadow IT.

The first phase involved 15 scoping interviews with management controllers and 7 CIOs or project managers for cost reduction initiatives. The second step involved collecting information such as organizational charts, procedures, reference documents, and data files on stock prices, purchase volumes, and transactions.

The four workshops in the third step addressed cost reduction initiatives, economic transparency, procurement, financial monitoring, and key performance indicators. Finally, the fourth step enabled the formalization of the target, including the organization, objectives, and cost-saving plan, as well as the target processes.

The quantitative data used in this study primarily relates to the first two months of the project, during which the team focused on identifying the scope of IT costs. This scope encompasses all of the group's IT costs, including both those recorded by the IT department and those associated with shadow IT. This identification allowed for the quantification of the extent of shadow IT. Although the researcher did not participate in the data production, the data was provided to them and analyzed for the purposes of this study.

As part of this mission, the researcher conducted fifteen interviews with participants from diverse populations to gather qualitative information.

In addition to the interviews, several relevant documents were collected during Phase 2. These documents included organizational charts, procedures, reference materials, detailed cost analyses, process maps, and a list of applications used, along with their status regarding potential decommissioning.

Phase 3 consisted of organizing five half-day workshops focused on cost reduction projects, their financial monitoring, and the associated governance. These workshops allowed participants to work on defining the IT cost base, assessing the amount of shadow IT, and developing potential cost reduction strategies.

All of this data—interview transcripts, workshop notes, end-of-mission reports, collected documents, and the researcher's continuous presence within the Group for six months—made it possible to:

• Describe the methods used to detect shadow IT, particularly by analyzing the accounting records and definitions used within the Group;

• Understand the governance issues and power dynamics between IT managers and the finance department;

• Gather verbatim comments from participants through coding of responses during interviews, in order to illustrate the analyses.

C. Results

The group's objective was to reduce costs over a two-year period in response to a significant increase in outsourcing costs. To this end, external firms were consulted to conduct comparative analyses and obtain industry data. These actions resulted in a substantial amount of financial and operational data.

As part of this study, the group identified costs related to shadow IT, estimated to represent a portion of total IT costs. The definition used to describe shadow IT was as follows: "Shadow IT includes all IT expenditures not incurred within IT departments or joint structures responsible for IT projects." This definition aligns with previous research, emphasizing that expenditures not approved by the Information Systems Department are identified by the departments responsible for the spending, whether IT departments or joint structures.

IT expenditures were meticulously examined to establish a benchmark for assessing potential savings. To achieve this, several analytical approaches were used to detail the costs:

• Organization: Costs were analyzed within each business IT department, as well as across the various organizational structures. Some costs were directly allocated to the IT departments, while others were recorded within the business structures.

• Expense Types: Costs were classified into three main categories: IT department costs, costs of mixed structures managing IT projects, and costs associated with shadow IT, originating from external organizations not involved in IT cost management.

• Nature of Expenses: Expenses were grouped into three main categories: purchases and external expenses (subcontracting, hardware, software, telecommunications, etc.), labor (salaries, social security contributions), and direct capitalized purchases.

A detailed analysis was performed using an Excel file to list the costs, based on an extract from the accounting ERP system covering all group costs. The management controller received authorization from senior management to access financial data beyond the IT departments. Several criteria were used to specifically identify IT costs, focusing particularly on organizational structure and excluding costs related to shadow IT within departments and joint structures responsible for IT projects. This approach allowed for the precise quantification of shadow IT costs. Expenses related to SaaS cloud services were subject to inconsistent accounting treatment. Invoices from cloud application providers were recorded in different expense categories, sometimes categorized as software license fees, sometimes as IT services, and even as non-IT services when SaaS solutions were integrated into broader offerings. This diversity of treatment led to an imperfect classification of information systems costs, as these were not systematically identified as such by financial management systems. This situation is partly explained by the absence, during the period in question, of a sufficiently explicit accounting framework for the treatment of software solutions.

To address these ambiguities, a revision of the accounting rules for software was undertaken, leading to the introduction of the concept of "IT solution." This conceptual shift broadens the traditional view of software by encompassing all digital functionalities that enable the processing, securing, and transmission of data, regardless of its physical medium. The implementation of this new accounting framework aims to consolidate IT costs into a unified category, thereby facilitating their identification and monitoring. However, while this clarification improves the allocation of expenses related to information systems, it does not, on its own, guarantee a comprehensive identification of the costs associated with cloud usage outside the core IT department. Analysis of the method chosen by the company to identify these costs reveals an approach based on the use of accounting categories dedicated to information technology and telecommunications. This approach offers the advantage of a common and standardized language, facilitating the initial detection of IT expenses. However, the costs thus identified only cover part of the scope of so-called "invisible" information systems, as they correspond to expenses incurred at the operational level without being directly managed by the IT department. This characteristic distinguishes the approach adopted from much academic work, which focuses primarily on the uses and costs incurred by end users.

Discussions with financial management stakeholders have led to the development of a more comprehensive method for identifying these expenses. This method is based on the observation that organizations are increasingly using external providers offering business services that integrate digital tools, particularly in cloud environments. In this context, IT costs are often included in overall billing, making their direct identification difficult. A cross-referencing approach between the costs related to business services and a list of cloud solution providers thus appears to be a relevant lever for improving the detection of these expenses, although this method is still under development.

Finally, the analysis of external costs related to information technology and telecommunications reveals that expenses incurred outside the central IT department represent a significant portion of overall costs. This share is particularly pronounced for software-related expenses, and even more so for those related to its provision through leasing, an area where cloud solutions play a dominant role. These results underscore the growing importance of information systems not directly managed by the IT function, particularly in the field of software solutions.

Interviews conducted with financial management personnel and operational managers involved in cost control initiatives highlighted the indirect effects of IT rationalization policies on business practices. In a context of budget constraints, several entities were unable to secure application development or upgrades from the central IT department.

This situation was part of a broader program aimed at streamlining the application portfolio, one of the main objectives of which was to reduce the number of applications in service in order to reallocate financial resources to maintaining tools deemed priorities. Analysis of the application portfolio, supported by enterprise architecture studies, identified a significant number of applications likely to be retired over a multi-year period, based on assumptions regarding their average lifespan. However, decommissioning applications proved to be a particularly complex process, requiring adjustments to operational practices, substantial technical interventions, and careful management of associated data. While this approach represented a significant lever for reducing expenses, its gradual implementation limited its immediate impact on expected savings.

Faced with the impossibility of using new in-house solutions, some operational stakeholders opted for alternative solutions by directly engaging external providers offering cloud-based applications. This choice allowed them to meet their functional needs while charging the costs to their own budgets, outside the established IT governance framework. This situation illustrates a characteristic case of unofficially recognized information systems, as defined in the literature, where digital solutions are used within the organization without formal validation from the IT department. These practices can also be analyzed as hidden costs, insofar as the associated expenses escape the IT function's monitoring and control mechanisms and are not fully integrated into existing management information systems.

The observed situation highlights a loss of confidence among some operational stakeholders in the central IT function, leading them to adopt alternative methods of consuming digital resources, primarily through cloud solutions. Initially, these uses remained largely invisible to the financial management systems of the information systems. The comments gathered during the interviews reflect a shared sense of disconnect between the organizational constraints imposed by IT governance and the demands for responsiveness and flexibility expressed by operational activities. The interviewees particularly emphasized the perceived slowness of internal development and validation processes, as well as the inadequacy of certain standardization approaches to the specific and urgent needs of the business. Faced with these constraints, using external providers offering rapidly deployable solutions appears to be a pragmatic response for ensuring business continuity. This trend is all the more striking given that it involves managers initially committed to controlling IT spending, but who have prioritized immediate operational efficiency.

This choice has led to the implicit outsourcing of certain IT decisions and the allocation of corresponding costs to operational budgets, outside the control of the IT department. This mechanism has thus contributed to the development of practices related to information systems that are not officially recognized, widening the gap between the actual use of digital technologies and formal governance frameworks.

Following the findings from the initial phases of the project, the organization initiated a change in its governance to better regulate these practices. The actions implemented focused in particular on structuring IT procurement processes and strengthening the associated financial oversight. The objective is twofold: firstly, to streamline and centralize decisions regarding the acquisition of digital solutions in order to limit uncontrolled use; secondly, to improve the visibility and monitoring of IT expenditures, including those incurred outside the traditional scope of the IT function.

IV. DISCUSSION

From a theoretical perspective, this research demonstrates that business units, as well as IT professionals within these units, do not consider shame to be a major obstacle to the development of shadow IT (SIT). Indeed, several respondents explicitly stated that they deliberately circumvent formal procurement policies. They use SIT solutions and conceal the associated costs. The cost-cutting context in which this study was conducted prevented IT managers from adopting deviant behaviors to leverage the benefits of the IT system. Financial governance took precedence: monitoring the IT budget was deemed more crucial than implementing security or mitigation measures (Akinsola, 2026).

This research addresses the three propositions formulated in the literature review:

Proposition 1: Cloud-based IT systems can be likened to historical hidden costs.

This proposition is validated. Cloud applications were directly ordered by business units without approval or budget allocation from the IT department. These costs, invisible in the IT department's financial information system, were nevertheless detectable in the Group's overall financial system. They therefore correspond to historical costs, since they escape the IT department's direct control while being recorded in the Group's accounts.

Proposition 2: Technical solutions are the simplest way to detect cloud-based IT infrastructure (STI).

This proposition is not validated. The case study reveals that a method not described in the literature can identify STI costs. Analysis of accounting and analytical accounts made it possible to detect IT expenditures incurred outside the IT department. The method used by management control to identify these costs is based on the assumption that costs are recorded outside the IT department and in mixed structures managing IT projects.

Hidden opportunity costs, resulting from inefficient practices or malfunctions, remain invisible in the accounts and require further evaluation.

Proposition 3: Appropriate governance enables the detection and control of STI.

This proposition is partially validated. Although the Group implemented an IT cost reduction plan and documented governance rules, these efforts did not prevent business units from contracting directly with suppliers for IT services without going through the IT department. However, financial governance enabled the identification of IT-related costs, thus facilitating their control. Financial indicators were established to monitor compliance with the rules and measure their effectiveness. Subsequently, governance was

strengthened through stricter procurement rules, mandating the use of a centralized service center for IT purchases.

One of the significant findings of this study lies in the formalization of a classification of IT-related costs. This classification identifies four groups of IT costs:

• Category A expenses: These costs are directly borne by the IT department. They represent the majority of external costs in this study.

• Category B expenses: These costs are incurred by departments other than IT and represent a portion of external costs. In some cases, such as for cloud-based applications, these costs can even reach a higher level. These expenses fall into the category of shadow IT, meaning they are hidden from the IT department.

• Category C expenses: These costs are borne directly by end users, for example, for using applications on their own devices. Although these costs cannot be measured by the company, they result in hidden costs for the IT department and other departments. These practices can lead to malfunctions, data loss, and overconsumption of IT resources. Incidents related to the use of incompatible applications have been reported. Furthermore, sensitive data is circulating on unsecured platforms, violating security policies.

• B' Expenses: Initially classified as Category C, these expenses can increase Type B costs. They represent IT expenses directly incurred by users but reimbursed by business departments through expense reports. Although these costs have been identified, their valuation has been deemed disproportionate to their financial impact.

Another major contribution of this study lies in enriching the definition of hidden costs. This research highlights the intentional concealment of certain IT costs by business managers who do not have the authority to generate such expenses. These managers, while involved in controlling IT costs, are outside the scope of the IT department and lack direct access to business accounts.

This study also underscores the importance of strict governance for shadow IT and highlights the key role of finance in legitimizing IT system decisions. The research focuses on cloud computing, emphasizing the need for precise contracts with external partners. Strengthened procurement governance has improved collaboration between business units and the IT department.

Furthermore, this study highlights the importance of a systemic approach involving senior management. This intervention facilitated the detection of hidden costs and the creation of a dedicated IT procurement service center. It is emphasized that the mistake of gradually phasing out beneficial cloud applications must be avoided.

It is important to note that this analysis is based on a specific case, and a future study could explore the strategies and mechanisms in place within this company in greater depth. Establishing procurement governance and a service center could streamline costs. It would also be relevant to assess the opportunity costs associated with using cloud computing to inform future research on this topic.

V. CONCLUSION

Information Technology Services (ITS), particularly cloud-based services, extend beyond end users within companies. In the case study, the identified costs include services that deliberately consumed IT resources without the approval of the IT department. The case study confirms that ITS detection can be achieved beyond traditional technical means, such as connection monitoring. In this instance, we introduced a practical and operational methodology based on accounting principles, enabling the identification of ITS costs through the analysis of accounting records and, subsequently, through cross-referencing with suppliers, thus facilitating the identification of cloud services.

Our research, conducted prior to the recent revisions to accounting rules (2024) by the French Accounting Standards Authority (ANC), has demonstrated that broadening the scope of the "software" account, now called "IT solution," will facilitate more comprehensive and accurate monitoring of cloud-related costs, thereby improving visibility into ITS.

This study makes an original contribution, notably by adopting a financial approach to IT analysis and refining Savall and Zardet's (2020) definition of hidden costs. It has formalized a typology of IT costs, distinguishing between:

• IT costs directly charged to the IT department, which are not considered IT or hidden costs.

• Costs related to business units, without IT approval, which constitute both IT and hidden costs.

• Costs directly incurred by end users, which are not directly part of the company's costs but may constitute IT.

The last two cost categories can lead to hidden opportunity costs, generating quality issues and security risks. IT is, by its very nature, a hidden cost because, although it is identifiable at the company level, IT managers often lack sufficient visibility into these costs. Strengthened governance, coupled with clearer accounting rules and rigorous monitoring of financial indicators, could improve the detection and control of IT systems. Furthermore, consolidated procurement governance will allow for better definition of purchasing rules and control of IT-related costs. Our results reveal significant tensions between the IT department, business units, and the finance department, but also that the company studied ultimately prioritized strict financial governance, thus ensuring better control of IT-related costs.

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Pedagogical Innovation and Knowledge Transfer : Levers of Effective Learning in Higher Education - The Case of Students in Public Health Sciences Institutions

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Abstract

Faced with profound transformations in the academic environment marked by innovation, evolving competency needs, and the demand for greater personalization of learning pathways, Moroccan public institutions are increasingly called upon to rethink their pedagogical approaches to meet the expectations of students and stakeholders in the health sector. Indeed, pedagogical innovation and knowledge transfer have emerged as major strategic levers for fostering effective learning within higher education institutions, particularly in health sciences programs (Ahessad J. & Lahboub I., 2024).

In this context, our research aims to analyze the combined impact of pedagogical innovation and knowledge transfer on the quality of learning among students enrolled in Moroccan public health sciences institutions. Based on a confirmatory quantitative methodology, this study aims to test how innovative practices can foster not only the active appropriation of knowledge but also its effective mobilization in professional settings. Knowledge transfer, in this perspective, appears as a key process to strengthen student autonomy, develop critical thinking, and enhance their ability to address complex situations.

Our article highlights the structuring role of pedagogical innovation in transforming learning dynamics, while emphasizing the importance of a supportive ecosystem for knowledge transfer. However, the results of our study reveal several persistent obstacles: resistance to change among certain actors, insufficient pedagogical training for instructors, limited infrastructure, and the absence of a clear institutional framework that promotes the systemic integration of these practices.

Keywords— University student learning, knowledge transfer, pedagogical innovation, public health sciences institutions

VI. INTRODUCTION

The pervasive presence of technology and digital tools is reshaping behaviors and practices across all areas of activity, both professional and personal. In the digital era, higher education systems are confronted with new challenges that must take into account the emerging expectations of 21st-century students. These systems increasingly question which fundamental competencies need to be developed in order to respond to the growing interest in innovation and to meet the needs of tomorrow's society.

Today, it is difficult to envisage the evolution of pedagogical approaches without harnessing the potential of Information and Communication Technologies (ICT). ICTs are increasingly regarded as an integral component of contemporary university education systems. Their integration into teaching methods has already initiated innovation, which should also extend to students' learning modes and to instructors' pedagogical practices.

Numerous forms of innovative pedagogy are well documented in the literature, including collaborative learning and project-based pedagogy, learner-centered approaches aimed at fostering autonomy, the hybridization of training systems, and flipped classroom scenarios. All these perspectives are grounded in the innovative potential offered by ICTs in teaching and learning processes.

Despite the difficulties faced by the education system in disseminating pedagogical successes and genuinely fostering innovation among its stakeholders, many initiatives have emerged. This study is aligned with this perspective, as it is the result of reflection and effort on the part of students to promote change through the innovation of teaching practices. Accordingly, our ambition is to provide elements of response to the following research question:

To what extent does knowledge transfer promote university students' learning in the era of innovative pedagogical practices?

Within this context, the objective of our research is to highlight innovative practices in university pedagogy, as well as the prospects for integrating these practices into higher education. It also seeks to examine a number of issues that we believe may influence the future of technology integration in university pedagogy.

To achieve the objectives of this research, we adopt a post-positivist paradigm, also referred to as modified positivism, which assumes that reality exists independently of the mind and of the descriptions constructed about it. This paradigm is particularly suited to our analysis, as the construction of our research object primarily involves examining empirical facts in order to uncover the underlying reality of the knowledge transfer process within higher education institutions.

Accordingly, we employ a hypothetico-deductive approach, since our research aims to test formulated hypotheses in order to measure the impact of knowledge transfer on students' learning within public health sciences institutions.

Finally, we consider it appropriate to conduct a quantitative study based on questionnaire distribution, combined with reliability analysis and structural equation modeling, using SPSS and AMOS version 29. This methodological approach allows us to address our research question through numerical data and to analyze the results of the statistical survey in a rigorous and logical manner.

VII. LITERATURE REVIEW

A. Theoretical Foundations of University Students' Learning

Organizations need to rapidly acquire and learn knowledge in order to enhance their productivity and efficiency and to deliver value to their clients (Salomon & Martin, 2008). Organizational learning is therefore widely recognized as a key mechanism for developing competitive advantage (Kuo, 2011).

Yli-Renko et al. (2001) argue that the accumulation of knowledge through learning constitutes a driving force for organizational growth and development. The ability of an organization to learn, as suggested by Moingeon and Métais (2000), represents a core capability that enables the creation and implementation of knowledge and know-how. The literature on organizational learning is extensive and well established (Koenig, 1994; Huber, 1991; Levitt & March, 1988; Fiol & Lyles, 1985; Argyris & Schön, 1978).

Koenig's (1994) theory of organizational learning is based on the idea that learning modifies both situations and the way situations are managed. Organizational learning theories generally consider learning to be organizational as soon as the acquisition of knowledge—even when it is individual—leads to a change in organizational behavior.

Huber (1991) also states that an organization learns when one of its units acquires knowledge that it recognizes as potentially useful to the organization. Organizations primarily learn through their individual members, who continuously acquire new knowledge (Reid et al., 2010). The organization itself does not learn independently; rather, individuals are the main actors in the learning process.

According to Huber, organizational learning theory places the individual at the center of the learning system by considering them the primary actor within it. Organizational learning initially occurs through individuals who share newly acquired knowledge with one another before it is disseminated and generalized across the organization.

Similarly, Levitt and March (1988) demonstrate that organizations can learn from direct experience. To do so, they must interpret experience, which is not always straightforward because existing routines shape interpretations. Organizations can also learn from the experiences of others.

Learning as the development of the knowledge base: Organizational choices are grounded in prior knowledge, and organizational effectiveness is determined by the quality of the knowledge base available for strategic decision-making. Knowledge distributed across the organization is transferable among members through shared understanding; it is embedded in work procedures and organizational structures. Knowledge thus emerges as the outcome of the learning process.

Organizational learning as the capitalization of experience: Learning can occur through the accumulation of experience or through experimentation (Koenig, 1994). Knowledge is produced through the acquisition of know-how and through reflection-in-action. Consequently, learning is oriented toward the intelligence of experimentation, which is based on constructive reflexivity.

It can therefore be argued that organizational learning theories manifest themselves when there is either exploitation or exploration of knowledge within organizational action, where routines, rules, and values exist. These theories explain that individuals make organizational choices progressively as they gain experience (exploitation) or when they are confronted with new experiences (exploration).

In addition, learning is not limited to the acquisition of individual competencies; rather, its primary objective is the renewal or transformation of collective knowledge and competencies, which constitute the central foundation of learning at the organizational level.

Finally, it should be noted that individual interactions are a necessary condition for learning at the group and organizational levels (Argyris & Schön, 1978). Individuals learn through interaction and by acting as mediators in information exchanges, while groups learn when members cooperate in pursuit of a shared objective (Bennis & Nanus, 1985).

B. Innovative Practices in University Pedagogy

The concept of pedagogical innovation, at the core of which lies the teaching–learning dynamic, takes on particular significance when combined with a program-based approach and when reflection encompasses all or a substantial part of the training activities within an academic curriculum.

