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Sustainability for Regions



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INSIGHTS INTO REGIONAL DEVELOPMENT*

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RENEWABLE ENERGY LANDSCAPES: A COMPARATIVE ANALYSIS OF LITHUANIA'S, EUROPE'S AND AFRICA'S GREEN STRATEGIES*

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Abstract. This study explores the renewable energy trajectories of Lithuania, Europe, and Africa, focusing on their strategies, achievements, and prospects. It highlights Lithuania's significant investment in wind and biomass energy, evaluating its progress within the broader European context and its role in the Baltic region's energy transition. The analysis underscores Europe's leadership in renewable energy, noting its advanced policies and technological innovations that set global benchmarks. In contrast, Africa's renewable energy potential is examined alongside its infrastructural and financial challenges, revealing opportunities and barriers. Key findings include Lithuania's substantial reliance on wind and biomass, Europe's prominent role in renewable energy adoption, and Africa's promising yet uneven progress. This comparative study provides insights into diverse approaches to renewable energy and their implications for the global transition towards sustainable energy.

Keywords: Renewable Energy; Lithuania; Europe; Africa; Green Strategy

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1. Introduction

The transition to renewable energy has emerged as a critical global priority, spurred by the urgent need to combat climate change and bolster energy security. For nations like Lithuania, this shift is not only an environmental imperative but also a strategic move to lessen dependence on imported fossil fuels and diversify energy sources (A. Adesina and G. Demas 2022; European Commission 2021a; Lietuvos Respublikos energetikos ministerija 2024). Lithuania's commitment to renewable energy positions it as a key player in the Baltic region's energy transformation, aligning with broader European objectives to cut greenhouse gas emissions and achieve climate neutrality (A. Adesina 2022; International Energy Agency 2023b; IRENA 2023).

Lithuania's renewable energy trajectory is marked by ambitious targets and significant progress. The country has made considerable investments in wind, solar, and biomass energy (CAN Europe 2024; European Environment Agency. 2022), reflecting its determination to reduce its carbon footprint and enhance its energy independence. By adopting a forward-thinking energy strategy, Lithuania aims to balance its renewable energy portfolio while navigating the challenges of a smaller national energy market (REN21 2022; World Bank Group 2004).

As Lithuania pursues its renewable energy goals, it is crucial to evaluate how its achievements and challenges measure up against the broader European landscape. This article delves into Lithuania's renewable energy journey, comparing its progress with that of other European nations (bp 2023; European Commission 2023a). We will explore the drivers behind Lithuania's energy policies, assess the implications of its successes and setbacks, and consider how its experience fits into the larger European context (Artelys 2018; United Nations Environment Programme 2022).

Furthermore, to provide a comprehensive view of the global renewable energy movement, this article will also offer a comparative perspective on Africa's renewable energy landscape. Africa, with its vast potential for solar and wind energy, presents both opportunities and obstacles that parallel those faced by Lithuania (Alex 2022; SolarPower Europe 2023). By examining these diverse contexts, we aim to contextualize Lithuania's renewable energy efforts within a global framework and highlight the interconnected nature of the renewable energy transition (Ramírez, Fraile, and Brindley 2019; Kou 2023; European climate foundation 2024; Murphy 2022).

2. Lithuania's Renewable Energy Landscape

Lithuania, a small Baltic nation, has made commendable progress in renewable energy development, particularly given its historical reliance on imported energy sources. The closure of the Ignalina Nuclear Power Plant in 2009 marked a significant turning point, leading Lithuania to prioritize energy security and sustainability. This shift has been marked by a focused effort to increase the share of renewables in its energy mix. As of 2023, Lithuania generates about 50% of its electricity from renewables, a significant achievement for a country with a relatively small energy market (Gecevičius and Kavaliauskas 2021; Jorgenson et al. 2024; Klevas, Streimikiene, and Grikstaite 2007). This section details Lithuania's renewable energy achievements and future targets as shown in Figure 1.