The Higher Council for Education, Training and Scientific Research (CSEFRS) has developed a strategic vision covering the period 2015–2030. This vision emphasizes the need to renew pedagogical practices through the integration of Information and Communication Technologies (ICT), by "developing a national strategy that will place them at the

service of learning quality at the level of programs and training from the earliest cycles of education, through various digital media, interactive programs, and networks" (CSEFRS, 2015).

In recent years, new technologies and video-based teaching formats - such as flipped classrooms and, in particular, Massive Open Online Courses (MOOCs) - have contributed to the evolution of university pedagogy. They have also fostered the emergence of new modalities for training instructors in university-level pedagogy.

Unlike flipped classrooms and MOOCs, in which distance learners generally follow courses asynchronously, virtual classrooms allow learners to attend courses synchronously in real time, as well as asynchronously through recorded sessions for those who are unable to attend live. In the context of virtual classrooms, distance learners participate in courses simultaneously with on-site learners, within the same digital space and on the same online platform.

The use of ICT in the learning process currently represents a key competence for students, enabling them to better adapt to a constantly evolving environment. Although ICTs have not yet fully revolutionized the traditional classroom, they have already transformed students' learning experiences by reducing constraints related to time and space and by facilitating access to information.

In the contemporary context, pedagogical innovation constitutes a major challenge for the development of higher education institutions worldwide. Driven by major political initiatives, pedagogical innovation represents one of the principal levers of progress for any higher education institution.

C. Research Hypotheses

Based on the key concepts presented in this theoretical section and on the initial assumptions previously outlined, we propose a preliminary research model derived from theory, integrating the relationship between the two variables under investigation.

On the one hand, the literature review, academic conferences, and para-university events conducted across various institutions, and on the other hand, empirical studies, field observations, and the quantitative approach adopted, have all served as a foundation for formulating and refining our research hypotheses. We first focus on the direct effects of the determinants of knowledge transfer on the different dimensions of organizational learning.

This leads us to formulate the following main hypothesis:

H1: Knowledge transfer has a positive impact on the dimensions of organizational learning among university students.

This main hypothesis is further specified through the following sub-hypotheses:

H1.1: The nature of knowledge positively affects organizational learning among university students.

H1.2: The sender–receiver relationship positively affects organizational learning among university students.

H1.3: Knowledge transfer capacity positively affects organizational learning among university students.

H1.4: Knowledge transfer characteristics positively affect organizational learning among university students.

VIII. RESEARCH METHODOLOGY

This section focuses on the research methodology adopted in this study. It begins with a justification of the choice of the target population, followed by a presentation of the epistemological positioning and the sampling procedure, and concludes with a description of the data collection process and the measurement instruments used to address the research problem.

A. Selection of University Students

The study of learning within the context of health sciences students represents a logical choice due to the numerous advantages it offers, both in terms of theoretical knowledge acquisition and practical skill development. Health sciences are characterized by continuous evolution, driven by new discoveries, techniques, and technologies. Consequently, students are required to rapidly integrate and apply up-to-date information.

Research in medical education has demonstrated that learning and the use of active pedagogical methods are essential for enabling students to cope with this growing complexity. For instance, a study by Cook et al. (2010) on active learning in medicine highlights that the integration of active pedagogical strategies enhances knowledge acquisition and retention.

Similarly, Davis et al. (2013) emphasizes that learner-centered pedagogical approaches, which promote autonomy and reflective thinking, enable health sciences students to better develop decision-making and reasoning skills that are essential for real-world practice. Indeed, health sciences students are expected to develop practical competencies while simultaneously applying theoretical knowledge.

Education in the health sciences is not limited to individual competencies; it also involves the ability to work within interprofessional teams, which constitutes a crucial component of health sciences practice (Reeves et al., 2016). Boud and Falchikov (2007) show that health sciences students are more engaged in their learning when they participate in practical and collaborative activities, leading to improved retention of knowledge and skills.

Overall, the study of learning and knowledge transfer in the field of health sciences is essential to ensure that students acquire not only solid theoretical knowledge but also practical skills and the ability to solve complex problems.

B. Epistemological Positioning

We adopted a quantitative methodology to structure the scientific approach followed in this research, both to ensure the rigorous achievement of the study objectives and to guarantee the validity and reliability of the quantitative results obtained. The quantitative methodology aims to generalize the study's conclusions by collecting data from a representative sample of the target population. This approach is grounded in a positivist epistemological stance, based on the principle that scientific inquiry constitutes the primary foundation of reality

and that the scientific method is the only means of establishing objective truth.

Within this framework, we assume that the techniques, procedures, and methods employed enable a more precise understanding of the research problem and the subject of this article. We rely on a deductive, or hypothetico-deductive, epistemological positioning in order to measure the variables of the model and to test the resulting research hypotheses through empirical analysis. Specifically, structural equation modeling (SEM) was employed to test causal relationships and to evaluate the proposed model using AMOS software.

The objective of this study is therefore to highlight and empirically test the dimensions of knowledge transfer and their impact on the learning of health sciences students within Moroccan public higher education institutions.

C. *Sampling Procedure, Data Collection, and Measurement Instruments*

In any research endeavor, the ideal approach would be to study the entire population; however, in most cases, populations are sufficiently large that it is impractical to include all individuals. Snowball sampling is a non-probabilistic technique in which data are collected from participants who are easily accessible within the researchers' networks. Participation may be influenced by respondents' interest in the research topic, their willingness to express opinions, their level of dissatisfaction, their motivation to support specific viewpoints, and, most importantly, the inclusion and exclusion criteria established for the study.

The use of this method was justified by field constraints that necessitated the adoption of non-probabilistic empirical approaches. Nevertheless, such methods limit the scope and generalizability of the findings. To measure knowledge transfer, we adopted the four dimensions proposed by Prévot (2005). The measurement instrument consists of 22 items covering the four dimensions of knowledge transfer, namely the nature of knowledge, the sender–receiver relationship, transfer capacity, and organizational characteristics. The measurement scale developed by Prévot (2005) was followed to assess knowledge transfer.

A questionnaire survey was conducted among students enrolled in public health sciences institutions in Morocco. Responses were received from nearly 34 institutions out of a total of 37. The majority of respondents were affiliated with the Faculties of Dental Medicine in Rabat (57 respondents) and Casablanca (53 respondents), representing 25.4% and 23.7% of the sample, respectively. These were followed by the Faculties of Medicine and Pharmacy in Rabat (31 respondents), Marrakech (28 respondents), and Casablanca (20 respondents). The Faculties of Medicine and Pharmacy in Fès, Agadir, Tangier, and Oujda accounted for 6.7%, 3.6%, 3.1%, and 2.2% of respondents, respectively.

The study highlights the diversity of the institutions included, encompassing all Moroccan regions, thereby providing an overview of the distribution of students enrolled in health sciences programs. The Rabat–Salé–Kénitra region accounted for 28.3% of respondents, while the Casablanca–Settat region represented 24.3%, together accounting for more than half of the total number of health sciences students (52.6%).

A total of 548 questionnaires were collected. The sample comprised 48% male and 52% female respondents, with an average age ranging between 18 and 30 years. Participation in the survey was voluntary. Data collection methods varied across institutions due to specific constraints related to reaching students. Accordingly, the questionnaire was disseminated through university portals, email communications, and student groups on social networking platforms such as LinkedIn. In addition, the snowball sampling technique was also employed to further distribute the questionnaire and reach a larger number of students.

IX. RESULTS

A. *Analysis of Dimensionality and Reliability of the Independent Variables: Knowledge Transfer*

Four main dimensions of knowledge transfer were identified: the nature of knowledge, the sender–receiver relationship, transfer capacity, and knowledge transfer characteristics.

- Homogeneity and Reliability of the Variables:

The nature of knowledge was measured using three items. The Kaiser–Meyer–Olkin (KMO) index of 0.624 indicates that these three items are suitable for factor analysis. In addition, Bartlett's test of sphericity confirms that the correlations among all items are acceptable, as evidenced by a significance level of 0.000. The dimensionality analysis reveals the existence of a single dimension for the nature of knowledge, measured by the following items: NC1, NC2, and NC3. These items explain approximately 53.103% of the total variance.

The sender–receiver relationship was measured using nine items. The KMO index of 0.853 indicates that these items are highly appropriate for factor analysis. Bartlett's test of sphericity also shows acceptable correlations among all items, with a significance level of 0.000. The dimensionality analysis reveals the existence of two dimensions for the sender–receiver relationship. The first dimension is measured by the following items: RER5, RER6, RER7, RER8, and RER9. The second dimension is measured by the following items: RER1, RER2, RER3, and RER4. However, the items constituting the second dimension explain only 12.565% of the variance. Consequently, we decided to separate the items into two components and to remove those associated with the second dimension. The transfer capacity dimension was measured using three items.

The KMO index of 0.614 indicates that these items are suitable for factor analysis. Bartlett's test of sphericity confirms acceptable correlations among the items, with a significance level of 0.000. The dimensionality analysis reveals a single dimension for transfer capacity, measured by the following items: CAPT1, CAPT2, and CAPT3. These items explain approximately 52.585% of the variance.

The knowledge transfer characteristics were measured using seven items. The KMO index of 0.718 indicates that these items are appropriate for factor analysis. Bartlett's test of sphericity confirms acceptable correlations among all items, with a significance level of 0.000. The dimensionality analysis reveals the existence of two dimensions for knowledge transfer characteristics. The first dimension is

measured by the following items: CT1, CT2, CT3, CT4, and CT7. The second dimension is measured by the following items: CT5 and CT6. However, the items constituting the second dimension explain only 12.565% of the variance. As a result, we decided to separate the items into two components and to remove those associated with the second dimension.

The separation of dimensions reflects the theoretical contributions of the SECI model proposed by Nonaka and Takeuchi (1995), which is based on the distinction between explicit and tacit knowledge. This model comprises four stages: socialization, externalization, combination, and internalization. In this context, the first dimension is theoretically linked to socialization, where new knowledge emerges through interactions, whereas the second dimension refers to externalization, which involves the transformation and capitalization of knowledge acquired during the socialization process.

As previously mentioned, and according to the table above, two factorial axes were identified. The first axis (socialization) includes five items and accounts for 36.62% of the initial variance, while the second axis (externalization) comprises two items with an eigenvalue of 53.50%. We subsequently proceeded with a reliability analysis of the retained component.

Table.1: Analysis of Variable Homogeneity

Variables	(KMO) Index	Bartlett's Test	Cronbach's Alpha
Knowledge Transfer	0,700	0,000	0,649
Organizational Learning	0,689	0,000	0,686
Nature of Knowledge	0,624	0,000	0,557
Sender–Receiver Relationship	0,853	0,000	0,766
Transfer Capacity	0,614	0,000	0,546
Organizational Characteristics	0,718	0,000	0,691

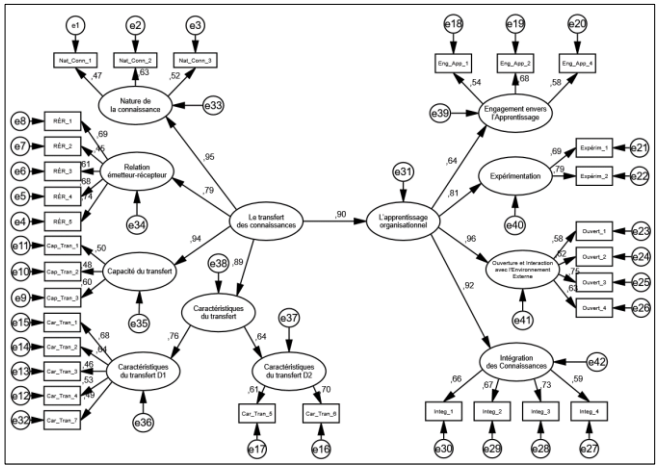
Source: *Results derived from the survey data analyzed using SPSS 22*

B. Structural Model Analysis: Testing the Main Model

Knowledge transfer has a positive and statistically significant impact on university students' learning, with an estimated value of 0.90. This effect is reflected through the dimensions of knowledge transfer, namely the nature of knowledge (0.95), transfer capacity (0.94), transfer characteristics (0.89), and the sender–receiver relationship (0.79). It is also reflected through the dimensions of learning, including openness and interaction with the external environment (0.96), knowledge integration (0.92), experimentation (0.81), and commitment to learning (0.64). The positive and significant impact is likewise observed at the level of the items measuring both the learning dimensions and the knowledge transfer dimensions.

The figure below presents the factor loadings of the tested model across variables, dimensions, and items, thereby providing an overall view of the relationships and results discussed above.

Figure 1: Main Model of the Direct Effect



Source: *AMOS 29*

X. DISCUSSION OF RESULTS

Structural equation modeling, using AMOS software, was employed to analyze all the variables included in our model and to derive a set of results that provide significant added value to this study.

Within the context of knowledge transfer and organizational learning, the findings reveal a positive and statistically significant relationship between the dimensions of knowledge transfer (the nature of knowledge, the sender–receiver relationship, transfer capacity, and transfer characteristics) and student learning. This indicates that students' learning is positively influenced by these factors.

These results are consistent with prior studies that have examined the relationship between knowledge transfer and students' organizational learning (Prévot, 2005; Lawson et al., 2008; Lauzier et al., 2013). These authors found that knowledge transfer oriented toward best practices has a positive effect on organizational learning among university students in the health sciences.

According to the study by Barrette et al. (2012), the acquisition and transformation of knowledge constitute the primary facilitators influencing individual learning, while also exerting a significant impact on organizational learning. This dual effect is consistent with information processing theory (Huber, 1991), which considers knowledge acquisition and transformation as essential levers for stimulating organizational learning. This theory further suggests that formalizing these processes enhances not only individual

knowledge but also the organization's overall learning capacity.

Moreover, Hansen et al. (1999) emphasize that knowledge is often closely tied to the individual who developed it and is primarily transferred through direct person-to-person contact. Human networks that foster sharing and flexibility play a crucial role in knowledge transfer (Vătămănescu et al., 2020; Lardón-López et al., 2022). In addition, within the university learning context, trust between parties enhances knowledge transfer (Becerra et al., 2008). Hansen et al. (1999) also highlight the importance of information technologies in the storage and transfer of explicit knowledge. Although digitalization is pervasive in today's environment, the impact of digital technologies on knowledge transfer remains underexplored. Venkitachalam and Schiuma (2022) identify four research directions related to knowledge management in the digital era that warrant further in-depth investigation.

The establishment of a knowledge-sharing culture, along with corresponding practices, represents a central pillar for strengthening knowledge-sharing behaviors. Nowacki et al. (2015) stress that promoting such practices requires the development of an appropriate organizational culture. Knowledge sharing is, in itself, a learning process that fosters organizational learning.

Soares and Almeida (2014) argue that "appropriate knowledge sharing is crucial for organizational learning," which, in turn, contributes to competency development. They further reinforce this view by asserting that competency development stems from organizational learning practices.

Numerous scholars thus emphasize the importance of knowledge sharing and its effect on strengthening organizational learning practices, which support the development of learning processes and the enhancement of competencies. Wang et al. (2014) point out that competencies emerge directly through learning. Furthermore, as knowledge is an individual resource that is shared within the organization, it is essential to promote organizational learning to ensure the internal transfer, development, and sustainability of knowledge (Argyris & Schön, 2002).

Among contextual factors, learning culture emerges as the most decisive. An organization with a well-established learning culture, in which learning is perceived as a core value, creates a favorable climate for the recognition of work and reflective practice. This finding aligns with the perspectives of numerous scholars who acknowledge the decisive impact of learning culture on organizational learning.

Finally, the results of this study corroborate our assumptions and are consistent with the conclusions of researchers such as Dragnić (2014) and Eruemegbe (2015), who demonstrate the positive impact of organizational learning on knowledge transfer. These findings are also aligned with Piaget's (1976) learning theories.

Table.1: Overview of the Quantitative Findings

Hypotheses	Hypothesis Status
H1: Knowledge transfer has a positive impact on the dimensions of organizational learning among university students.	**Supported**
H1.1: The nature of knowledge positively affects organizational learning among university students.	Supported
H1.2: The sender–receiver relationship positively affects organizational learning among university students.	Supported
H1.3: Knowledge transfer capacity positively affects organizational learning among university students.	Supported
H1.4: Knowledge transfer characteristics positively affect organizational learning among university students.	Supported

XI. CONCLUSION

Within the scope of this research, we aimed to make a modest contribution to the study of factors related to the learning of students in Moroccan public health sciences universities. Our approach sought both to explain and describe, by presenting the main variables related to our research topic, as well as the profile of Moroccan university students. This final section provides a retrospective overview of the research process and offers a general synthesis of the key findings.

From our literature review and empirical study, it is evident that organizational learning must be emphasized, particularly its relationship with knowledge transfer. It is also essential to identify the different configurations of knowledge transfer, to highlight the types, drivers, motivations, and barriers of organizational learning, and to assess their influence on university behavior.

Learning and knowledge transfer are pervasive in Moroccan universities. Organizational learning is integral to university strategies, which primarily aim to develop the competencies and skills of students through knowledge transfer. Universities strive to create relationships, interactions, and connections among all members, reducing hierarchical barriers and fostering a work environment conducive to learning and knowledge sharing.

Successful knowledge transfer requires an overall volume of know-how and expertise, strong interpersonal relationships among members, well-structured work organization, and

favorable organizational and cultural characteristics. Learning is based on the creation, retention, and transfer of knowledge, which confirms that organizational learning in universities relies heavily on the internal dissemination of knowledge.

Finally, knowledge transfer is a critical factor for the success and development of the teacher–student relationship. It plays a decisive role and significantly impacts organizational learning.

The empirical part of our research primarily aimed to validate our theoretical model and test the research hypotheses. To achieve this, structural equation modeling was employed in a comprehensive quantitative analysis, combining both descriptive and explanatory approaches. In this process, we followed a hypothetico-deductive reasoning framework. We selected a relatively large sample to ensure better representativeness. Targeting students from public health sciences universities was essential, as these students possess deep knowledge and insight into learning within their institutions.

Our sample included Moroccan health sciences universities, and a total of 548 questionnaires were distributed and carefully analyzed. This research provided valuable answers to critical questions concerning the factors that enhance the learning of higher education students in Morocco.

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Morocco's International Scientific Cooperation: Participation and Positioning in European Research and Innovation Programmes (Horizon 2020 and Horizon Europe)

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Abstract

International scientific cooperation has become a strategic lever for strengthening the capacity of emerging countries to integrate into the global knowledge and innovation economy. In this context, Morocco has positioned itself as a strategic partner in the Euro-Mediterranean region in the field of research and innovation, particularly through its active participation in the European Union's framework research programmes.

Against this background, the research question of this study is formulated as follows: How does Morocco's participation in European research and innovation programmes reflect its international scientific positioning, and what are the main contributions and challenges for the development of the national research and innovation system?

To address this question, this paper analyses Morocco's scientific positioning within this framework of cooperation, focusing on three main dimensions. First, it examines the level of participation of Moroccan institutions in EU-funded projects in terms of volume, targeted scientific fields, and established partnerships. Second, it explores the strengths and opportunities offered by this cooperation, particularly in terms of capacity building, scientific visibility, and integration into European research networks. Third, it identifies the persistent limitations and challenges related to institutional constraints, governance of the national research system, and the valorisation of research results produced through these collaborations.

Through this analysis, the study aims to highlight the role of international scientific cooperation in Morocco's national strategy for higher education, research, and innovation, while also questioning the country's ability to position itself as a competitive and sustainable actor within the European Research Area (ERA).

This contribution is part of a broader reflection on science diplomacy, considering Morocco's participation in Horizon 2020 and Horizon Europe not only as a lever for academic development, but also as an instrument for international integration and scientific visibility.

Keywords: scientific cooperation; European research programmes; Euro-Mediterranean partnerships; Moroccan research system.

I. Introduction

Scientific research has become a central driver of economic development, innovation, and international visibility. In a context marked by increasing scientific and technological competition, emerging countries are encouraged to strengthen their integration into international knowledge production networks in order to enhance their visibility, consolidate their scientific capacities, and position themselves sustainably within the global knowledge economy.

For Morocco, this dynamic reflects a dual strategic challenge. On the one hand, it involves strengthening internal capacities in research and innovation; on the other hand, it concerns the affirmation of a scientific position within the Euro-Mediterranean space. The country's growing participation in European framework programmes for research and innovation, notably Horizon 2020 and Horizon Europe, illustrates

this orientation towards greater openness and progressive integration into European scientific networks.

Beyond access to financial resources, these programmes constitute structuring instruments of scientific cooperation. They provide Moroccan stakeholders with opportunities for organisational learning, development of institutional partnerships, capacity building, and alignment with international research standards. In this regard, participation in European programmes appears as a lever for scientific visibility and integration into networks of excellence, reflecting a political willingness to open up and converge with Euro-Mediterranean dynamics.

However, while Morocco's participation in international research and innovation programmes has increased over the past decade, the nature and scope of this scientific positioning remain insufficiently analysed from an empirical perspective. The ability to transform participation into sustainable benefits for the national research and innovation system depends on multiple institutional, organisational, and human factors, whose effects remain unevenly documented in the literature.

In this context, this study aims to analyse Morocco's scientific positioning through its participation in Horizon 2020 and Horizon Europe. It is based on a dual approach: first, a review of the literature on international scientific cooperation, science diplomacy, and the internationalisation of research systems; second, a descriptive and comparative analysis of Morocco's participation data in European programmes, in order to characterise cooperation dynamics, key scientific fields, and established partnerships.

By combining these two dimensions, the objective is to better understand the internationalisation dynamics of the Moroccan research and innovation system and to shed light on the place Morocco occupies within Euro-Mediterranean, African, and international scientific networks.

II. Literature Review

A. International scientific cooperation as a vector of scientific positioning

International scientific cooperation has emerged as a structuring dynamic of national research and innovation systems, in a context where knowledge production, circulation, and valorisation are key determinants of competitiveness and development. The knowledge economy relies not only on the accumulation of scientific capital, but also on the ability of actors to interact within transnational networks, access shared infrastructures and skills, and adopt common standards (David & Foray, 2002; Foray, 2004). This progressive internationalisation of research is reflected in the continuous growth of co-publications, inter-institutional collaborations, and the structuring of epistemic communities at the global level (Dong et al., 2017; Wagner et al., 2015).

Beyond access to financial resources, scientific cooperation plays an organisational and institutional role. It contributes to collective learning, the diffusion of research management practices, the adoption of quality and research ethics standards, and the integration of researchers into reputation networks—dimensions commonly associated with scientific visibility and international credibility (OECD, 2013; Tijssen et al., 2012). In an environment increasingly shaped by global challenges such as climate change, health, food security, and energy transitions, transnational cooperation also acts as a driver of interdisciplinarity and innovation by fostering complementarities between heterogeneous scientific systems (UNCTAD, 2024).

In contemporary debates, the OECD highlights that international scientific cooperation is currently being reshaped by geopolitical tensions, concerns related to technological sovereignty, and issues of security and resilience. This context reinforces the importance of empirical analyses aimed at understanding how emerging countries integrate into international scientific networks (OECD, 2025a).

International scientific cooperation can therefore be analysed as both a space of opportunity and constraint, within which non-central countries seek to consolidate their position through strategies of thematic alignment, partnership development, and institutional capacity building.

From this perspective, a country's international scientific positioning can be assessed through empirical indicators such as participation intensity in competitive programmes, diversity and stability of partnerships, thematic specialisation, capacity to engage in excellence-based consortia, and, more broadly, relative position within international research networks. This approach makes it possible to analyse dynamics of integration and visibility without assuming a direct causal impact on the overall performance of the national system.

B. European research and innovation programmes as structuring instruments of cooperation

European framework programmes for research and innovation represent one of the most structured forms of transnational scientific cooperation, combining

competitive funding, quality requirements, multi-actor partnerships, and thematic priorities aligned with major societal challenges. Horizon 2020 (2014–2020), followed by Horizon Europe (2021–2027), were designed as key instruments to strengthen scientific excellence, stimulate innovation, and structure large-scale collaboration networks (European Commission, 2025a).

These programmes are embedded within the broader objective of deepening the European Research Area (ERA), which aims to promote the free circulation of researchers, knowledge, and technologies, and to improve the alignment of research policies across Europe (European Commission, 2024). The implementation of the ERA Policy Agenda 2022–2024 illustrates this dynamic by proposing voluntary actions to enhance the effectiveness and coherence of research and innovation systems (European Commission, 2024).

From the perspective of third countries, Horizon Europe promotes an "open to the world" approach, combined with differentiated eligibility and funding modalities depending on country status (associated countries, low- and middle-income countries, etc.). These arrangements directly influence the ability of non-European institutions to participate, coordinate projects, and derive sustainable benefits from their engagement (European Commission, 2024).

For partner countries in the Southern Neighbourhood, these mechanisms offer both opportunities for integration into international consortia and an institutional learning framework related to complex project management, administrative and financial compliance, and scientific quality standards.

The literature on collaboration networks shows that competitive programmes tend to structure "ecosystems" in which reputation, experience, and relational density play a crucial role in accessing consortia and maintaining regular participation (Wagner et al., 2015). In this context, analysing a country's participation in Horizon 2020 and Horizon Europe amounts to empirically observing its integration trajectories within a highly regulated space, as well as its thematic priorities and dominant partnerships elements fully consistent with the descriptive and comparative approach adopted in this study.

C. Science diplomacy and international cooperation: an analytical framework

The internationalisation of research is increasingly interpreted through the lens of science diplomacy, understood as the use of science, research collaboration, and scientific networks to support foreign policy objectives, cooperation, influence, and the management of global public goods. The typology proposed by the Royal Society and the American Association for the Advancement of Science (AAAS) distinguishes three complementary dimensions: science in diplomacy, diplomacy for science, and science for diplomacy (Royal Society & AAAS, 2010).

Within this framework, participation in transnational programmes such as Horizon may reflect diplomacy for science, when diplomatic frameworks facilitate cooperation, as well as science for diplomacy, when scientific collaboration contributes to trust-building, projection of scientific competence, and non-coercive international positioning (Flink & Schreiterer, 2010). Research on soft power further highlights that scientific reputation and the ability to contribute to global agendas constitute important vectors of influence, particularly for countries seeking to consolidate their position within international networks (Nye, 2004).

More recently, the Royal Society has emphasised that science diplomacy operates in an "era of disruption", characterised by geopolitical polarisation, technological security concerns, competition for talent, and access to research infrastructures. In this context, science diplomacy functions both as a tool for cooperation and as a space of tension, reinforcing the relevance of empirical approaches that document partnership configurations, relational dependencies, and institutional capacities (Royal Society, 2023).

Similarly, Gluckman and colleagues stress the pragmatic dimension of science diplomacy, shaped by practices, intermediary institutions, and incentives embedded in major research programmes (Gluckman et al., 2017; Gluckman, 2022).

From this perspective, analysing a country's positioning through Horizon 2020 and Horizon Europe contributes to understanding science diplomacy "in practice", by showing how cooperation materialises through networks, thematic priorities, and partnerships, rather than remaining at a purely conceptual or normative level.

D. Morocco and Euro-Mediterranean scientific cooperation: state of the literature and research gaps

The literature on Morocco's national research and innovation system highlights efforts towards structuring and internationalisation, while also underlining persistent challenges related to governance, funding, valorisation, and linkages between academic research and the productive sector (Hamidi, 2013; Elkhadri, 2021). Within this trajectory, Morocco's integration into international

cooperation frameworks represents a strategic axis, particularly in the Euro-Mediterranean space, where the European Union plays a central role as a scientific, financial, and institutional partner.

From the perspective of European policies, the European Commission presents Morocco as a bilateral cooperation partner in research and innovation and emphasises that Horizon Europe is "open to the world", with mechanisms allowing the funding of entities established in Morocco under specific conditions (European Commission, 2025b).

This institutional architecture reinforces the relevance of empirical analyses of Moroccan participation, not only to document volumes and thematic areas, but also to characterise Morocco's position within Euro-Mediterranean networks and the evolution of its partnerships.

However, despite valuable contributions on Morocco's innovation system, the literature remains relatively limited in terms of comparative, data-driven analyses of Morocco's scientific positioning through its participation in European framework programmes over a period covering both Horizon 2020 and Horizon Europe. Existing studies often rely on general approaches (reforms, governance, institutional diagnostics), while detailed analyses of collaboration networks, profiles of participating actors, and thematic specialisation linked to Horizon programmes remain underdeveloped.

It is precisely within this gap that the present study is situated. By exploiting official data from the Horizon Dashboard (European Commission, 2026) and combining a descriptive, comparative, and network-oriented analysis, the study empirically documents: (i) the scale of Moroccan participation; (ii) key scientific fields; (iii) institutional profiles of participating actors; (iv) the geographical and relational structure of partnerships; and (v) Morocco's relative position among Southern Neighbourhood, African, and international partner countries. In doing so, it contributes to the literature by offering an empirically grounded analysis of scientific positioning, anchored in theoretical frameworks of scientific cooperation and science diplomacy.

III. Research Objectives and Questions

A. Research interest

International scientific cooperation now occupies a central place in national research and innovation strategies, particularly for emerging countries engaged in the internationalisation of their scientific systems. Beyond access to funding, participation in major international research programmes represents a key vector of scientific visibility, institutional structuring, and integration into global knowledge production networks.

In this context, European framework programmes for research and innovation—especially Horizon 2020 and Horizon Europe—constitute strategic instruments of Euro-Mediterranean scientific cooperation. For Southern Neighbourhood partner countries, and Morocco in particular, these programmes offer multiple opportunities: participation in excellence-based consortia, learning international research management standards, strengthening institutional capacities, and integration into the European Research Area (ERA).

The scientific interest of this study lies in analyzing Morocco's effective positioning within these programmes through an empirical reading based on participation, funding, thematic focus, and partnership data. While several studies address international scientific cooperation from conceptual or institutional perspectives, few provide a structured and comparative analysis of Morocco's role in European research programmes over an extended period covering both Horizon 2020 and Horizon Europe.

Empirically, this research contributes to documenting Morocco's scientific integration dynamics at Euro-Mediterranean, African, and international levels. It also informs debates on science diplomacy by showing how participation in European programmes functions as an instrument of visibility and international positioning beyond strict financial returns.

B. Research problem

Despite Morocco's increasing participation in European research and innovation programmes over the past decade, the nature and scope of its international scientific positioning remain insufficiently analysed from an empirical perspective. While available data indicate sustained Moroccan involvement in several strategic scientific fields, they also raise questions regarding the structure of participation, sectoral distribution, and the country's capacity to secure long-term integration into international research networks.

Accordingly, the research problem does not aim to establish a direct causal relationship between participation in European programmes and the overall performance of the national research system. Rather, it seeks to analyse and characterise Morocco's scientific positioning through its participation in Horizon 2020 and Horizon Europe.

The central research question is formulated as follows:

How is Morocco's participation in Horizon 2020 and Horizon Europe characterised, and what does it reveal about its scientific positioning within Euro-Mediterranean, African, and international cooperation networks?

This problem involves a simultaneous examination of:

- the scale and evolution of Moroccan participation;
- key scientific fields;
- institutional profiles of participating actors;
- partnership dynamics;
- and Morocco's relative position compared to other partner countries.

C. Research questions

To address the central research problem, the study is structured around the following research questions:

- What is the level and evolution of Morocco's participation in Horizon 2020 and Horizon Europe in terms of number of projects, institutional participations, and mobilized funding?
- Which scientific and technological fields show the strongest Moroccan involvement, and how do these fields evolve between the two programmes?
- Which types of institutional actors (universities, research centers, public bodies, private sector) structure Moroccan participation?
- How does Morocco position itself comparatively vis-à-vis Southern Mediterranean, African, and other international partner countries?
- What scientific partnership dynamics emerge from collaboration networks established through European projects?

IV. Methodology

This study adopts a descriptive and comparative approach based on the use of quantitative and documentary secondary data, with the aim of analysing Morocco's scientific positioning in European research and innovation programmes.

A. Data sources

The data used in this study are mainly drawn from:

- the official European Commission platform (Horizon Dashboard: https://dashboard.tech.ec.europa.eu/), which provides detailed information on projects, participations, funding, thematic areas, and collaboration networks ;
- institutional reports of the European Commission related to Horizon 2020 and Horizon Europe;
- national data from the National Centre for Scientific and Technical Research (CNRST) and the Ministry of Higher Education, Scientific Research and Innovation (MESRSI);
- academic and institutional sources (OECD, Union for the Mediterranean, PRIMA) used to contextualise the results.

B. Analytical approach

The analysis is based on three complementary levels:

- Descriptive analysis, aimed at quantifying Moroccan participation in terms of projects, institutional participations, and funding obtained, as well as analysing its temporal evolution.
- Thematic analysis, used to identify dominant scientific and technological fields and to observe continuities and shifts between Horizon 2020 and Horizon Europe.
- Comparative and network analysis, employed to position Morocco relative to other partner countries (Southern Mediterranean, Africa, global level) and to analyse scientific partnership dynamics through collaboration networks.

C. Methodological limitations

It should be noted that this study does not aim to measure the causal impact of participation in European programmes on the overall performance of the national research and innovation system. The results should be interpreted as an analysis of scientific positioning and cooperation dynamics, rather than as a comprehensive evaluation of long-term socio-economic or institutional impacts.

V. Results

The analysis presented in this section aims to highlight the main dynamics of Morocco's participation in the European framework programmes for research and innovation, namely Horizon 2020 (2014–2020) and Horizon Europe (2021–2027). These programmes are the European Union's flagship instruments to support

scientific excellence, foster international cooperation, stimulate innovation, and strengthen technological competitiveness at the global level. For Southern Neighbourhood partner countries, and for Morocco i particular, they represent a strategic opportunity to integrate into the European Research Area (ERA), access expert networks, develop capacities, and enhance the valorisation of scientific results.

Examining data from these programmes makes it possible to capture several dimensions of this cooperation. It sheds light not only on the scale of Morocco's engagement (in terms of number of projects, funding volumes, and profiles of participating institutions), but also on the thematic diversity of intervention areas, Morocco's relative position in the Euro-Mediterranean and African spaces, and the scientific partnership dynamics developed with European countries.

The purpose of this section is therefore to provide an analytical and structured reading of the available results, in order to identify major trends, assess progress achieved, and evaluate the strategic scope of Euro-Moroccan scientific cooperation. The analysis draws on quantitative data from the European Commission's dashboards (Horizon Dashboard), complemented by qualitative elements that help to better understand the effects of this participation on the structuring and visibility of Morocco's national research and innovation system.

A. Morocco's participation in Horizon 2020 and Horizon Europe

i. Number of projects and funding

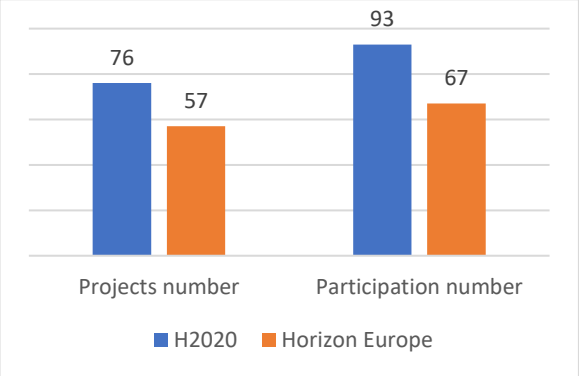

Fig.1: Number of projects and Moroccan participations

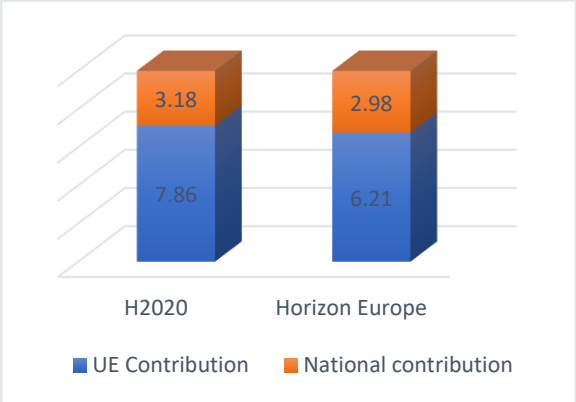

Fig.2: Allocated budget (EUR million)

An examination of the number of projects and Moroccan participations in European research and innovation programmes shows sustained and structurally significant engagement in Euro-Mediterranean scientific cooperation. During Horizon 2020 (2014–2020), Morocco was involved in 76 projects, accounting for a total of 93 participations. Under Horizon Europe (2021–2027), it already records 57 projects and 67 participations. Although the overall number of projects is slightly lower under Horizon Europe at this stage, this trend should be interpreted since the programme is still ongoing, suggesting a continued increase in Moroccan engagement by the end of the period.

These results confirm the growing ability of Moroccan institutions—including universities, research centers, private actors, and NGOs—to join competitive international consortia and meet the technical and scientific requirements of European calls for proposals. The difference between the number of projects and the number of participations also reflects a diversification of partnerships, with some institutions involved in several projects simultaneously.

In terms of funding, the data show that Morocco received a European contribution of EUR 7.86 million under Horizon 2020, complemented by a national contribution of EUR 3.18 million. Under Horizon Europe, the EU contribution reaches EUR 6.21 million, accompanied by national funding of EUR 2.98 million. This evolution indicates sustained financial engagement from both partners and reflects the increasing maturity of Moroccan proposals as well as their alignment with European research and innovation priorities.

Overall, these two indicators suggest Morocco's lasting anchoring within the European Research Area. The growth in institutional participation, combined with the mobilisation of significant European and national funding, confirms the strategic role of

scientific cooperation as a lever for capacity building, technology transfer, and international visibility.

ii. Participant profiles and evolution of Moroccan involvement

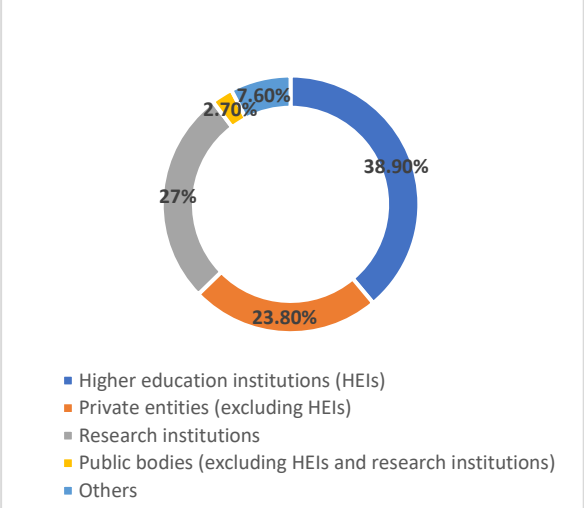

Fig.3: Profile of Moroccan institutions participating in Horizon 2020

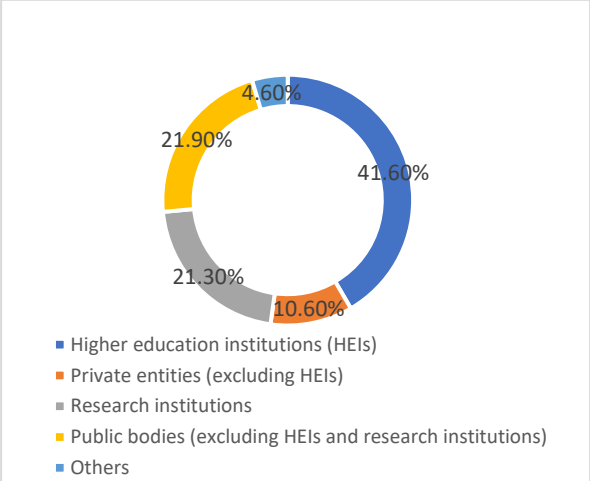

Fig.4: Profile of Moroccan institutions participating in Horizon Europe

An analysis of the profile of Moroccan institutions involved in European research programmes highlights the strong presence of the academic sector in international scientific cooperation. Under Horizon 2020, higher education institutions represent the largest share of participants (38.9%), followed by research institutions (27%) and private entities (23.8%). Participation by public bodies outside universities and research centers remains marginal (2.7%), as does the "other" category (7.6%).

Under Horizon Europe, this trend continues while showing a slight diversification of participating actors. Universities further strengthen their leading role with 41.6% of participation, while research institutions and public bodies record a notable increase (21.3% and 21.9%, respectively). In contrast, private-sector participation falls to 10.6%, reflecting the still limited involvement of Morocco's entrepreneurial sector in European research projects. This evolution highlights both the central role of academia in cooperation dynamics and the need to strengthen bridges with the productive sector, particularly to support innovation and the valorization of research results.

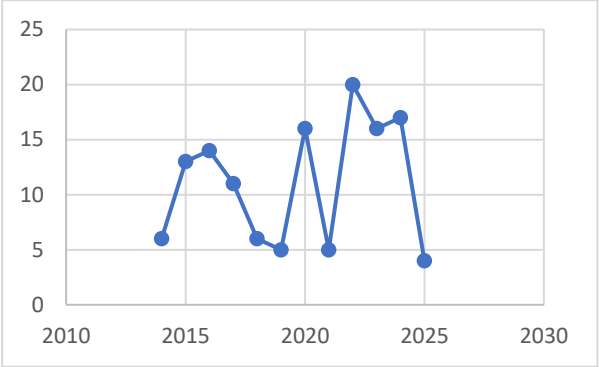

Fig.5: Annual evolution of Moroccan participation in projects

The annual evolution of the number of projects shows significant fluctuations in Moroccan engagement since 2014. After notable growth between 2014 and 2016, participation declines between 2017 and 2019, possibly linked to institutional constraints and specific call cycles. Participation then increases again from 2020, with peaks in 2022 and 2023, reflecting growing maturity among Moroccan actors and better mastery of project preparation and submission procedures. These variations also reflect the emergence of new partner institutions and Morocco's gradual integration into more complex and strategic consortia.