Wind Energy

Wind energy has emerged as the most successful renewable source, with wind farms generating 11.5% of the nation's electricity in 2021 (Lietuvos vėjo elektrinių asociacija 2022). Lithuania's investment in onshore wind farms, particularly along the Baltic Sea coast, has leveraged favorable wind conditions that bolster their efficiency (Wind 2024). Wind power is the largest contributor, producing approximately 25% of the nation's electricity (Janeliūnas 2021; Jankevičienė and Kanapickas 2023).

Biomass Energy

Biomass has also become a cornerstone of Lithuania's renewable energy strategy, especially in the heating sector. Biomass, sourced from local wood waste and agricultural residues, now accounts for 70% of district heating, significantly reducing dependence on imported natural gas and supporting local job creation (Jonynas et al. 2020). Biomass, leveraging Lithuania's agricultural and forestry byproducts, provides about 20% of the country's energy, demonstrating its crucial role in the national energy mix (Varnagiryte-Kabasinskiene et al. 2019).

Solar Energy

Solar energy, while less prominent due to lower solar irradiance compared to southern Europe, has been growing steadily (Guigaitė and Jakubavičius 2022). As of 2023, solar power contributes approximately 7% to Lithuania's electricity generation, supported by increasing residential and commercial installations (Gecevičius and Kavaliauskas 2021; Kozlovas et al. 2023).

Future Targets

The Lithuanian government has been proactive in fostering renewable energy through policies like the National Energy Independence Strategy, which aims for 100% renewable electricity consumption by 2050, and advancements in energy storage technologies like the Kruonis Pumped Storage Plant with a capacity of 165 MW (European Investment Bank 2024; Lietuvos Respublikos energetikos ministerija 2018; Media 2020). Additionally, decentralized energy production is on the rise, with increasing installations of solar panels supported by government incentives (Katinas and Markevicius 2006; Vezzoli et al. 2018).

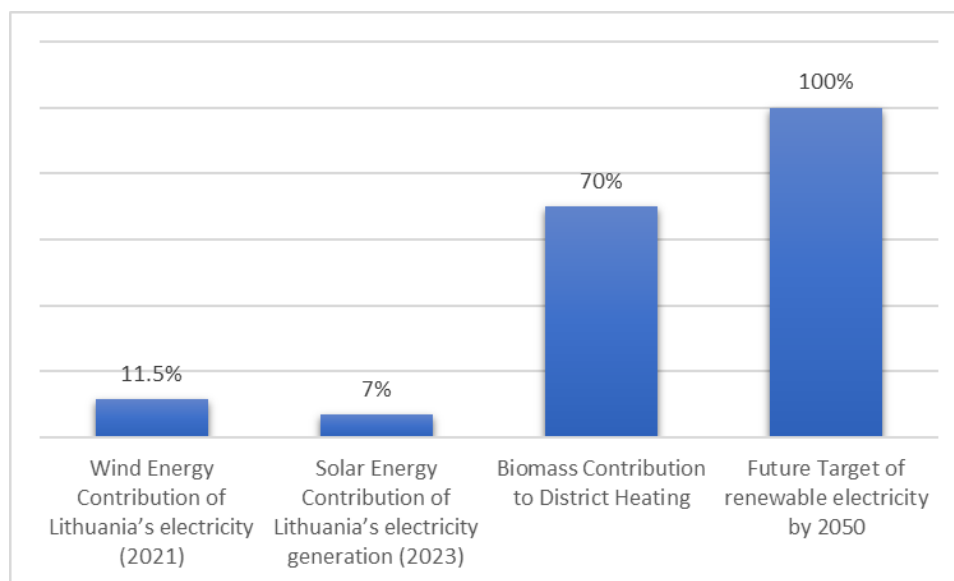


Figure 1. Lithuania's Renewable Energy Statistics and Target

Source: Lietuvos vejo elektrinių asociacija (LVEA) and International Renewable Energy Agency (IREA)