Overall, these results confirm that Moroccan participation remains largely driven by universities and research centres, which are the main vectors of scientific cooperation. However, recent trends suggest a gradual broadening of actor profiles—particularly public institutions—and underline the still under-exploited potential of private actors within the national innovation system. Strengthening the link between academic research and socio-economic needs therefore appears as a strategic challenge for the next phase of participation.

iii. Thematic distribution

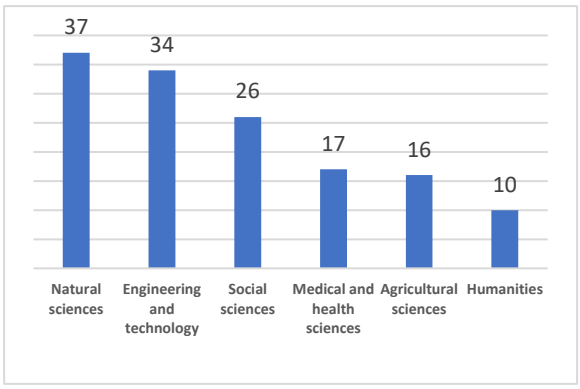

Fig.6: Thematic distribution of projects involving Morocco in Horizon 2020

Fig.7: Concept map of keywords (Horizon 2020) by EuroSciVoc

The thematic distribution of Moroccan projects under Horizon 2020 shows a strong predominance of natural sciences (37 projects) and engineering and technology sciences (34 projects), followed by social sciences (26 projects). Medical and health sciences (17 projects), agricultural sciences (16 projects), and humanities (10 projects) are less represented, yet they still indicate a multidisciplinary participation.

The conceptual map (Euroscivoc) confirms this pattern, showing a strong concentration around agriculture, water management, irrigation, nutrition, and ecosystems. Cross-cutting themes such as governance, civil society, energy transition, and food security are also present. This structure reflects Morocco's alignment with Euro-Mediterranean strategic priorities, particularly in sustainability, climate, and natural resource management.

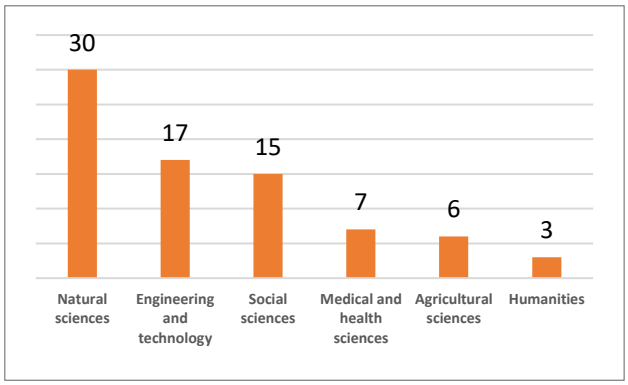

Fig.8: Thematic distribution of projects involving Morocco in Horizon Europe

Fig.9: Concept map of keywords (Horizon Europe) by EuroSciVoc

Under Horizon Europe, the main disciplinary areas remain broadly consistent, while emerging themes become more prominent. Natural sciences and engineering remain central, but the conceptual map shows a rise of new issues such as climate change, ecosystems, human migration, employment, and public health.

Dominant concepts also highlight a growing focus on future-oriented themes: renewable energies (including hydrogen), big data, artificial intelligence, circular economy, health and pandemics, as well as governance and entrepreneurship. This evolution reflects Morocco's gradual integration into the European Union's global priorities, particularly those linked to the green and digital transitions.

A comparison between Horizon 2020 and Horizon Europe leads to two key findings:

- strong continuity around structuring themes such as agriculture, water, ecosystems, and energy—shared priorities between Morocco and the EU;
- notable diversification under Horizon Europe, marked by the emergence of transversal societal issues (migration, employment, governance, artificial intelligence), reflecting

Morocco's adaptation to evolving international scientific agendas.

Overall, this thematic distribution illustrates Morocco's ability to align with European priorities while leveraging its scientific strengths in agriculture, water, and climate-related fields. This dual dynamic contributes to strengthening the country's visibility and its role as a regional pivot in Euro-Mediterranean cooperation.

B. Morocco's comparative positioning in European programmes

i. Comparison with Southern Mediterranean countries

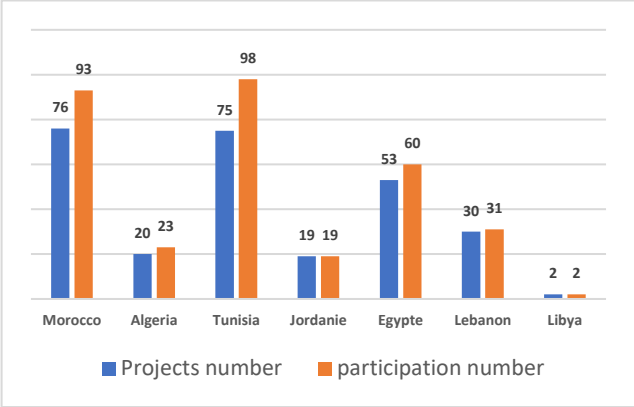

Fig.10: Comparison with Southern Mediterranean countries in Horizon 2020

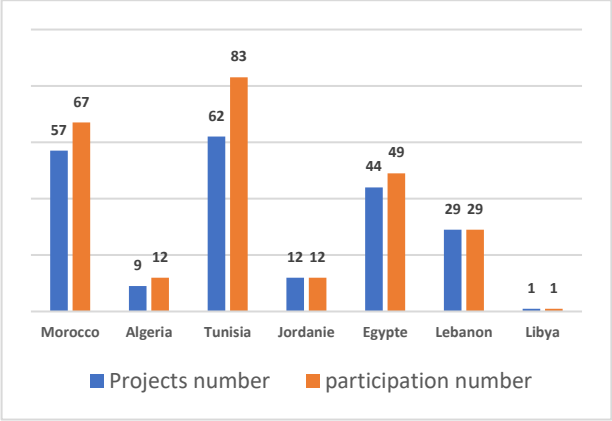

Fig.11: Comparison with Southern Mediterranean countries in Horizon Europe

Comparative analysis highlights Morocco's leading position among Southern Mediterranean partner countries in both Horizon 2020 and Horizon Europe. Under Horizon 2020, Morocco ranks among the top three most involved countries, with 76 projects and 93 participations, slightly behind Tunisia (75 projects, 98 participations) and ahead of Egypt (53 projects, 60 participations). Algeria, Lebanon, Jordan, and Libya show significantly lower levels of engagement.

Under Horizon Europe, a similar pattern is observed. Morocco records 57 projects and 67 participations, consolidating its position among the leading countries alongside Tunisia (62 projects, 83 participations) and Egypt (44 projects, 49 participations). These figures confirm the ability of Moroccan institutions to maintain a high and regular level of involvement and reflect institutional and organisational maturity in managing European projects.

This performance also illustrates Morocco's growing recognition as a strategic partner for Euro-Mediterranean research, able to mobilise competitive consortia and align with EU scientific priorities. It also reflects the effectiveness of national policies supporting research internationalisation, particularly within the ESRI 2030 framework.

ii. Comparison with African countries

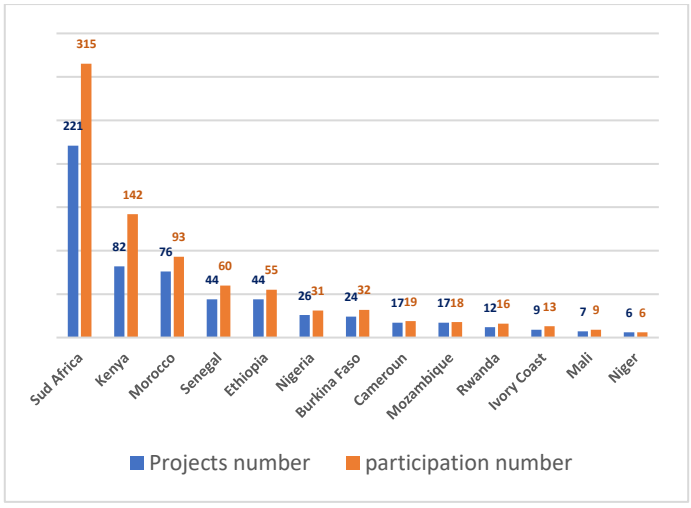

Fig.12: Comparison with African countries in Horizon 2020

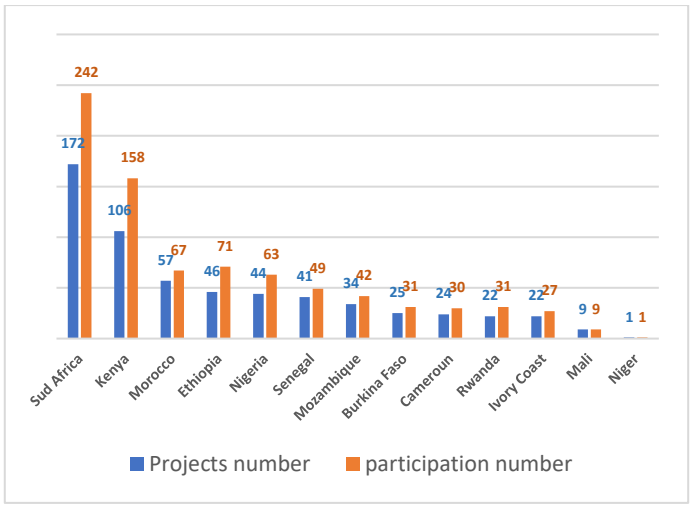

Fig.13: Comparison with African countries in Horizon Europe

At the African level, Morocco ranks among the most active countries in European programmes, although it remains behind two clear leaders: South Africa and Kenya. Under Horizon 2020, Morocco holds the third position in Africa, behind South Africa (221 projects, 315 participations) and Kenya (82 projects, 142 participations), with a total of 76 projects and 93 participations. This position is significant given the country's size, R&D resources, and the relatively recent development of its scientific system compared to the two leading countries.

Under Horizon Europe, Morocco maintains its position among the top three, with 57 projects and 106 participations, behind South Africa (172 projects, 242 participations) and Kenya (106 projects, 158 participations). The gap remains substantial, but it underlines Morocco's potential for progress, particularly by expanding its partnership network and increasing participation in projects with high technological value added.

This positioning strengthens Morocco's role as a regional scientific hub in North Africa and across the continent, acting as an interface between Europe and Sub-Saharan Africa. It also reflects recognition of its institutional capacities, scientific expertise, and strategic alignment with both African and European R&I priorities.

iii. Morocco's positioning at the global level

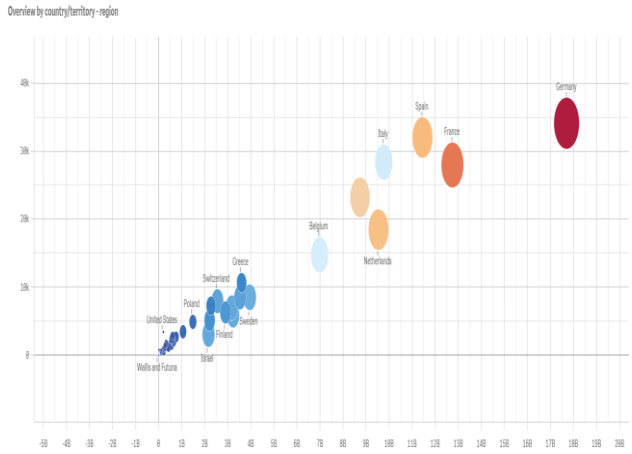

Fig.14: Overview of global participation in Horizon 2020 and Horizon Europe

The global overview of participation in Horizon 2020 and Horizon Europe shows a strong concentration of scientific output and access to funding among industrialised European countries. Major EU Member States, especially Germany, France, Italy, Spain, and the Netherlands, dominate in terms of coordinated projects and allocated budgets. Germany, for instance, stands out with funding above EUR 17 billion, followed by France (around EUR 13 billion) and Spain (nearly EUR 11 billion).

At an intermediate level, several associated or strategic partner countries such as Switzerland, Israel, Poland, and Greece mobilize substantial budgets and participate in many consortia. This hierarchy reflects the maturity of scientific ecosystems, the density of research networks, and the institutional capacity of these countries to design and coordinate complex projects.

Fig.15: Concept map of major global themes by EuroSciVoc

The analysis of dominant scientific concepts in funded projects highlights the diversification of research priorities globally. The most represented themes relate to ecosystems, climate change, economic models, artificial intelligence, machine learning, renewable energies, and the circular economy.

Emerging topics such as sensor technologies, proteins and enzymes, molecular biology, robotics, the Internet of Things, and precision medicine also occupy a significant place. This thematic distribution reflects evolving priorities towards multidimensional global challenges, where environmental, technological, economic, and health issues are interconnected. It also underlines the growing importance of interdisciplinary approaches in international research policies.

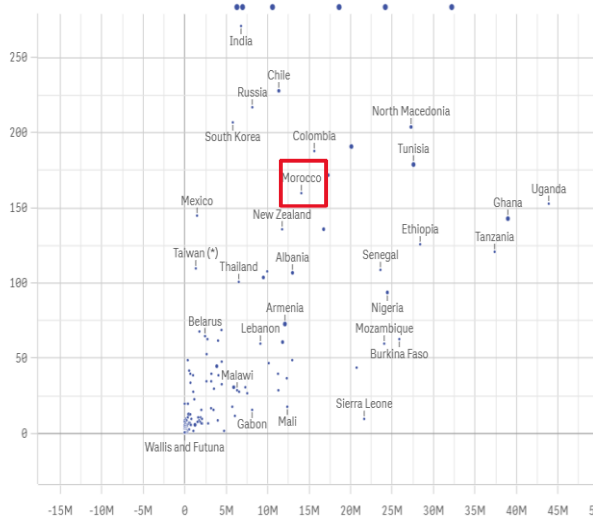

Fig.16: Morocco's positioning in relation to the rest of the world

The third graph illustrates Morocco's position among third countries and international partners participating in European programmes. While Morocco remains far behind global leaders in terms of project numbers and funding obtained, it falls within an intermediate group of emerging countries, alongside Tunisia, Colombia, Mexico, and New Zealand.

With more than 150 cumulative participations across Horizon 2020 and Horizon Europe, Morocco stands out as one of the most dynamic African and Mediterranean countries in international scientific cooperation. This position reflects a growing potential for collaborative research and an enhanced ability to integrate into competitive international consortia. However, the significant gap with major scientific powers highlights the need to continue strengthening the national research system, particularly regarding funding levels, valorisation mechanisms, and private-sector involvement.

Overall, these data confirm that Morocco is increasingly recognised as a credible scientific actor internationally, even though it has not yet reached the performance levels of major research countries. Its intermediate position reflects an upward trajectory and substantial growth potential, especially if it succeeds in strengthening institutional capacities, widening strategic partnerships, and investing further in R&D.

This dynamic opens promising perspectives: in the medium term, Morocco could become a regional scientific hub, acting as a bridge between Europe, Africa, and the Arab world, and contributing actively to major global challenges such as the energy transition, food security, environmental sustainability, and technological innovation.

Although the United States, China, Japan, and South Korea are among the world leaders in research and development, their presence remains marginal in Horizon participation rankings. This situation can be explained by several complementary factors:

- Non-associated status: these countries are not officially associated with Horizon 2020 or Horizon Europe. They may participate in certain projects but are generally not eligible for direct European Commission funding, which limits their number of participations.
- Targeted and bilateral partnerships: their contribution often takes place through bilateral cooperation projects or thematic joint initiatives (e.g., energy, health, artificial intelligence), rather than broad participation across all European calls.
- Priority given to national programmes: these countries have powerful national research programmes, such as the National Science Foundation (NSF) and the NIH in the United States, the National Natural Science Foundation of China (NSFC), and the Japan Science and Technology Agency (JST), which concentrate most funding and collaborations.
- Indicators focused on associated and strategic partners: European reporting mainly highlights EU Member States, associated countries, and priority partners within EU research and innovation policy.

Therefore, their low visibility in the graphs does not reflect weak scientific performance, but rather a different cooperation model that is less institutionalised within Horizon Europe. This highlights the specificity of the European programme, which primarily aims to strengthen the European Research Area while remaining open to targeted strategic partners.

C. Morocco's international scientific collaboration dynamics

i. Collaboration links in Horizon 2020

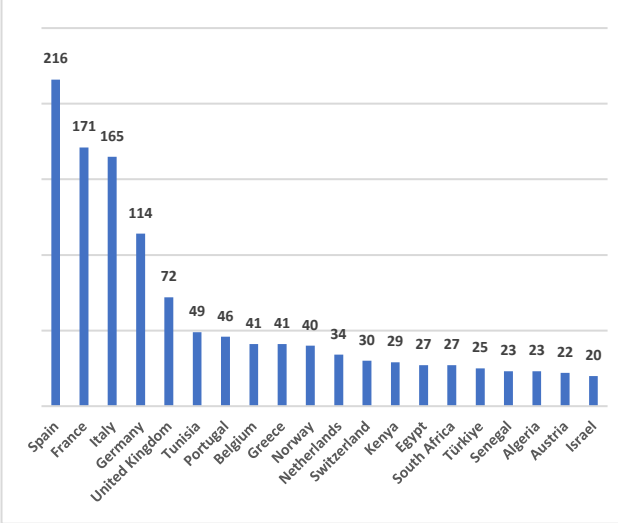

Fig.17: Top partner countries for Morocco in Horizon 2020

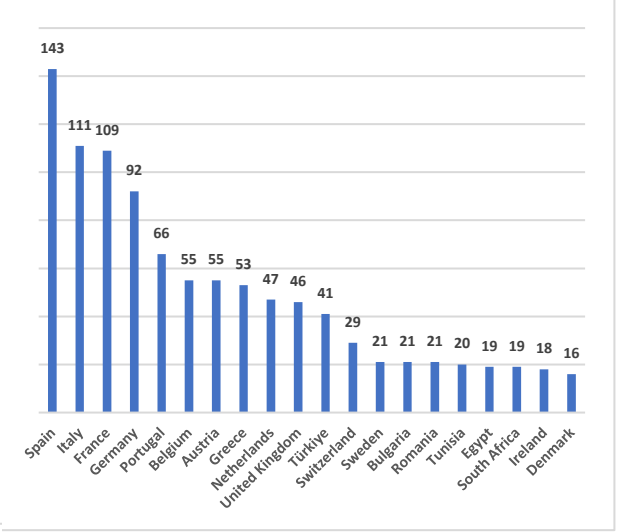

Fig.19: Top partner countries for Morocco in Horizon Europe

Fig.18: Collaboration map in Horizon 2020

The analysis of collaboration links established by Moroccan institutions under Horizon 2020 reveals a strong concentration of partnerships with European countries, confirming the central role of the European Union in driving international scientific cooperation. The data show that Morocco's main partners are Spain (216 collaborations), France (171), Italy (165), and Germany (114). These four countries, among the most active in the programme, account for more than half of Morocco's collaborations, reflecting solid historical, linguistic, and scientific ties.

A significant presence is also observed for other Member States such as the United Kingdom, Portugal, Belgium, and Greece, which actively contribute to joint projects. The presence of Southern partners particularly Tunisia, Egypt, Kenya, and South Africa, indicates an emerging South–South dynamic, especially in areas related to agriculture, water management, and environmental sustainability.

The collaboration map confirms Morocco's geographical and strategic centrality within these networks. The country appears as a connection node linking Europe to Africa and, to a lesser extent, other regions of the world. This intermediary position reflects not only the ability of Moroccan institutions to integrate into competitive international consortia, but also their growing role in building triangular partnerships between Europe, the Mediterranean, and Africa.