3. Renewable Energy in Europe

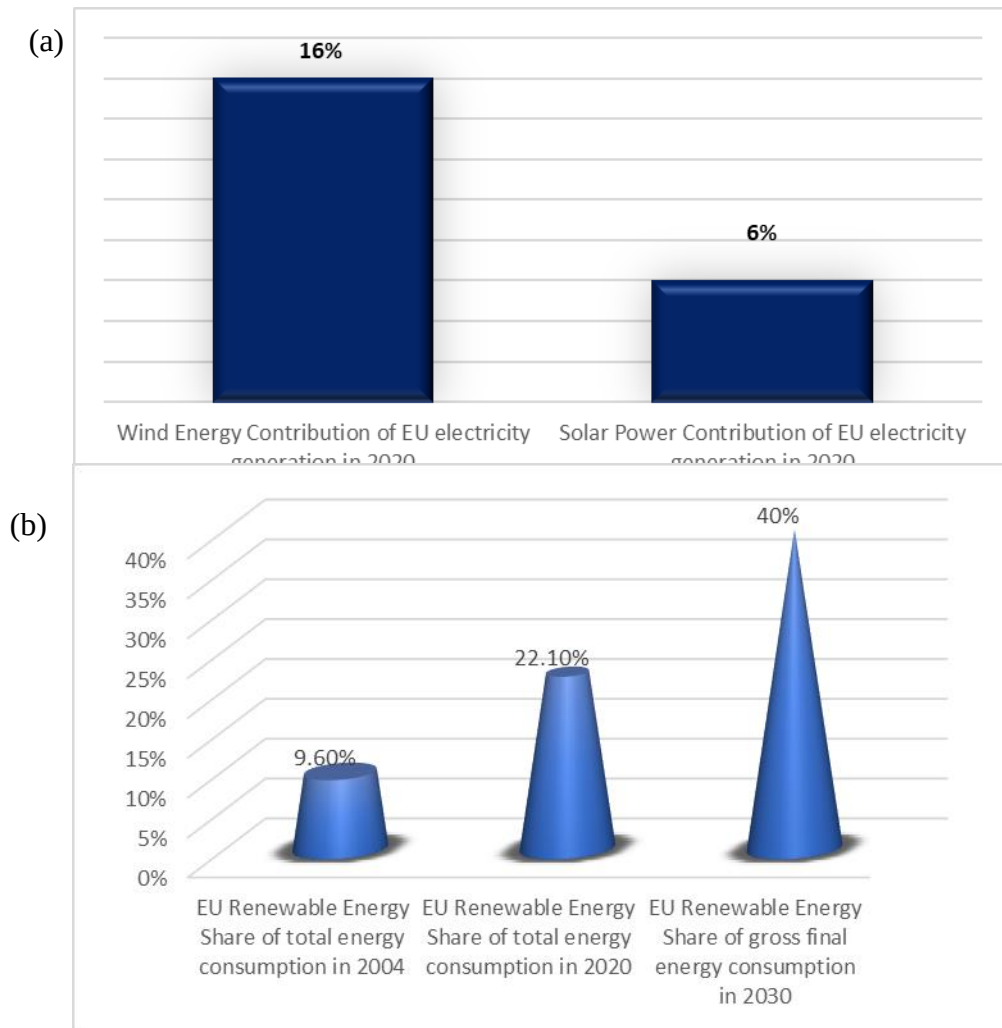
Europe has been a global leader in the adoption of renewable energy, driven by the urgency of addressing climate change, reducing greenhouse gas emissions, and enhancing energy security. The European Union (EU) has implemented several pivotal policies to spearhead this transition, with the European Green Deal being a cornerstone (Sandri et al. 2023). This ambitious initiative aims to make Europe the first climate-neutral continent by 2050, with a target of increasing the share of renewable energy in gross final energy consumption to at least

40% by 2030 (European Commission 2022; European Parliament 2022). This section reviews Europe's overall renewable energy progress, key contributors, and challenges.