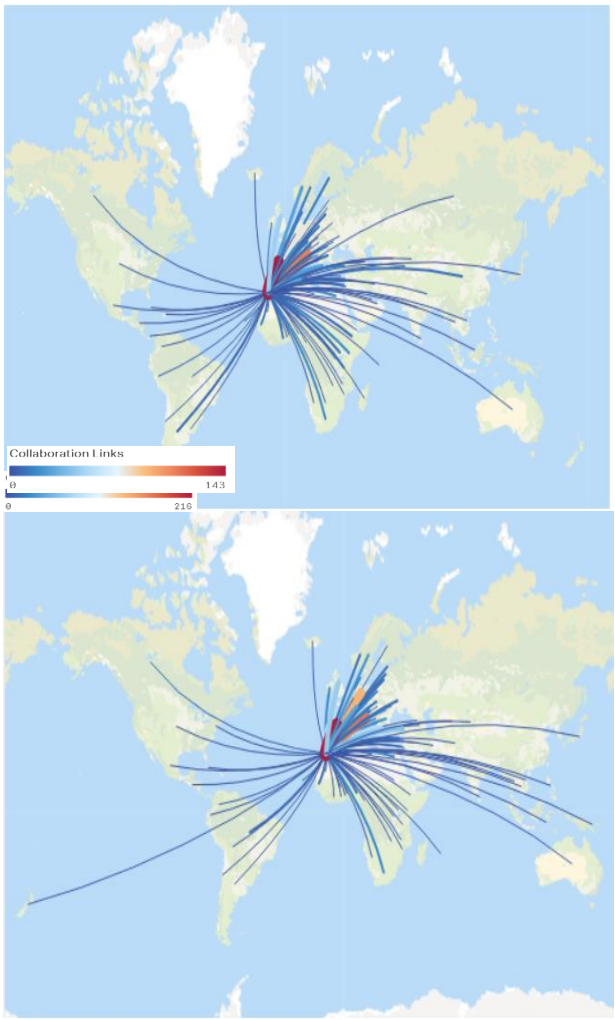

Fig.20: Collaboration map in Horizon Europe

ii. Collaboration links in Horizon Europe

Under Horizon Europe, partnership structures remain broadly stable, although some notable changes can be observed. Spain remains Morocco's main partner (143 collaborations), followed by Italy (111), France (109),

and Germany (92). These four countries continue to form the pillars of the Euro-Moroccan scientific network, reflecting continuity in academic relationships developed over the previous decade.

However, the circle of partners is gradually expanding, with increased involvement of countries such as Austria, Turkey, the Netherlands, and Greece. This diversification reflects openness towards new thematic networks, particularly in the areas of digital transition, artificial intelligence, and sustainable technologies. It also illustrates the growing prominence of multi-party consortia including public, private, and academic partners.

The mapping of collaboration links in Horizon Europe reinforces these observations. Morocco increasingly emerges as a pivotal actor in knowledge flows, consolidating its position in the Euro-Mediterranean space while strengthening connections with Sub-Saharan Africa, Latin America, and parts of Asia. This geographical expansion of partnerships opens new opportunities for collaborative research and supports the internationalisation of the national research and innovation system.

Overall, the data show that Morocco's scientific cooperation remains strongly anchored in Europe, with a clear predominance of partnerships with Southern and Western European countries. This concentration reflects strong historical, cultural, and institutional ties, as well as a deliberate strategy of integration into the European Research Area.

At the same time, the broadening of partnerships beyond the European core, especially towards African, Mediterranean, and extra-European countries, illustrates an evolving Moroccan science diplomacy that is more open and strategic. This dynamic positions Morocco as a scientific connector across several geographical and thematic spaces, acting as a bridge between Europe, Africa, and the Arab world. To further strengthen this position, it will be essential to increase private-sector involvement in collaborations, enhance the valorisation of joint research results, and sustain strategic partnerships beyond the duration of funded projects.

VI. Conclusion

This study analysed Morocco's scientific positioning through its participation in the European research and innovation programmes Horizon 2020 and Horizon Europe, using a descriptive and comparative approach based on secondary data from official European Commission sources. The objective was not to measure the causal impact of these programmes on the overall performance of the national research system, but rather to characterise the participation dynamics, partnership patterns, and thematic specialisation that structure Morocco's international integration.

The results show that Morocco's participation in European programmes follows a trajectory of progressive and structured integration into the European Research Area. This integration is reflected in regular involvement in collaborative projects, a concentration on strategic scientific fields aligned with both European priorities and national sustainable development challenges, and a solid anchoring in Euro-Mediterranean cooperation networks. Morocco therefore emerges as a credible regional scientific actor, able to mobilise long-term partnerships and participate in competitive international consortia.

Comparative analysis also indicates that Morocco occupies a leading position among Southern Mediterranean countries and ranks among the most active African participants in European research and innovation programmes. This relative positioning strengthens its role as a scientific bridge between Europe, Africa, and the Arab world, and reflects a certain level of institutional maturity in managing international research projects. However, the gap that remains with major global scientific powers highlights structural limitations of the national system, particularly in terms of research funding, valorisation of results, and private-sector involvement.

Beyond quantitative indicators, this participation can be interpreted as an instrument of science diplomacy. By embedding itself sustainably within European research networks, Morocco mobilises scientific cooperation as a lever for international visibility, institutional recognition, and scientific soft power. This dimension gives Horizon programmes a strategic scope that goes beyond academic research, contributing to Morocco's international positioning in a context of increasing competition for resources, talent, and knowledge networks.

Nevertheless, the sustainability of this trajectory will depend on the capacity of the national research and innovation system to consolidate its achievements. Strengthening linkages between academic research and innovation, expanding private-sector participation, diversifying partnerships beyond the European core, and establishing effective valorisation mechanisms appear as key conditions for turning international scientific cooperation into a long-term development lever.

Ultimately, Morocco's participation in Horizon 2020 and Horizon Europe reflects an ongoing process of openness and consolidation of international scientific positioning. While this trajectory demonstrates strong potential, it calls for deeper strategic reflection on public research and innovation policies in order to

strengthen the structural impact of scientific cooperation and position Morocco sustainably among emerging scientific actors on the international stage.

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AI and Information Systems Governance: Towards a Revision of Traditional Frameworks

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Abstract—

The widespread adoption of artificial intelligence (AI) in organizations—estimated at 50% according to the McKinsey Global Institute (2023) [1]—is profoundly transforming information systems (IS) and their governance mechanisms. While traditional frameworks such as COBIT [2], ITIL [3], or ISO standards [4][5] provide robust foundations, they reveal significant limitations when confronted with AI-specific challenges, including the lack of integration of ethical dimensions [6][7][8], insufficient explainability of algorithmic decisions [9][10], unclear accountability in case of failure [11][12], and governance cycles too slow to keep pace with the exponential rate of innovation [13].

As emphasized by Floridi, Cowls, and Taddeo (2023) [17], European AI governance now places stronger emphasis on transparency, traceability, and algorithmic accountability, complementing traditional frameworks such as ISO and COBIT. Recent trends identified by Gartner (2024) [18] also confirm that organizational maturity in AI governance depends on the ability to automate compliance and to embed continuous feedback loops within management frameworks.

To analyze these issues, this research combines an extensive review of academic and professional literature with case studies of two multinational organizations: Amazon, which faced gender bias in its recruitment system [14], and Apple Card, in partnership with Goldman Sachs, which encountered bias in its credit scoring models [10][15]. The analysis highlights that current frameworks are insufficient to manage AI-specific risks and require adjustments at strategic, tactical, and operational levels.

The main contribution of this study lies in proposing a hybrid governance model integrating innovative mechanisms—such as the fusion of IS/AI governance committees, AI centers of excellence, and MLOps practices [16]—to ensure a more agile, transparent, and ethical governance approach.

Keywords—**Artificial Intelligence; IT Governance; Frameworks; Algorithmic Ethics; COBIT; Organizational Transformation.**

XII. INTRODUCTION

Artificial intelligence (AI) is now emerging as a major driver of organizational transformation, with an estimated adoption rate of 50% among companies according to McKinsey (2023) [1]. Its integration into areas such as finance, logistics, and human resources is reshaping information systems (IS) and putting their governance mechanisms to the test [3][6][7].

Traditional frameworks—COBIT [2], ITIL [3], and ISO standards [4][5]—provide a solid foundation but reveal significant limitations when confronted with the specificities of AI: insufficient integration of ethical dimensions [6][8], difficulties in explaining complex models [9][10], unclear responsibilities in the event of failure [11][12], and evolution cycles that are too slow [13][16]. As shown by Floridi, Cowls, and Taddeo (2023) [17], European AI governance now emphasizes transparency, traceability, and algorithmic accountability, thereby complementing traditional frameworks such as ISO and COBIT.

Recent trends identified by Gartner (2024) [18] confirm that organizational maturity in AI governance depends on the ability to automate compliance and integrate continuous feedback loops into management frameworks.

The cases of Amazon and Apple Card, marked by algorithmic biases in recruitment and credit allocation respectively [14][10][15], provide concrete illustrations of these shortcomings. This raises the central question: how can IS governance frameworks be adapted to maximize the value of AI while effectively managing its risks?

XIII. CONTEXT AND PROBLEM STATEMENT

AI now represents a lever of organizational transformation comparable to the advent of the Internet in the 1990s or cloud computing in the 2010s [3][6]. It is being integrated into a wide range of business processes—logistics, finance,

healthcare, and human resources—profoundly reshaping information systems (IS) governance [1].

However, this accelerated diffusion gives rise to specific risks:

• Bias and discrimination in automated decision-making [14][10].

• Opacity of models, making explainability difficult [9].
• Grey areas regarding responsibility in the event of system failure [11][12].

• A mismatch between the rapid evolution of technologies and the slow pace of normative and regulatory processes [13][16].

As a result, the central question becomes: how can IS governance frameworks be adapted to capture the value of AI without suffering from its ethical, technical, and legal pitfalls? [6][7][16].

As demonstrated by Floridi, Cowls, and Taddeo (2023) [17], European AI governance now places emphasis on transparency, traceability, and algorithmic accountability, thereby complementing traditional frameworks such as ISO and COBIT.

XIV. METHODOLOGY

III.1 LITERATURE REVIEW

An in-depth analysis of academic and professional contributions was conducted:

• **Academic research** (Brynjolfsson & McAfee [3], Jobin et al. [6], Raji et al. [10]) on the organizational and ethical impacts of AI. As shown by Floridi, Cowls, and Taddeo (2023) [17], European AI governance now emphasizes transparency, traceability, and algorithmic accountability, complementing traditional frameworks such as ISO and COBIT.

• **Institutional publications** (Accenture [9], OECD [7], UNESCO [8]) highlighting responsible governance and emerging regulation (AI Act [12]). The World Economic Forum (2024) [20] also stresses that AI governance must be supported by global audit and transparency frameworks, while the European Data Protection Board (2025) [19] emphasizes the compatibility between data protection and algorithmic governance.

III.2 CASE STUDIES

To concretely illustrate the limitations of governance frameworks when confronted with the specificities of AI, two emblematic cases were analyzed: Amazon and Apple Card.

III.2.1 AMAZON – GENDER BIAS IN RECRUITMENT

In 2018, Amazon abandoned a machine-learning-based recruitment tool after discovering that it systematically penalized female candidates in technical fields [14]. The algorithm, trained on historical data dominated by male profiles, reproduced and amplified gender discrimination.
• **Ethical risk:** violation of the principle of equal opportunity, negatively affecting diversity and inclusion.
• **Organizational risk:** loss of credibility and reputational damage, with Amazon heavily criticized for failing to anticipate bias.
• **Link to IS governance:** absence of algorithmic auditability mechanisms in traditional frameworks (COBIT, ITIL) [2][3], which do not explicitly address bias detection and correction.

III.2.2 APPLE CARD – BIAS IN CREDIT SCORING

Apple Card faced bias in its credit-scoring models, disadvantaging certain customer categories [10][15][15]. These biases, stemming from socio-economic data, called into question the fairness and transparency of the decision-making process.

• **Regulatory risk:** potential non-compliance with anti-discrimination and consumer protection regulations [12].

• **Technical risk:** difficulty in explaining decisions made by complex algorithms, particularly those based on neural networks [9].

• **Strategic risk:** loss of customer trust, potentially affecting long-term banking relationships and institutional reputation.

• **Link to IS governance:** ISO standards [4][16], while effective in clarifying governance responsibilities, remain too generic to address opacity and shared responsibility between humans and AI.

III.2.3 SYNTHESIS

These two cases demonstrate that the risks identified in the literature—algorithmic bias [14][6], insufficient explainability [9][10], and grey areas of responsibility [11][12]—are already materializing in practice. before need for more dynamic and ethical governance, capable of anticipating and correcting AI-related deviations before they produce large-scale negative effects. As shown by Floridi, Cowls, and Taddeo (2023) [17], European AI governance now emphasizes transparency, traceability, and algorithmic accountability, complementing traditional frameworks such as ISO and COBIT.

III.3 KEY FINDINGS

The combined analysis of the literature review and case studies reveals four major limitations of traditional frameworks when applied to AI systems:

III.3.1 ETHICS AND ACCOUNTABILITY

Established frameworks such as COBIT [2] and ISO 38500 [4] emphasize control, compliance, and strategic alignment, but they do not explicitly provide mechanisms to integrate principles of algorithmic ethics (fairness, non-discrimination, respect for human rights) [6][7][8]. This gap creates a normative vacuum: if an algorithm reproduces bias, there is no clear internal process to identify and correct it. The Amazon case [14] illustrates this limitation, as the absence of ethical tools embedded in governance led to the deployment of a discriminatory system, directly affecting the fairness of recruitment processes. As shown by Floridi, Cowls, and Taddeo (2023) [17], European AI governance now emphasizes transparency, traceability, and algorithmic accountability, complementing traditional frameworks such as ISO and COBIT.

III.3.2 EXPLAINABILITY AND AUDITABILITY

Frameworks such as ITIL [3] and ISO 38500 [4] define quality and auditability processes for IT services, but they are not designed to manage opaque AI models, particularly deep neural networks [9][10][15]. This makes it extremely difficult to explain algorithmic decisions to users or regulators. The Apple Card case [10][15][15] illustrates this challenge: despite structured IT governance, Apple was unable to provide clear explanations of its scoring model's logic, fueling distrust among customers and regulatory authorities.

III.3.3 RESPONSIBILITY AND LIABILITY

Current standards define general responsibilities (e.g., ISO 38500 [4]) but do not specify who should be held accountable when an AI-driven decision causes harm: the algorithm designer, the data team, IT management, or the organization as a whole [11][12]. This grey area weakens governance. In Apple's case, when customers challenged credit-scoring decisions, it was difficult to identify the true party responsible—the tool, the technical team, or senior management [10]. This legal and organizational uncertainty exposes companies to significant reputational and financial risks.

III.3.4 OVERLY SLOW EVOLUTION CYCLES

Recent trends identified by Gartner (2024) [18] confirm that organizational maturity in AI governance depends on the ability to automate compliance and integrate continuous feedback loops into management frameworks. ISO and ITIL frameworks rely on lengthy update and standardization processes, sometimes spanning several years [13][16]. By contrast, AI models evolve on much faster cycles, sometimes within months. This mismatch creates misalignment between the pace of technological innovation and the adaptability of governance mechanisms. In the Amazon case, the recruitment tool generated bias before corrective governance measures could be implemented. The slowness and rigidity of frameworks prevented a proactive response, exacerbating ethical and reputational consequences.

III.4 ANALYTICAL SYNTHESIS

These shortcomings show that traditional frameworks, while effective for managing conventional information systems, are insufficient to address the challenges specific to AI. Amazon illustrates the ethical and reputational risks associated with the absence of bias control, while Apple highlights issues of transparency, fairness, and accountability. Taken together, these cases underscore the need for more agile, explainable, and accountability-driven governance capable of keeping pace with rapid technological change and preventing societal harm.

XV. METHODOLOGY

Table 1: Strengths, Limitations, and Proposed Adaptations of Major Governance Frameworks in the Context of AI

Framework	Strengths	Limitations in the Face of AI	Proposed Adaptations
COBIT 2019 [11]	Strategic/IS alignment, value management	Does not address bias and ethics [5][15]	Merging IS/AI committees [18], ethical indicators
ITIL 4 [13]	Service management, continuous improvement	Cycles too slow, lack of explainability [1][7]	Extension toward MLOps [19], AI auditability
ISO/IEC 38500 [12]	Clarifies governance responsibilities	Too generic, insufficient for AI-related risks [10]	Integration of the AI Act [10], human/AI accountability
ISO/IEC 23053 [19]	Framework for managing AI systems	Insufficient ethical and organizational coverage [5]	AI Centers of Excellence [9], standardized audits
IEEE 2857/2863 [17][18]	AI governance, privacy	Limited adoption, weak IS integration	COBIT/ITIL harmonization, ethical KPIs

The table highlights that while traditional governance frameworks provide strong structural foundations, they require significant adaptation to address the ethical, technical, and organizational challenges introduced by artificial intelligence.

CRITICAL ANALYSIS

The comparative review highlights several key insights:

1. No comprehensive coverage of AI challenges
Each framework contributes a useful dimension (control with

COBIT, quality with ITIL, clarification of responsibilities with ISO 38500, technical management with ISO 23053, ethics and privacy with IEEE). However, none of them individually addresses the full range of AI-related issues: bias, explainability, accountability, and rapid innovation cycles.

2. An imbalance between technical and ethical approaches

ISO and ITIL frameworks primarily focus on organizational and technical aspects (quality, processes, service management), whereas emerging frameworks such as IEEE place greater emphasis on privacy and ethics. This imbalance creates a risk of fragmented practices if organizations fail to effectively articulate and integrate these approaches.

3. Slow adaptation to the rapid cycles of AI

Historical frameworks (COBIT, ITIL, ISO 38500) rely on lengthy update processes. Yet AI technologies evolve within months. This mismatch prevents governance mechanisms from keeping pace and increases the risk of harmful outcomes before corrective measures can be implemented.

4. Emerging initiatives still limited

IEEE standards and ISO/IEC 23053 represent a significant step toward AI-adapted governance, but their adoption remains embryonic. Their integration with traditional frameworks is still weak, hindering the development of a coherent and universal governance framework.

Conclusion of the Comparative Analysis

The World Economic Forum (2024) [20] also emphasizes that AI governance must be supported by global audit and transparency frameworks, while the European Data Protection Board (2025) [19] stresses the compatibility between data protection and algorithmic governance.

This study confirms that while each framework represents a piece of the puzzle, none provides a complete solution to the challenges posed by AI. This justifies the proposal of a hybrid governance model, combining the structural robustness of existing frameworks with new mechanisms (algorithmic ethics, explainability, agile cycles, and ethical performance indicators). Such a model should also promote normative interoperability between established standards (COBIT, ITIL, ISO) and emerging ones (IEEE, AI Act), in order to ensure more coherent and resilient governance. As shown by Floridi, Cowls, and Taddeo (2023) [17], European AI governance now emphasizes transparency, traceability, and algorithmic accountability, complementing traditional frameworks such as ISO and COBIT.

V. CONTRIBUTIONS

V.1 THEORETICAL CONTRIBUTION

This research proposes an extension of traditional governance frameworks to integrate the specificities of artificial intelligence. The approach is designed as a multi-level model (strategic, tactical, and operational), enabling coverage of global steering needs, organizational implementation, and the technical management of AI systems.

V.1.1 STRATEGIC LEVEL: TOWARD INTEGRATED AND RESPONSIBLE GOVERNANCE

At the highest level, this study recommends merging IS and AI governance committees. This integration makes it possible to move beyond a siloed view of technology and governance and to establish a holistic approach aligning:
• the organization's strategic objectives with AI use cases;
• value creation (innovation, competitiveness, efficiency) with societal responsibility (ethics, sustainability, inclusion) [16];
• proactive consideration of reputational and regulatory risks, particularly with the entry into force of the European AI Act.

This integrated governance addresses the need to ensure that AI is not merely an optimization tool, but also a vector of trust and legitimacy for internal and external stakeholders.

V.1.2 TACTICAL LEVEL: INSTITUTIONALIZING AI GOVERNANCE

At the organizational level, the study proposes the creation of an AI Center of Excellence within the IT department. Its mission is twofold:

1. **Standardization and compliance:** ensuring compliance with emerging regulations (AI Act [12], IEEE standards [16]) and recognized governance principles (ISO, COBIT).
2. **Development of internal capabilities:** training employees, raising awareness of algorithmic bias and ethical issues, and fostering an organizational culture of digital responsibility [9].

This center would act as a bridge between corporate strategy and operational teams, facilitating the adoption of consistent practices and avoiding fragmented approaches.

V.1.3 OPERATIONAL LEVEL: MANAGING THE AI MODEL LIFECYCLE

Finally, at the technical level, the study recommends adopting MLOps (Machine Learning Operations) practices. Inspired by DevOps methods, this model aims to:

• integrate AI model management into continuous development, deployment, and monitoring cycles [5];

• ensure traceability and auditability of models throughout their lifecycle (from training to production updates);

• enable greater responsiveness to the rapid evolution of algorithms and regulatory contexts.

The integration of MLOps directly addresses the limitations of traditional frameworks, particularly their slow adaptability and lack of continuous model monitoring.

V.2 INTEGRATIVE AND EVOLUTIONARY CONTRIBUTION

The added value of this contribution lies in its ability to articulate three complementary levels of governance, thereby combining:

• strategic vision (alignment, responsibility, legitimacy);
• tactical organization (structures, skills, compliance);
• operational efficiency (dynamic and ethical management of AI models).

This multi-level model provides an evolutionary framework capable of strengthening the robustness and legitimacy of governance systems while integrating the disruptive specificities of AI.