Renewable Energy Share

By 2022, the EU had made significant strides, with renewable energy sources accounting for approximately 22.1% of its total energy consumption, a considerable increase from just 9.6% in 2004 (Fig.2.b) (Eurostat Statistic Explainer 2024). The rapid growth of wind and solar power has been a notable success story (Fig.2.a). Wind energy alone contributed 16% to the EU's electricity generation in 2020 (European Commission 2023b), while solar power accounted for nearly 6% (International Renewable Energy Agency 2024). This growth has been underpinned by robust national policies, generous subsidies, and the establishment of an integrated European energy market that facilitates cross-border electricity trade. The EU's €1.8 trillion investment under the European Green Deal Investment Plan underscores its commitment to this green transition, positioning Europe as a global leader in environmental sustainability (European Commission 2021b).

Figure 1. Wind and solar energy contribution in EU electricity generation (a), the evolution of renewable energy share during years (b)



Source: European Commission, Eurostat, and European parliament.

Country-Specific Insights

Denmark is a frontrunner in wind energy, with wind turbines supplying nearly 50% of the country's electricity in 2022, thanks to extensive investments in both onshore and offshore wind farms (Agnolucci 2007). Spain and Italy are key players in solar energy (Fig.3.a), with Spain boasting over 20 GW of installed solar capacity and Italy surpassing 25 GW as of 2023, driven by supportive policies and favorable weather conditions (Ferrara et al. 2024; International Energy Agency 2023a; Red Eléctrica 2024). Hydropower remains a cornerstone of renewable energy in countries like Sweden and Austria, where it supplies approximately 40% and 60% of their electricity needs, respectively, owing to their abundant water resources and advanced hydropower infrastructure (Wagner et al. 2015; Wang 2006; Zhong, Bollen, and Rönnberg 2021) (Fig.3.b). This rich tapestry of renewable energy sources across Europe not only highlights the region's commitment to reducing greenhouse gas emissions and improving energy security but also underscores its leadership in technological innovation and sustainability practices.

Nonetheless, Europe faces substantial challenges in achieving its renewable energy goals. The recent energy crisis, exacerbated by geopolitical tensions such as the war in Ukraine, has highlighted vulnerabilities in Europe's energy supply chains and the urgent need to accelerate the shift towards domestically produced renewable energy (Kuzemko et al. 2022; Skalamera 2023). While countries like Germany and Spain are making notable progress, the pace of transition varies significantly across the EU, with some nations still heavily reliant on coal and other fossil fuels (Eyl-Mazzega and Mathieu 2020).



Figure 2. Solar energy potential in Spain and Italy (a), Hydropower production in Sweden and Austria (b)

Source: International Energy Agency, and IEA

4. Africa's Diverse Renewable Energy Resources

Africa's renewable energy potential is vast, encompassing solar, wind, hydropower, biomass, and geothermal energy (Fig.4). This section explores Africa's progress, key projects, and challenges.

Solar Energy

Solar energy is a major focus, with Africa's high solar irradiance enabling significant solar power projects. For instance, Morocco's Noor Ouarzazate Solar Complex, with a capacity of 580 megawatts (MW), is one of the world's largest solar installations and demonstrates the continent's solar potential (Cantoni and Rignall 2019; World Bank Group, African Development Bank, and European Investment Bank 2017).

Wind Energy

Wind energy is also expanding, particularly in regions with favorable wind conditions. Kenya's Lake Turkana Wind Farm, the largest in Africa, boasts a capacity of 310 MW and plays a crucial role in the country's energy mix (Mukhtar et al. 2023; Simberg-Koulumies 2024).

Hydropower

Hydropower remains a significant component, with the Grand Ethiopian Renaissance Dam expected to provide approximately 6,450 MW, substantially increasing regional energy capacity (Ahmed et al. 2024; Liersch, Koch, and Hattermann 2017), (Jiregna Tadese 2020).