VI. LIMITATIONS AND FUTURE RESEARCH

VI.1 LIMITATIONS

• **Sectoral scope:** the study covers technology, banking, and logistics, but not healthcare or public administration, where issues such as confidentiality and social equity are critical [7].

• **Regulatory maturity:** the European AI Act [12] is still being deployed, making it difficult to assess its real impact.

• **Limited adoption of emerging standards:** IEEE 2857/2863 [15][16] are not yet widely adopted.
• **Speed of evolution:** governance frameworks risk becoming obsolete if AI continues to evolve faster than normative processes [13].

VI.2 FUTURE DIRECTIONS

• Extend the analysis to critical sectors (healthcare, education, strategic industries, public administrations).

• Explore the coexistence of AI with other disruptive technologies (quantum computing, blockchain).

• Develop ethical performance indicators integrated into existing frameworks.

• Empirically test the effectiveness of hybrid approaches through pilot projects.

• Promote normative interoperability between traditional frameworks and emerging standards [15][16][16].

VII. CONCLUSION

The World Economic Forum (2024) [20] also emphasizes that AI governance must be supported by global audit and transparency frameworks, while the European Data Protection Board (2025) [19] stresses the compatibility between data protection and algorithmic governance.

Information systems governance is at a strategic turning point in the face of the massive rise of artificial intelligence. Traditional frameworks such as COBIT, ITIL, and ISO [2][4][3], while providing a solid foundation, do not fully address AI-specific challenges, particularly ethics, transparency, and rapid evolution [6][10][12]. As shown by Floridi, Cowls, and Taddeo (2023) [17], European AI governance now emphasizes transparency, traceability, and algorithmic accountability, complementing traditional frameworks such as ISO and COBIT.

This study demonstrates that only a hybrid, multi-level approach can meet these challenges. At the strategic level, merging IS and AI committees aligns performance, innovation, and societal responsibility. At the tactical level, establishing an AI Center of Excellence within the IT department ensures regulatory compliance and skills development [9][12][15]. At the operational level, adopting MLOps practices guarantees comprehensive and transparent management of the AI model lifecycle [16].

This model not only provides a framework for steering and control but also transforms AI into a lever for sustainable value creation and societal trust. By combining rigor, agility, and ethical integration, IS governance can anticipate and mitigate risks while maximizing innovation.

Future evolution must remain dynamic and sector-specific, capable of adapting to new regulations, emerging technical standards, and disruptive technologies. This transformation paves the way for responsible, high-performing, and sustainable governance, in which AI becomes a reliable and ethical driver of innovation. The World Economic Forum (2024) [20] also emphasizes that AI governance must be supported by global audit and transparency frameworks, while the European Data Protection Board (2025) [19] stresses the compatibility between data protection and algorithmic governance.

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Leveraging AI in Human Resources: Strategic alliance through the lens of change

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Abstract*— With artificial intelligence, companies are accelerating their pace of digitalization, and human resources are one of the departments most affected by this change. Human resources management is entering a new era, not only impacted by but also redefining its position within companies. Today, the HR function is no longer what it was (managing administrative tasks) but has become a strategic partner for companies (planning the future of the company). This article focuses on the notion of change management and the new role of human resources as a strategic actor within the company. This study is based on an exploratory qualitative methodology. The research analyzes recent scientific literature in depth to identify trends in this field, best practices, and major challenges. The research thoroughly analyses recent scientific literature to identify trends in this field, best practices, and major challenges. The results of this article demonstrate that without the support of the HR function, organizational change projects cannot be completed without failure. Because the problem does not lie solely in the adoption of technology itself, but rather in the acceptance of these technologies by employees, this is where we talk about the indispensable strategic role of the HR function.

***Keywords*— Artificial intelligence, Human resources management, change management, resistance.**

XVI. INTRODUCTION

The current economic environment, recognized by its volatility and increased complexity, the integration of artificial intelligence in companies today goes beyond the idea of simply implementing a technological tool, but it is a profound change that affects both the culture and the structure of a company. The adoption of artificial intelligence reshapes the role of each employee within the organization; in other words, artificial intelligence is a force that makes certain professions and skills appear and disappears others. The success of this digital transformation depends not only on the technology itself, but also on the ability of human resources to supervise and guide this change project. At the heart of organizational transformations, the human resources function is positioning itself as a strategic partner. The study by (Sheokand Rashmi Associate Professor, 2024) examines the importance of HR management in harmonizing talent during structural change. Following the methods of ADKAR (Hiatte), a diagnostic tool that focuses more on individuals and enables HR to understand employees' doubts and accompany them to accept change, and Kotter, a practical guide to ensure that companies don't lose direction despite the storms (changes). Change is not a choice but a condition for sustainability in a volatile economic environment. Research by (El-Dirani et al., 2019) points out that the HR function is at the heart of restructuring; by mobilizing critical steering resources, it goes beyond the operational dimension to become the conductor of a fluid and permanent transition. The authors (NEJJAR & DAGHRI, 2023a) point out that today, HR is seen as an indispensable strategic compass that steers the success of the structure in the face of rapid changes

in the global environment. And not just as a support function that manages staff. The objective of this research is to answer the following question: How artificial intelligence can help human resources to manage the risks of change? The study is based on solid theoretical foundations of existing literature reviews dealing with the same subject, with the aim of understanding the best HR solutions to manage change risks and subsequently creating a theoretical model for managing HR risks using artificial intelligence. This article offers an enriched theoretical vision on the contribution of artificial intelligence in managing organizational change risks. Deduce that artificial intelligence is an external factor that influences the way in which the organization works. This article is structured as follows: after the introduction, the second section which deals with the The fundamentals of change management , the third section addresses the strategic role of human resources in the company and especially in change management, the fourth section highlights the contribution of artificial intelligence in organizational change management and finally a small conclusion.

II. THE FUNDAMENTALS OF CHANGE MANAGEMENT :

This chapter examines the theoretical underpinnings and important phases of change management, which can help organizations to better transform themselves.

A. *The theoretical foundations of change management:*

Organizational change management (OCM) has become an essential part of corporate policy for companies wishing to remain competitive and sustainable in increasingly unstable environments. Far from being a secondary concern, OCM is now recognized as an essential factor in the success or failure of transformation initiatives. As (Lojić & Đurić, 2011) argue, competing in dynamic markets requires not only technological investment, but also a robust change management strategy that addresses both operational risks and human resistance. The Organizational Change Management (OCM) approach. The article by (CHKOUR & KECHAD, 2024) shows that the success of organizational change depends on good human resources management. The role of human resources is to give meaning to change, transforming the feeling of uncertainty into effective participation in the various stages of implementing change projects. For a company to ensure a certain sustainability in the market, it is true that it must adopt advanced technological tools and transform old working methods. But also, the willingness of the parties involved collaborating and sharing work with artificial intelligence. As article of ((Dhanabhakyam, 2023) , the document states that change management is a well-structured and controlled process that manages both the plan (roadmap, how the change should be implemented) and the people during the period of change. Human resources play an important role in the supervision and guidance of a change project, demonstrating that the HR function plays an indispensable role in leading change. Article written by (NEJJAR & DAGHRI, 2023b). The research underlines that the function has gone beyond its traditional role of administrative personnel management to become a force that drives organizational success. Another relevant document that highlights the importance of organizational change management is the work of (Mukhlis & Tyas, 2024)). This document states that change management is an important factor that ensures not only the adoption of technological innovations by the company, but also their effective use by employees. Reading another chapter emphasizes that companies should not only focus on acquiring new machinery, but should also take their human capital into consideration, the chapter written by, (Gray & Wilkinson, 2016) This chapter serves as a practical guide, focusing on the fact that the success of a change project does not lie in investment and the adoption of new machines by companies, but rather that companies must focus more on people and their emotions. Several articles address the importance of organizational change management, including the article (Aninkan, 2018). Among these articles, which focuses on the fact that the success of organizational change depends on how the company manages change. In other words, everything depends on how the company plans, communicates, and executes this change, as these elements guarantee successful change that translates into effective company performance. Another article called (Kanaane & Peterossi, 2015) shows that if a company is going to implement a real project that will profoundly change its working methods, it must put organizational change management (OCM) in place. The article gives an example of the implementation of a system called Enterprise Resource Planning (ERP) and highlights the role of OCM in the success of this transition. OCM guarantees both technical and human success. As several articles discuss the idea that any company launching a change project impact not only its employees but also its overall performance, whether that company adopts good organizational change management will be the only tool to determine whether the impact of change is positive or negative. This is exactly what the article entitled (Ploscaru et al., 2023) proves. The article is named (Costel Loloiu et al., 2015) . On one hand, the article highlights that there is no precise way that companies must follow to manage a change, it's case by case. On the other hand, the study aims to understand why employees refuse change, even if the change is in their interest. A search of (Phillips, 1983) the study on one hand emphasizes that any company wants to keep its sustainability and positioning especially in a rapidly changing environment, it will be obliged to leave its comfort zone, on the other hand, research mentions the difficulties that a company faces when moving from a stable and normal situation to a changing one. Every company step outside its comfort zone in order to adapt to the demands of its external environment. With the advent of new technologies, companies are increasingly adopting these tools, which impact the traditional methods they are accustomed to working with. For this reason, companies must not only invest in adopting new technologies, because the problem is not in the technology itself; the problem lies in employee

resistance to change. This is where organizational change management (OCM) comes into play. OCM is an essential strategic tool that ensures that the change project launched is completed successfully and without failure.

A. Organizational change management process:

Under the pressure of digital transformation, David Autissier and his team are reinventing change management. In his articles, he proposes moving from a tool-centric vision to a more human and global one, a method that shifts human resources from a secondary role to a more strategic one, enabling the company to adapt rapidly. Autissier and her team explain the evolution of change: at the beginning, (Autissier et al., 2014), it's about managing small changes, talking about how to accompany people to familiarize themselves with new digital tools at a time when everything is done on screen, then we move on to collective action (Autissier et al..., 2015), explain the shift from classic and rigid accompaniment (based on lots of tools) to a more flexible and rigid model for managing change in companies, to arrive at a global management of transformation (Autissier et al., 2018), studying the past of coaching methods to shed light on why companies are no longer content to make small, unimportant changes, but are tackling a complete transformation.

Table n°1: The stages of change management according to Autisier :

Autissier and his team tell us in detail how change management was assessed, moving from classic to modern management. This table lists the most important stages to remember.

Models	Step 1	Step 2	Step 3	References
The traditional method	Diagnosis: How to carry out an inventory of fixtures	Coaching: We don't leave employees to face change alone	Monitoring: Checking whether employees are using the new tools and whether work is progressing perfectly	(Autissier et al., 2014)
The participatory model	Define: Explain the reason for change to employees	Experiment: test to see what really works and correct mistakes quickly	Anchor : make change normal, make employees more flexible to change ideas	(Autissier et al., 2015)
Large-scale change management	Strategic diagnosis: checking whether the company is ready for far-reaching change	Transformation management : ensuring that all departments are moving in the same direction	Organizational capacity : The company learns to adapt on its own	(Autissier et al., 2018)

Source: Conducted by author's

III. THE ROLE OF THE HR FUNCTION IN CHANGE MANAGEMENT:

This section highlights the evolution of the HR function from a mere administrative function to a true strategic partner, while detailing the concrete actions taken by human resources at each stage of the change process to ensure effective employee support.

A. *The HR function as a strategic lever for change management:*

The success of a change project, whether technological or strategic, is not limited to the adoption of the technology itself or the development of new strategies. It depends on the ability and willingness of employees to change. In this section, this research tries to explain for readers and help them to understand the key role of human resources in organizational change management. Most change projects are completed but without success, the failure is mainly due to humans (employee resistance, disengagement, etc...). Companies understand that they must involve human resources. Today, the HR function has become a strategic partner in organizational management change with the aim of making change projects successful. In order to build a solid conceptual framework, this document deeply the existing literature dealing with this subject, and why human resources have become a strategic actor that ensures the success of transformation projects. In order to build a solid conceptual framework, this subsection is dedicated to analyzing and understanding existing work on the role of human resources in organizational change management. The work (Coffie et al., 2024) highlights the strategic role of human resources in managing organizational change during periods of transformation. The document highlights the impact of each HR function, such as communication, training, and engagement, on the success of the change project launched by the company. The difficulty lies not in implementing new ideas such as adopting new technologies, changing leadership, etc., but in employee resistance to change. (Mishra et al., 2021) Highlights this point by demonstrating the indispensable role of human resources in the success of change projects. Several articles highlight the need for change for companies that want to maintain a certain strength in the market, especially with global demands, but this change cannot be achieved without a well-defined and managed strategy for human resources to address the central issue of resistance to change. The work of (Kriemadis et al., 2023) demonstrates the role of human resources function in avoiding the problem mentioned above. Like several articles that agree on the need for organizational change initiated by the organization itself for its own benefit. The work of (Ullah, 2012) emphasizes the need to push the company out of its comfort zone for its own benefit and also discusses the strategic role of human resources in the success of change projects. In other words, human resources can be described as a bridge or intermediary linking the objectives set by senior management and the employees who will translate these

objectives into results on the ground. Another chapter that shows us the indispensable role of human resources in the success of a change project. The work of (Malik, 2015) highlights the indispensable role of human resources in the successful completion of change projects. The document describes the function of human resources as a bridge between the decisions and vision of senior management and the employees who translate the vision and theoretical decisions of senior management into real action on the ground. Without HR, companies may have good plans in theory but not in practice. The article of (Raeder, 2019) mentions that human resources in situations of change should not use old methods. To be effective in these situations, they must change their methods and strategic visions to align with the specific needs of this change. In other words, human resources should not have a single approach and method for all situations; they must behave differently with changing situations to ensure its completion. A work of (Rustiawan et al., 2023) mentions that the success of a change project is not only limited to the adoption of new technological tools, but the company must put the HR function at the center of this transition, because this function will take care of the moral situation of the employees during the stressful period of change, accompany them, train them, listen to them, etc... This research highlights the indispensable strategic role of human resources. A document of (Baran et al., 2019) emphasizes that today human resources no longer handle administrative tasks such as payroll, validation of leave, etc... but they have become strategic partners that facilitate the speed of acceptance of the idea of change by employees and the execution of directives from senior management. In other words, the HR function is like a bridge that links employees and strategy.

B.The change management process and HR :

In the face of current change, the human resources function must deal with many risks; among these risks is employee resistance to change, which pushes human resources to act even before it blocks. Here we have a proactive HR function and not reactive. The role of artificial intelligence and with the current technological evolution, it has become a strategic partner for companies and more precisely the HR function, this technology and thanks to the algorithms, the ability to analyze a very large number of data quickly and helps HR make the right decision. This section of the article discusses how artificial intelligence can help the HR function succeed in a change project. The most important thing is not the integration of technologies such as artificial intelligence and the cloud into the HR business process, but rather how a company can manage this change. The article by (Ramesh Nyathani, 2024) addresses a very important concept, namely change management, and states that for a company to successfully adopt AI- and cloud-based systems in the HR process, companies must first understand and better manage their human capital. Another article mentions that the change must not be imposed on employees. It must be an exchange between senior management (concerning the idea of change and the strategy that employees must follow) and employees (who will declare to senior management the good practices and methods to be followed to apply these ideas on the ground without any problem, these exchanges will be made through human resources which play an indispensable role. It is the only way to guarantee the success or failure of a project. The article (Daniel Valtiner and Christian Reidl, 2021) emphasizes the role of artificial intelligence and provides a clear guide for this technological integration to be successful under problem. Research of (Shah et al., 2017) deals with how human resources can use artificial intelligence and big data tools. These technologies help human resources to detect employees who may refuse the idea of change and make action plans to avoid falling into problem situations before they actually arrive on the field.

Table n°2: Strategic contributions of human resource functions in organizational change management

Aspect of Change Management	Role of Human Resource managers	Contribution of Artificial Intelligence	Impact on Change Success	References
Diagnosis of the Current Situation	Understand employee conditions before initiating change	Analyze employee data (e.g. performance, absenteeism, satisfaction); identify stress and resistance zones	Enables proactive HR interventions; facilitates early detection and resolution of resistance	(Shah et al., 2017). (Coffie et al., 2024) (Lojić & Đurić, 2011)
Internal Communication / Reducing Misunderstandings	Share change-related information across the organization	Chatbots provide consistent, real-time answers to employee queries	Ensures uniform information dissemination& reduces confusion and resistance	(Ramesh Nyathani, 2024) (Phillips, 1983) (Aninkan, 2018)
Training and Support	Train and support employees throughout the change process	Develop personalized training plans based on employee needs and skill levels	Accelerates employee adaptation; enhances learning and engagement	(Dhiman, 2025) (Coffie et al., 2024) (Mishra et al., 2021)
Social Climate Management	Monitor and address employee stress and emotional responses	Analyze employee messages to detect sentiment and satisfaction levels	Enables timely HR interventions; supports mental well-being and motivation	(Ramesh Nyathani, 2024) ; (Costel Loloiu et al., 2015) (Aninkan, 2018) ; (Shah et al., 2017)
Quick and Effective Decision-Making	Use dashboards to monitor key HR indicators	Generate real-time dashboards with performance, satisfaction, and engagement metrics	Enhances strategic agility; supports data-driven HR decisions	(Prasanth et al., 2023) ; (Saba et al., 2021); (Prorok & Takacs, 2024)

Culture and Leadership	Identify internal influencers to drive change	Detect influential employees within teams using behavioral and network analysis	Facilitates targeted leadership delegation; boosts team motivation and cohesion	(Kanaane & Peterossi, 2015) ; (Kriemadis et al., 2023) ; (Ullah, 2012) ; (Daniel Valtiner and Christian Reidl, 2021)

Source: Conducted by author's

IV. ARTIFICIAL INTELLIGENCE IN CHANGE MANAGEMENT :

Following an examination of the added value of artificial intelligence, this section outlines how human resources are leveraging their know-how to support employees during the change management process, as well as practical recommendations.

A. The role of artificial intelligence in change management with HR involvement:

The article written by (Priyanghaa Mathialagan, 2025) shows that the integration of artificial intelligence is not just a matter of technical deployment but requires human-centered management to ensure balance and unity within the structure. Change is not automatic. Without the support of human resources, artificial intelligence runs the risk of simply increasing workload rather than enhancing content. The article by (BOUZERDA & HANI & JMAHRI & RAHMANI, 2025). The digital transition, driven by Big Data and artificial intelligence, is not only a change of tools; it's a new way of team managing. The issue is no longer technical, but human. The Human Resources function is central, transforming the fear of staff by creating commitment via continuous learning and transparency, positioning the individual as a player in the transition, rather than being marginalized by technical evolution. AI takes care of all the repetitive administrative tasks, while the task of human resources lies in preparing the minds of employees to use AI without doubts. As the Moroccan and international context analysis (Nabil, 2025) points out, the mission of human resources is to frame artificial intelligence so that it becomes a means of relieving the burden on employees. The reason for using artificial intelligence is not to increase the quantity of tasks carried out, but rather to improve the quality of the work done and give employees more time to focus on innovation. AI is a profitable investment for companies, but HR provides awareness and know-how. Without HR support, AI implementation will meet a lot of resistance. As indicated in the article (Gandía et al., 2025). Without limiting themselves to the performance of the tools, human resources must ensure that artificial intelligence is there to help employees and not to disrupt their lives.

Table n°3: Strategic contribution of AI in organizational change management aspects:

What AI brings to change management	**What Human Resources must do**	**The results for change management**	**References**
Artificial intelligence acts as a tool that accelerates the technological transformation of the structure. AI enables: **Optimize work:** work faster and better. **Decision-making based on data analysis:** anticipate the company's future needs in terms of skills. **Go digital to stay competitive and keep the company sustainable.**	Successful change management is demonstrated by: **A clear, well-explained discourse.** **Training employees to work easily with AI.** **Ensure that all employees are involved, and that everyone shares their opinions and ideas about the project.** **Put people before technology.**	Successful AI-HR collaboration has the following effects: **Reduced employee fear and resistance. Lasting involvement of employees in the project. Harmonization within the organization.** **Continuous learning environment.**	(Priyanghaa Mathialagan, 2025)
Artificial intelligence is no longer a choice but an obligation, it has become a strategic tool. Artificial intelligence : **Offers new, efficient ways of working.** **Processes large amounts of information.** **Handles repetitive Administrative tasks.**	Human resources intervene to ensure that : **People are always at the heart of the project, and are not replaced by machines. HR always keeps the human touch.** **AI does not reproduce discriminatory decisions. Train employees to master the new tools.**	Successful IA-RH collaboration has the following effects: **By respecting people, the transformation project is unlikely to fail.** **A decision acceptable to everyone, based on people's real skills.** **Employees keep their jobs and are ready to face tomorrow's changes.**	(BOUZERDA & HANI & JMAHRI & RAHMANI, 2025)
Artificial intelligence is a tool that makes change possible. Its role: **Improving productivity and optimizing costs:** working more efficiently and more cost-effectively. **Redefining management practices:** managing teams based on data and figures, not just intuition. **Create innovative ideas to ensure business survival.**	Human resources play an important role, acting as a guide that facilitates the transition to digital by: **Ongoing training:** teaching people how to use new tools. **Transparent communication:** Being clear with employees, telling them everything about AI to create a climate of trust. **Test AI little by little before rolling it out across the company, to give employees more time to get used to the new tools.**	The reasons behind the adoption of AI by companies lie in : **Motivation:** What are the company's objectives? **84%** the company wants to be more efficient. **65%** Desire to use new technologies to keep pace with other companies. **Obstacles to AI implementation :** **68%** Fear of the unknown (human side). **47%** Difficulty of implementation (technical side).	(Nabil, 2025) (Gandía et al., 2025)

Source: Conducted by author's

B. Recommendations

The article of (GHRASLI et al., 2025), highlights strategic recommendations for the adoption of artificial intelligence in human resources. Demonstrating that the successful integration of AI is conditional on rigorous preparation, human support and a permanent training environment. The article written by (Venugopal et al., 2024) details the key success factors for artificial intelligence in human resources. It shows that this digital innovation requires firm moral rules and honest communication to preserve employee trust. In conclusion, the study underlines the need to reposition the HR function as a strategic partner capable of taking advantage of technological tools while guaranteeing fair treatment for every employee, while proposing strategic recommendations for the implementation of artificial intelligence in human resources, such as the establishment of a rigorous control and monitoring system, an ethical framework and respect for employee privacy, ensuring that the deployment of artificial intelligence acts in synergy with the structure's strategic orientations, supporting employees and strengthening social ties with them. In the light of this analysis, the study by (Singh et al., 2025) converges on essential recommendations aimed at framing the integration of artificial intelligence into the human resources department; transparency and responsible governance of artificial intelligence, development of human capital (Upskilling), ensuring that artificial intelligence really serves the company's strategic purpose and not a tool installed for nothing. Another article by (Bar-Gil et al., 2023) shows that AI is not just a tool to be installed, but a genuine vector of transformation that makes companies more efficient and more credible in the long term, but the success of this technology requires specific strategic requirements such as: drawing up an ethical governance charter maintaining human supervision to guarantee continuous control to avoid discrimination, having a responsible and credible management strategy and, most importantly, keeping the balance between man and machine.

V. Conclusion:

The present work highlights two conclusions, the first concerning the transition of human resources from a simple support function to a very important strategic function for the success and longevity of a company in the long term. The second which highlights the factor that determines the success of a change project, for a project to be successful it depends not only on the technology itself, but in the acceptance and use of this technology by employees, it is here that the role of human resources comes.

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Analysis of the Impact of Economic Policies and Regulations on the Sustainability of Corporate Strategies

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Abstract -
This paper examines how economic policies and regulatory constraints shape the optimization of corporate sustainability strategies. Using a systematic literature review of 85 peer-reviewed articles published between 2010 and 2023 (Scopus and Web of Science), the study analyzes how firms optimize their strategic decisions under economic incentives (tax credits, innovation subsidies) and regulatory requirements (environmental standards, non-financial reporting).
The findings show that incentive-based policies enhance the optimization of low-carbon investment decisions, increasing the adoption of clean technologies by up to 35% among manufacturing SMEs. However, optimization outcomes remain uneven, as large firms capture nearly 65% of available incentives, generating structural inefficiencies and access constraints for smaller firms. Regulatory frameworks such as the CSRD and TCFD improve transparency and strategic alignment but introduce asymmetric compliance costs, affecting firms' optimization trade-offs between profitability, innovation, and regulatory compliance.
The study highlights persistent optimization tensions between economic performance, regulatory constraints, and sustainability objectives. It proposes an integrated analytical framework that models sustainability as a constrained optimization problem, balancing economic efficiency, social equity, and environmental performance. This research contributes to the optimization literature by providing insights into policy-driven strategic decision-making under regulatory and economic constraints.

Keywords — Optimization; Economic policies; Regulatory constraints; Corporate sustainability; SMEs; Strategic decision-making.

I. INTRODUCTION

In recent years, optimization has become a central paradigm for analyzing corporate decision-making under increasing economic, environmental, and regulatory constraints. Firms are no longer solely optimizing profit functions, but are required to integrate sustainability objectives, regulatory compliance, and social responsibility into their strategic optimization processes. Economic policies and regulatory frameworks act as external constraints and incentive mechanisms that reshape firms' optimization models, influencing investment choices, innovation trajectories, and long-term competitiveness.

The International Journal on Optimization and Applications (IJOA) provides an appropriate platform for this analysis, as sustainability challenges increasingly require optimization-based approaches that reconcile economic efficiency with environmental and social constraints. Understanding how firms optimize their strategies under these multidimensional constraints is essential for advancing both optimization theory and its practical applications in economics and management.

The remainder of this paper is organized as follows. Section II presents the motivation and methodology underpinning this study. Section III introduces the conceptual framework and optimization model. Section IV discusses the key findings from the systematic review. Finally, Section V concludes with implications and future research directions.

II. MOTIVATION & METHODOLOGY

A. Motivation

Optimization theory provides a powerful analytical framework for studying decision-making under constraints. In contemporary corporate environments, firms face increasingly complex optimization problems involving economic performance, regulatory compliance, and sustainability objectives. Economic policies and regulatory frameworks introduce external constraints and incentive mechanisms that reshape firms' feasible strategy sets, transforming sustainability into a constrained optimization problem rather than a purely normative objective.

Despite the growing literature on corporate sustainability, most studies adopt descriptive or policy-oriented perspectives, with limited integration of optimization logic. The existing research often fails to conceptualize how firms optimize strategic choices when confronted with asymmetric incentives, regulatory costs, and resource

constraints—particularly across heterogeneous firm sizes such as SMEs and large corporations.

This study is motivated by the need to bridge this gap by framing sustainability strategies as optimization problems under economic and regulatory constraints. By synthesizing empirical and theoretical findings through an optimization lens, the paper contributes to the objectives of the International Journal on Optimization and Applications (IJOA), which emphasizes the development and application of optimization-based approaches across multidisciplinary fields.

B. Methodology

This research adopts a systematic literature review methodology structured to support optimization-oriented analysis. The review follows the PRISMA guidelines to ensure transparency, reproducibility, and analytical rigor. A corpus of 85 peer-reviewed articles published between 2010 and 2023 was selected from the Scopus and Web of Science databases.

The selected studies were coded and analyzed to identify optimization mechanisms related to corporate decision-making under economic incentives and regulatory constraints. Each article was examined according to five analytical dimensions: policy instrument, firm characteristics, optimization objective (e.g., cost minimization, innovation maximization, compliance efficiency), constraint type, and strategic outcome.

Qualitative thematic analysis was conducted using NVivo to extract recurring optimization patterns, trade-offs, and constraint structures. A double-coding procedure applied to 20% of the sample ensured analytical consistency, achieving an inter-coder agreement rate of 92%.

By structuring the literature around optimization objectives and constraints, this methodology aligns with the scope of IJOA, offering a systematic synthesis of how optimization principles are applied—explicitly or implicitly—to sustainability-oriented corporate strategies.

III. Conceptual Framework and Optimization Model

In the context of optimizing corporate strategies under economic incentives and regulatory constraints, the total cost (C) can be modeled as the sum of investments in clean technologies (x) and compliance costs (y):

C = c1 x + c2 y \quad (1)

where:

- (x) represents the investment in green technologies,
- (y) denotes the cost of regulatory compliance,
- (c1) and (c2) are the respective unit cost coefficients associated with these expenditures.

The objective is to minimize the total cost (C) subject to economic policies and regulatory constraints such as budget limits, minimum environmental performance thresholds, and innovation incentives. This simple model captures the trade-offs firms face in allocating resources between technological investments and compliance efforts.

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Predicting Solar Energy using Artificial Intelligence Models

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Abstract

Accurate forecasting of Global Horizontal Irradiance (GHI) is essential for estimating photovoltaic power generation, yet it is strongly affected by climatic variability. This study compares five machine learning methods for GHI forecasting in Morocco: Convolutional Neural Networks (CNN), Support Vector Regression (SVR), Random Forests (RF), Artificial Neural Networks (ANN), and Long Short-Term Memory networks (LSTM). The dataset was obtained from the NSRDB and covers the period from January to December 2022. Model performance was evaluated using the coefficient of determination (R^2), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE). The results indicate that the ANN model achieves the highest accuracy, with an RMSE of 72.19 W/m², an MAE of 41.19 W/m², and an R^2 of 0.9142, demonstrating a strong agreement between predicted and observed values. This superior performance suggests that ANN models are particularly effective in capturing the nonlinear relationships between meteorological variables and GHI. The findings provide valuable insights for photovoltaic system optimization, energy planning, and predictive maintenance applications.

Keywords: Machine Learning, Global Horizontal Irradiation, Solar Forecasting, Renewable Energy, Artificial Intelligence.

XVII. INTRODUCTION

Solar energy is a virtually inexhaustible clean energy source and plays a key role in supporting the energy transition and reducing dependence on fossil fuels [8]. Today, thanks to photovoltaic systems, it provides electricity to homes, industries, and large-scale infrastructure, contributing to the sustainable development of the energy sector.

In Morocco, the energy sector plays a strategic role in economic and social development. Between 2010 and 2023, the installed capacity of renewable energy sources in Morocco has grown steadily, reflecting the country's commitment to sustainable development and energy transition. The country has committed to increasing the share of renewable energy to more than 52% of installed capacity by 2030. In 2023, national solar capacity reached approximately 831 MW, representing 7.3% of total capacity and nearly 18% of installed renewable power [2]. Annual solar production amounted to approximately 2,148 GWh, or 5.1% of national electricity production [2]. These results demonstrate the growing role of solar energy, with flagship projects such as the Noor Ouarzazate complex, one of the largest in the world.

Globally, 2023 set a record with 473 GW of new renewable capacity installed, nearly 75% of which came from solar photovoltaics [10]. This trend confirms the dominant role of this technology in the energy transition and highlights the importance of developing forecasting and optimization tools adapted to local specificities such as those in Morocco.

However, solar power generation is highly dependent on global horizontal irradiation (GHI), which varies directly with local weather conditions. Its intermittent and unpredictable nature poses a major challenge to power system stability and reliability [14].

To address this issue, accurate GHI forecasting is essential. This not only makes it possible to anticipate photovoltaic production, but also to improve energy management, operational planning and the integration of renewable sources into the grid [12]. In this context, the use of advanced machine learning techniques is a promising solution for modeling the complex relationships between climate variables and solar radiation.

This study provides a comparative analysis of several machine learning algorithms applied to WHI forecasting in Morocco using data from NSRDB for the period January–December 2022. Various approaches are used in this analysis, such as ANN, CNN, SVR, LSTM, and RF. These models were chosen for their ability to capture nonlinear relationships between climate variables. Their performance was measured using metrics such as RMSE, MAE, and R2. The objective is to identify the most effective algorithms for predicting GHI in Morocco. The results show that ANN provides the best prediction with an R2 of 0.91 and an RMSE of 72.19 W/m².

The document is structured as follows: Section 2 presents a literature review. Section 3 describes the methodology, including data collection and preprocessing. Section 4

presents the models and performance metrics. Section 5 presents the results and concludes the study. h trends in the optimization techniques and their applications in various fields.

XVIII. MOTIVATION & METHODOLOGY

A. Motivation

Time series have been extensively studied, and numerous studies have proven their effectiveness in estimating solar energy generation employing machine learning algorithms.

In study by El Maghraoui et al., the authors focused on the application of machine learning approaches to forecast energy consumption in open-pit mines [6]. Their study compared the performance of four models: ANN, SVR, DT, and RF. The results revealed that the RandomForest algorithm offered the best accuracy for this type of prediction.

Chu et al. proposes two approaches based on LSTM neural networks to develop a new solar irradiance prediction model, based on a dataset consisting of images [4]. The objective was to generate forecasts with horizons ranging from 5 to 60 minutes. The first approach uses as input variables the irradiance measured five minutes earlier, the current irradiance, and a central value extracted from the images. The second method improves these inputs by adding variance, a comparison between the red and blue channels of the image, and a three-step search technique. The experimental results showed that the second approach offered better predictive performance, highlighting the importance of leveraging more complex features derived from image processing.

In another study conducted by the same authors, the objective was to evaluate several machine learning techniques for forecasting the electricity consumption of hotel buildings employing a hotel in Shanghai as an example [5]. The algorithms studied included SVM, ANN, DT, and Random Forest (RF). The study compared their performance and identified Random Forest as the most accurate and robust, particularly for complex and nonlinear relationships between variables.

Chandola et al. built an LSTM model to predict solar irradiance 3, 6, and 24 hours in advance in dry regions of India [3]. They used a range of meteorological data such as temperature, humidity, wind, atmospheric pressure and different forms of irradiance (GHI, DHI, DNI). The model was tested on data from 2010 to 2014 collected in the Thar Desert. It performed well with a MAPE between 6.8% and 10.5%, which is quite accurate given the harsh climate.

Zhao et al. exploited a 3D-CNN model to anticipate direct normal irradiance with a 10-minute horizon [17]. The approach is based on the joint extraction of spatial and temporal features from cloud image sequences captured on the ground. The algorithm was trained using GBC images and DNI data collected between 2013 and 2014 via the NREL database. The model achieved a forecast accuracy of 17.06%.

B. Methodology

- *Data description*

The data used in this study to develop the CHI prediction model comes from the Marrakech site located at 31.6269°N latitude and 7.9881°W longitude at an altitude of approximately 466 m and characterized by a semi-arid climate with high solar exposure and low annual cloud cover. The variables considered for modeling include SHI, temperature, pressure, relative humidity, precipitable water, wind direction and wind speed covering the period from January to December 2022.

- *Data preprocessing*

Before modeling, the dataset was cleaned by processing missing values and detecting and correcting outliers. Next, a selection of explanatory variables was made in order to retain only those variables that made a significant contribution to the prediction. All variables were normalized to bring their values to the same scale. The data was then divided into training set (80%) and test set (20%). The Scikit-learn library was used to perform these operations and prepare the data for modeling.

- *Random Forest regressor*

Random Forest regressor is a statistical technique used to identify the most relevant input variables for a regression task. Each tree in the forest estimates the importance of each variable by measuring how much it reduces impurity at each split. The importance scores from all trees are then averaged to obtain a relative importance for each feature (Table 1). This approach is simple, computationally efficient, and effective in eliminating irrelevant or low-variance features, thereby improving model performance and focusing on the most informative variables. The model identified the five most predictive variables for GHI which are Relative Humidity, Wind Speed, Wind Direction, Temperature, and Precipitable Water.

. Table 1. The features importance scores

Features	Importance
Relative Humidity	0.429126
Wind Speed	0.130911
Wind Direction	0.121440
Temperature	0.094753
Precipitable Water	0.088843
Dew Point	0.056122
Pressure	0.041142
Surface Albedo	0.027324
Fill Flag	0.010339

- *the min–max scaling method*

Since the variables in the dataset have different scales (Table 2), which could affect model performance, all features were normalized using the min–max scaling method. This transformation brings all variables into the [0, 1] range using the formula:

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (1)$$

where:

x= original value, x_{min} = minimum value of the variable, x_{max} = maximum value of the variable, x' = normalized value between 0 and 1.

Table 2. List of meteorological data in used dataset.

Meteorological variable	unit
GHI	w/m2
Temperature	°c

Pressure	mbar
Relative Humidity	%
Precipitable Water	cm
Wind Direction	Degrees
Wind speed	m/s

- *RandomizedSearchCV*

RandomizedSearchCV is a module of the Scikit-learn library used for hyperparameter optimization. It samples a predefined number of parameter combinations from specified distributions. This approach helps identify the optimal configuration by selecting the set of parameters that provides the best performance [1]. In this study, RandomizedSearchCV was applied to explore the hyperparameter space while reducing computation time.

C. Forecast models

- *The support vector Regression*

Support Vector Regression is a supervised machine learning approach widely applied for regression tasks particularly in energy forecasting applications [11,15]. SVR aims to construct a function in an N-dimensional feature space that approximates the target values within a defined margin of tolerance (ε), while simultaneously minimizing model complexity. This approach allows the algorithm to capture both linear and nonlinear relationships between input variables and the target.

- *Artificial Neural Network*

An Artificial Neural Network (ANN) is inspired by the functioning of biological neurons in the human brain. It is composed of interconnected layers of nodes, each performing weighted computations followed by activation functions to capture non-linear relationships. An ANN typically includes an input layer, one or more hidden layers, and an output layer. Each node (artificial neuron) is associated with a weight and a bias (threshold). When the weighted sum of the inputs exceeds the threshold, the neuron is activated and passes its output to the next layer [13].

- *Convolutional Neural Network*

The convolutional neural network (CNN) has become one of the most widely used models in deep learning because of its strength in identifying complex, non-linear patterns within data. A standard CNN is usually built from three main types of layers: convolutional, pooling, and fully connected layers [16]. Among these, the convolutional layer plays the central role. It applies multiple kernels to the input, producing feature maps that allow the model to capture increasingly abstract and meaningful representations.

- *Random Forest*

Random Forest (RF) is a robust and widely used supervised machine learning algorithm that builds an ensemble of decision trees and aggregates their outputs to improve prediction accuracy. It is applicable to both regression and classification tasks [7]. Each tree is trained on a random subset of the data and features, which introduces diversity and reduces correlation among trees. By averaging predictions in regression or using majority voting in classification, Random Forest mitigates overfitting and delivers more stable, accurate and generalizable results in comparison with single decision tree.

- *Long Short-Term Memory*

Long short-term memory (LSTM) neural networks are an advanced variant of recurrent neural networks (RNN), designed to mitigate the problem of gradient vanishing when processing long time series. Using a system of gates (input, forget, and output), LSTM regulates the flow of information: it decides which data should be retained, which irrelevant data should be forgotten, and which information should be transmitted to the output [9].

- *Performance Indicators*

The purpose of verification is to evaluate the quality of forecasts. Several metrics can be used to assess the performance of machine learning models, and their suitability depends on the specific use case. In this study, the forecasting methods are evaluated in terms of accuracy and efficiency using the following statistical indicators: RMSE, R^2, and MAE.

Root Mean Squared Error: RMSE is a fundamental evaluation measure based on residual squaring, it takes the square root of the output of MSE. Its problem is that it penalizes larger errors.

$$\sqrt{\frac{1}{N}\sum_{i=1}^{N}(Yi - \hat{Y}i)^2} \quad (2)$$

Mean Absolute Error: The MAE calculates the absolute difference between the actual values and the predicted values. The lower the value of the MAE, the better the model, which indicates a better agreement between predicted and observed values. the formula to calculate the MAE:

$$\frac{1}{N}\sum_{i=1}^{N}|Yi - \hat{Y}i| \quad (3)$$

The coefficient of determination: The R^2 is the coefficient of determination. It is an indicator for judging the quality of a regression. It explains the strength of the relationship between an independent variable and a dependent variable in the regression model. The R^2 is calculated as follows:

$$1 - \frac{\sum_{i=1}^{N}(Yi-\hat{Y}i)^2}{\sum_{i=1}^{N}(Yi-\bar{Y}i)^2} \quad (4)$$

D. Results and Conclusion

This study aims to identify the most effective models among SVR, ANN, CNN, Random Forest, and LSTM for HSI prediction, using data from the NSRDB database over a one-year period.

Among the five models tested, ANN achieved the best performance, with the most favorable values for all evaluation metrics. The results of the models, expressed in terms of RMSE, MAE, and R^2 are presented in Table 3 and Figure 1. ANN ranks first, followed by LSTM.

The ANN model stands out for its superior accuracy, with an RMSE of 72.19 W/m², an MAE of 41.19 W/m², and an R^2 of 0.9142, indicating a strong fit between predicted and actual values. The LSTM (RMSE 75.63 W/m², R^2 0.9059) and Random Forest (RMSE 76.36 W/m², R^2 0.9040) also perform well, confirming that models capable of capturing nonlinear and temporal relationships are particularly effective for this

type of prediction. In contrast, SVR and CNN show poorer performance, suggesting that they are less effective at capturing SHI variations in this context.

The use of RandomizedSearchCV played a key role in optimizing the models. Table 3 summarizes the optimal hyperparameters for each algorithm. The ANN model appears to be the most suitable for solar power plants in Morocco, with the following optimal hyperparameters identified: learning_rate = 0.001, hidden_units = 64, hidden_layers = 3, dropout_rate = 0.1, activation = relu, epochs = 50, and batch_size = 32.

The results confirm that the ANN outperforms the SVR, RF, LSTM, and CNN models for GHI prediction. The study is based on data from the NSRDB database, and the five most relevant variables were selected using a Random Forest Regressor. These results have direct implications for energy producers and decision-makers. The use of ANNs makes it possible to optimize resource allocation, better plan energy demand, and reduce waste and dependence on non-renewable sources.

In terms of future prospects, one initial approach is to develop hybrid models combining deep learning and statistical methods. Another direction is the integration of additional data such as satellite observations and ground camera images to enhance the accuracy of forecasts.

In conclusion, this study highlights the importance of accurate SHI forecasts for improving energy management. The application of the ANN algorithm makes it possible to optimize the use of solar energy, reduce dependence on fossil fuels, and contribute to the transition to renewable sources.

Table 3. The prediction accuracy of studied models

Model	Model Accuracy		
	RMSE W/m²	MAE W/m²	R2
CNN	98.45	77.70	0.8405
LSTM	75.63	48.40	0.9059
ANN	72.19	41.19	0.9142
SVR	91.34	71.01	0.8627
RF	76.36	43.95	0.9040

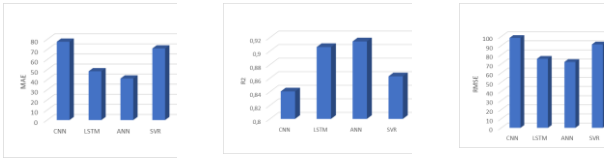

Fig.1. Ranking of the five algorithms

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Personalization and Customization in E-Commerce: An Exploratory Study of Collaborative Innovation

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***Abstract*— In the context of digital commerce, the role of consumers has progressively evolved from that of passive recipients to actors whose interactions may inform and shape innovation processes. This study examines how personalization, understood as automated system-driven adjustments, and customization, defined as user-initiated modifications, contribute to collaborative innovation in e-commerce environments. Relying on an exploratory qualitative approach, the research is grounded in two complementary theoretical perspectives: the interactive model of innovation (Von Hippel, 1986), which emphasizes the role of users in innovation processes, and the theory of value co-creation (Vargo & Lusch, 2004), which conceptualizes value as emerging through interaction and collaboration.**

Empirical data were collected through nine semi-structured interviews with digital professionals (including developers, digital project managers, and innovation consultants) and fifteen interviews with consumers with diverse profiles who regularly interact with personalized and customizable e-commerce platforms. The findings reveal a functional complementarity between personalization and customization. Personalization primarily generates implicit contributions through routine interactions and behavioral signals, which can be integrated into iterative innovation processes. Customization, by contrast, involves more explicit and deliberate forms of contribution, allowing users to influence the configuration and evolution of offerings.

Overall, the results highlight a form of collaborative innovation that emerges through the aggregation and interpretation of user-generated signals, rather than through formal participatory mechanisms. By shedding light on these implicit modes of contribution, this study contributes to a better understanding of how personalization and customization can operate as strategic levers for collaborative innovation in digital commerce.

***Keywords*— Personalization, Customization, Collaborative Innovation, E-commerce**

XIX. INTRODUCTION

Over the past years, the growing diffusion of intelligent technologies has progressively reshaped how organizations approach innovation. Innovation is no longer viewed solely as an internal activity, confined to research and development departments, but increasingly as a process that takes shape through interactions with actors outside organizational boundaries. In this context, the concept of augmented management, as discussed by Brynjolfsson and McAfee (2017), points to a move away from purely automated decision-making toward organizational arrangements that allow different forms of contribution and collaboration. Users are therefore no longer seen simply as recipients of products or services, but as stakeholders whose interactions can contribute to value creation within digital environments (Von Hippel, 2005; Prahalad & Ramaswamy, 2004). This shift echoes a broader view of collective intelligence, where innovation emerges from coordination rather than from isolated efforts.

The e-commerce sector offers a particularly appropriate setting to observe these developments. In 2024, global online sales exceeded USD 6.9 trillion, accounting for 23% of total worldwide retail sales (Statista, 2024). Beyond this quantitative expansion, e-commerce has also undergone a more qualitative transformation. Personalization and

customization have gradually become central practices, allowing firms to adjust their offerings, content, or services to heterogeneous preferences. At the same time, these practices help structure ongoing interactions between firms and their markets. Industry reports show that the absence of personalized recommendations continues to generate dissatisfaction among consumers, which underlines the strategic importance of personalization and customization in the design of contemporary value propositions (McKinsey, 2023).

Importantly, personalization and customization should not be reduced to technical or algorithmic adjustments. They are embedded in broader organizational and strategic processes that facilitate information flows, learning mechanisms, and the integration of external contributions into innovative activities. Several studies suggest that such practices may support forms of co-design and collaboration between firms and users, thereby contributing to collaborative innovation dynamics (Magne & Lemoine, 2015; Abidi-Barthe, 2020). From this perspective, personalization and customization appear less as isolated tools and more as organizational mechanisms that connect data, modular offerings, and coordination among the actors involved in innovation.

Despite the increasing attention devoted to these practices, existing research still provides only partial insights into how personalization and customization contribute to collaborative innovation. Much of the literature has focused on commercial outcomes or technological performance, while the organizational mechanisms through which these practices structure collaborative innovation processes, remain relatively underexplored (Kaiss, 2023). In addition, qualitative and inductive studies capable of capturing these mechanisms in practice are still limited.

Against this background, the present study seeks to contribute to the ongoing discussion by addressing the following research question from a managerial perspective: **How do personalization and customization practices influence collaborative innovation dynamics in the context of e-commerce?**

XX. RESEARCH OBJECTIVES AND QUESTIONS

The main objective of this research is to better understand how personalization and customization practices influence collaborative innovation dynamics in e-commerce. More specifically, the study examines how these practices contribute to shifting users from a position of simple recipients of offerings toward a role in which their choices and interactions may inform or support innovation processes. By approaching personalization and customization as organizational and strategic mechanisms, this research seeks to clarify their contribution to collaboration and value co-creation within e-commerce platforms.

A. Specific Objectives

- To explore how personalization and customization are understood and interpreted by digital experts and end consumers, with attention to the practical uses associated with each concept.
- To examine how consumers' micro-actions (such as selections, refusals of recommendations, or individual configurations) are perceived by professionals as informal inputs within innovation processes.
- To identify the organizational and technological mechanisms through which information generated by personalization and customization practices can be integrated into collaborative innovation dynamics.
- To analyze the conditions under which personalization and customization support coordination, learning, and knowledge sharing between firms and external actors involved in innovation.

B. Research Questions

- How do professionals and consumers distinguish between personalization and customization in digital environments?
- How are consumers' micro-actions interpreted and mobilized within collaborative innovation processes?
- To what extent do practitioners consider the data and signals generated through personalization and customization practices as meaningful resources for continuous improvement or innovation?

XXI. LITERATURE REVIEW

This study builds on a combined examination of two complementary theoretical frameworks: the interactive innovation model (Von Hippel, 1986) and the value co-creation theory (Vargo & Lusch, 2004). Together, these perspectives make it possible to understand how personalization and customization mechanisms reshape the relationship between firms and users within digital collaborative innovation processes.

A. User Contributions and Interactive Innovation

The innovation model introduced by Von Hippel (1986) emphasizes the active role of users -particularly lead users- in the creation and modification of innovations. This approach departs from traditional linear innovation models by highlighting the importance of reciprocal interactions between firms and users, where innovation emerges through continuous feedback, experimentation, and adjustment. In data-driven e-commerce environments, such interactions are intensified through the use of digital usage data, behavioral tracking systems, and adaptive technologies, which allow firms to continuously adjust their offerings based on observed user actions (Wirtz et al., 2019).

Within the e-commerce context, these dynamics are particularly pronounced, as users have gradually moved from being simple recipients of standardized offerings to becoming active contributors to distributed innovation processes. The integration of real-time data, recommendation algorithms, and rapid feedback mechanisms illustrates how Von Hippel's model has evolved within contemporary technological settings (Chatterjee et al., 2022). These developments reinforce the idea that innovation increasingly results from interaction and collaboration rather than from unilateral organizational decisions. This interpretation is in line with previous research suggesting that routine digital interactions generate meaningful behavioral signals that organizations can mobilize for innovation purposes. Without necessarily formalizing participation, these signals may be interpreted as informational inputs supporting ongoing adaptation and collaborative innovation processes (Hamadi, 2010).

B. *Value Co-Creation in the Service Economy*

The concept of value co-creation, introduced by Vargo and Lusch (2004, 2008) within the service-dominant logic (SDL), challenges the traditional view of value as a process produced solely by firms. This framework argues that value is created collaboratively through interaction and use. While firms provide resources and structure enabling conditions, value emerges through the integration of these resources by users in interaction with organizational systems (Vargo & Lusch, 2016). In this perspective, customers are viewed as co-creators of value and as active participants in innovation processes, rather than passive beneficiaries (Grönroos, 2017).

Applied to personalization and customization technologies, this theoretical lens allows these practices to be understood not merely as automated marketing tools, but as mechanisms that facilitate dialogue, coordination, and collaboration between firms and external actors. Through these mechanisms, personalization and customization support the integration of user-generated inputs into organizational learning and innovation processes (Wang et al., 2020).

C. *Personalization, Customization, and Value Creation*

Building on this reasoning, Arora et al. (2008) propose a relevant distinction between personalization and customization. Personalization relies on automated processes that use algorithms to analyze user-related data, whereas customization involves more explicit user participation through the deliberate selection or configuration of product or service attributes. Although conceptually distinct, both forms of individualization carry collaborative potential, as they enable users to influence the design, adaptation, or evolution of offerings (Pine & Gilmore, 2019).

In digital contexts, these practices extend beyond functional value creation. They contribute to the generation of relational and contextual value, by acknowledging user inputs and integrating them into the ongoing development of products and services (Tynan et al., 2014). This form of value creation plays an important role in collaborative innovation, as it encourages voluntary participation and supports sustained collaboration between firms and users over time.

XXII. METHODOLOGY

This research adopts a qualitative exploratory methodology, which is particularly suited to the analysis of complex phenomena that remain insufficiently theorized, such as the role of personalization and customization practices in collaborative innovation contexts. As emphasized by Miles, Huberman, and Saldaña (2014), qualitative approaches make it possible to identify interpretative categories emerging from actors' discourses, practices, and representations. The study follows an inductive research strategy, favoring analytical depth over statistical generalization (Denzin & Lincoln, 2018).

A. *Data Collection Strategy*

The study was conducted in two interrelated phases designed to integrate the perspectives of both professionals and consumers.

1) *First Phase – Expert Interviews*

The first phase consisted of semi-structured interviews with professionals operating in the digital and e-commerce ecosystem, including digital project managers, front-end developers, innovation consultants, and researchers specializing in data-driven and personalized systems. Participants were selected using purposive sampling (Patton, 2015), based on three main criteria:

- Their documented expertise in the design, implementation, or management of personalization and customization mechanisms
- Their involvement in organizations with varying levels of digital maturity, including start-ups, established e-commerce platforms, and technology-oriented agencies.
- Their experience with collaborative innovation practices and personalization strategies (Gilmore & Pine, 1997).

The objective of this phase was to explore the managerial and organizational logics underlying the integration of personalization and customization technologies, as well as the organizational trade-offs associated with collaborative innovation processes.

2) *Second Phase – Consumer Interviews*

The second phase focused on experienced e-commerce consumers who regularly interact with personalized and customizable digital environments. Participants were recruited using a snowball sampling technique (Glaser & Strauss, 1967), which facilitated access to diverse profiles while ensuring a sufficient level of familiarity with personalization mechanisms (Hassanein & Head, 2007).

Interviews, lasting between 37 and 76 minutes, were conducted following a flexible thematic guide structured around three main themes:

- Consumers' understanding of personalization and customization tools and their perceived role in digital exchanges.
- The evolution of the consumer's role in relation to brands or platforms within personalized environments.
- Perceptions of participation in innovation processes, whether explicit or implicit.

All interviews were audio-recorded, fully transcribed, and subsequently subjected to in-depth qualitative analysis.

Data were collected through nine semi-structured interviews with digital professionals and fifteen interviews with consumers with diverse profiles. The data collection process was continued until semantic saturation was achieved, as subsequent interviews did not yield additional insights relevant to the research objectives. A detailed overview of the respondents' profiles is provided in Appendix A (experts) and Appendix B (consumers).

B. Data Analysis Method

Thematic analysis was employed to analyze the collected data (Braun & Clarke, 2006; Clarke & Braun, 2017). This method allows for the identification of recurrent meanings while preserving the specificity of individual discourses. Its flexible and systematic structure makes it particularly suitable for identifying semantic patterns relevant to the research question and for capturing how personalization and customization practices are interpreted within collaborative innovation dynamics.

XXIII. DISCUSSION AND IMPLICATIONS

*A. **Personalization versus Customization***

The interviews conducted with experts from diverse professional backgrounds, including digital designers, web developers, and e-commerce project managers, reveal a shared and well-structured understanding of personalization and customization mechanisms. Across profiles, respondents consistently distinguish between two distinct logics: an automated and largely invisible logic on the one hand, and a voluntary, user-driven logic on the other.

Personalization is described by experts as a background mechanism relying on the automated exploitation of behavioral data. It operates without explicit user intervention and is designed to remain largely unnoticed. Its primary function is to adjust content, recommendations, or navigation paths in ways that simplify decision-making and reduce cognitive effort. From this perspective, personalization is not meant to attract attention to itself, but rather to shape interactions discreetly by optimizing relevance and efficiency. One expert explains: "*Users do not necessarily notice the changes taking place, but they perceive that the system works better. Everything feels smoother and more coherent, even if they cannot identify exactly why*."

In contrast, customization is associated with deliberate action and explicit choice. It allows users to actively configure specific elements of a product or service according to their preferences. Here, technology no longer operates silently in the background, but instead offers adjustable options that can be activated, modified, or disabled. Experts emphasize that this shift transforms the relationship between the user and the platform, moving from passive adaptation to active configuration. Customization is therefore perceived as fostering a more intentional and sometimes even creative interaction with digital systems.

These distinctions are echoed in the accounts provided by the fifteen consumers interviewed, who represent diverse profiles including students, young professionals, self-employed workers, and retirees. Most participants recognize the usefulness of personalization for its capacity to save time, reduce search effort, and improve the relevance of available options. "*The products shown to me usually match what I am looking for. It saves me a lot of time and avoids long and unnecessary searches.*" (Respondent 5)

At the same time, customization is associated with individual choice and autonomy. Several consumers highlight their appreciation for being able to adjust filters, display parameters, or configuration options independently. "*I like being able to make adjustments on my own, without the system deciding everything for me.*" (Respondent 2)

Taken together, these findings suggest that personalization and customization correspond to different, yet complementary, modes of interaction. While personalization operates through automated adjustment, customization relies on explicit user input. This distinction plays a central role in shaping how innovation pathways are structured, as it determines the types of signals generated and the degree of intentionality behind user contributions.

*B. **From Individual Adjustment to Collaborative Innovation***

One of the most significant findings of this study concerns how consumers perceive their own contribution to innovation processes. Many participants report having observed changes in their usual e-commerce platforms over time, which they implicitly attribute to their past behaviors, choices, or feedback. Even in the absence of direct communication, this perception of influence contributes to a sense of informal collaboration. "*After leaving a negative review, I noticed that the recommendations seemed to improve. I cannot say for sure that there is a direct link, but the suggestions felt more relevant afterwards.*" (Respondent 9)

This perception reflects a subtle yet important shift: users begin to view their routine actions not only as consumption behaviors, but also as signals that may shape future developments. Experts confirm this interpretation, emphasizing that even the most implicit forms of user behavior represent valuable inputs for continuous improvement. "*Every applied filter, every click, and every rejected recommendation provides information. Even without explicit feedback, these signals help refine the system over time.*" (Web Developper)

Beyond explicit feedback mechanisms, such as reviews or ratings, experts highlight the growing importance of behavioral traces generated through everyday use. These traces are continuously captured, analyzed, and reintegrated into design and development cycles. As a result, innovation emerges less as a discrete event and more as an ongoing, iterative process embedded in routine interactions.

This mechanism sheds light on a form of collaborative innovation that differs from conventional co-creation models based on workshops, crowdsourcing initiatives, or formal participation programs. Instead, it reflects a form of "silent" collective intelligence, in which innovation is gradually shaped through aggregated and often unintentional contributions. From this perspective, personalization and customization function as interfaces between individual actions and organizational learning processes.

Importantly, experts emphasize that strategic challenge does not lie solely in data collection, but in the organizational capacity to interpret and mobilize these signals. Translating dispersed micro-actions into meaningful design decisions requires coordination between technical teams, marketing units, and innovation managers. When such coordination is achieved, personalization and customization become powerful levers for collaborative innovation, allowing firms to integrate user-generated signals into continuous cycles of experimentation and adjustment.

XXIV. CONCLUSION AND PERSPECTIVES

This study highlights a clear and structured differentiation in the ways digital personalization and customization tools are perceived and experienced by both consumers and professionals. Although these two forms of individualization rely on distinct technological principles, they do not appear to be contradictory. On the contrary, they operate in a complementary manner, each contributing differently to value creation within digital environments.

Personalization primarily operates in the background, characterized by its discreteness, fluidity, and seamless integration into digital systems. It relies on automated mechanisms that infer preferences without requiring explicit user input, allowing platforms to adjust content and offerings in a continuous manner. This form of adaptation contributes to efficiency by reducing cognitive effort and facilitating smoother interactions. Customization, by contrast, introduces a dimension of intentional choice and individual expression. It enables users to actively configure certain elements of products or services, thereby positioning them as contributors to the shaping of the offer. This form of involvement is closely associated with a stronger sense of control and appropriation.

Together, these two dynamics shed light on complementary dimensions of digital innovation. While personalization supports efficiency through invisible adaptation, customization fosters explicit contribution through deliberate intervention. The findings suggest that collaborative innovation does not rely exclusively on formal participatory mechanisms. Instead, it can also emerge through incremental adjustments informed by the observation, interpretation, and integration of users' micro-actions within continuous improvement processes.

One of the main contributions of this research lies in its emphasis on the interpretative role of digital interactions within collaborative innovation dynamics. Routine actions, often perceived as trivial or unintentional, may acquire strategic significance when they are systematically captured and translated into design or development decisions. In this sense, users may act as indirect contributors to innovation, even in the absence of explicit collaborative arrangements.

Nevertheless, this study presents several limitations inherent to its exploratory nature. First, the size and composition of the sample limit the generalization of the findings. Although the sample is diverse and theoretically grounded, the results cannot be extended to all digital consumers. Second, the study focuses on B2C visual environments, such as fashion, home décor, and technology, where interaction and configuration play a central role. Different patterns may emerge in B2B contexts or in services characterized by lower levels of visible interaction.

Future research could build on these findings by testing the identified mechanisms on a larger scale in order to assess their robustness and managerial implications. In this respect, the use of mixed or quantitative methodologies would be particularly relevant. More broadly, this study opens avenues for further investigation into emerging forms of participation in innovation within personalized digital ecosystems. It also invites practitioners to reconsider personalization not only as a tool for optimization or conversion, but as a strategic lever for fostering collaborative innovation.

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APPENDICES

Appendix A - Profile of expert respondents

Table 1- Profile of expert respondents

Expert ID	Position	Sector / Type of organization	Years of professional experience	Interview duration
E1	Web developper	Freelancer	6	52
E2	Front-end Developer	E-commerce platform	8	47
E3	Digital Project Manager	Technology startup	10	61
E4	Innovation Consultant	Consulting firm	12	55
E5	General director	Digital marketing agency	7	49
E6	Product Manager	Online retail company	9	63
E7	Software Engineer	Tech company	11	58
E8	Digital Strategist	Digital agency	14	76
E9	Academic Researcher	University	15	54

Appendix B - Profile of consumer respondents

Table 2 - Profile of consumer respondents

Respondent ID	Age range	Gender	Socio-professional category	Frequency of online purchases	Digital proficiency	Interview
C1	18 – 25	Female	Student	Very frequent	High	41
C2	26 – 35	Male	Employee	Frequent	High	38
C3	36 – 45	Female	Self-employed	Moderate	Medium	44
C4	26 – 35	Female	Employee	Frequent	High	39
C5	46 – 55	Male	Merchant	Moderate	Medium	52
C6	18 – 25	Male	Student	Frequent	High	37
C7	36 – 45	Female	Employee	Frequent	Medium	48
C8	56 +	Female	Retired	Occasional	Low	55
C9	26 – 35	Male	Employee	Very frequent	High	43
C10	36 – 45	Male	Self-employed	Moderate	Medium	50
C11	18 – 25	Female	Student	Frequent	High	40
C12	26 – 35	Female	Employee	Frequent	Medium	46
C13	46 – 55	Male	Employee	Occasional	Medium	59
C14	36 – 45	Female	Employee	Frequent	High	42
C15	26 – 35	Male	Employee	Very frequent	High	45

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