Biomass and Geothermal Energy

Biomass energy, derived from agricultural residues and wood, supports rural energy needs and small-scale industries. Geothermal energy, while less developed, shows considerable promise in the East African Rift region, with Ethiopia and Kenya leading exploration efforts. Ethiopia's Aluto Langano Geothermal Plant contributes 70 MW to the national grid, showcasing the potential for geothermal development (Benti et al. 2023; Samrock et al. 2020). Together, these renewable sources address critical energy access issues and position Africa as a key player in the global clean energy transition.

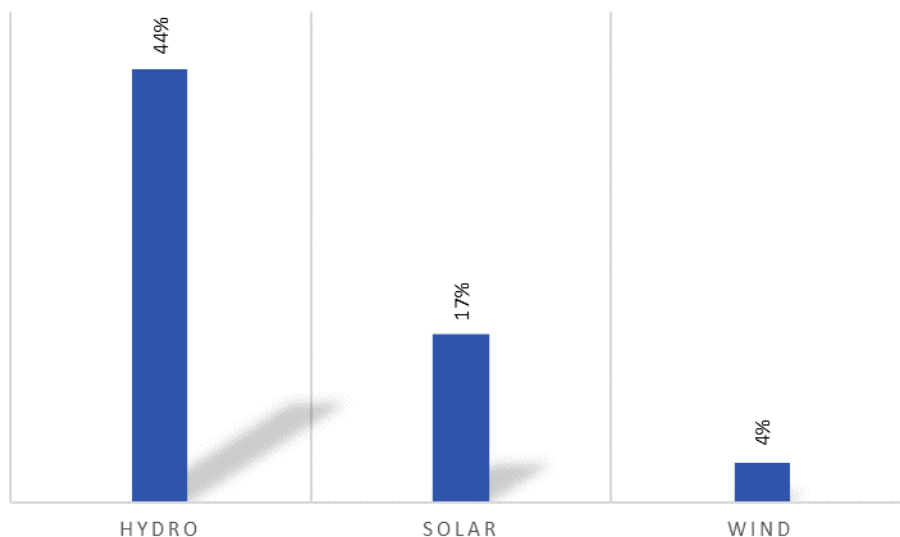


Figure 3. Top Renewable Energy Sources in Africa (2022)

Source: International Renewable Energy Agency (IRENA)

5. Comparative Analysis

Comparing Lithuania's renewable energy achievements with those of other European countries and Africa reveals differing levels of progress and potential. Lithuania and Europe are both advancing in the realm of renewable energy, though their approaches and achievements reflect their unique contexts. In Lithuania, approximately 50% of electricity is derived from renewable sources, with wind power and biomass. Solar energy, while expanding, remains limited due to the country's lower solar irradiance compared to sunnier regions. This mix is largely shaped by Lithuania's geographic advantages for wind and biomass resources and the ongoing efforts to enhance its solar infrastructure (Eurostat n.d.; Janeliūnas 2021). In contrast, Europe's renewable energy landscape is more varied and advanced (Fig.5). Denmark stands out with wind power generating approximately 50% of its electricity, thanks to extensive investments in both onshore and offshore wind farms (Danish Energy Agency 2023). Additionally, hydropower plays a significant role in northern and central Europe (International Energy

Agency 2022). Europe's broader renewable energy portfolio is supported by comprehensive policies and substantial investments from the EU and member states, enabling a more diversified approach to renewable energy (European Commission 2021b). Germany, despite its challenges with phasing out nuclear power and reducing coal dependence, has made substantial progress. By 2022, Germany generated 40% of its electricity from renewables, with wind and solar power being pivotal (Agora Energiewende n.d.). The Energiewende policy has been crucial in this achievement, establishing Germany as a major player in the global renewable energy market (Hake et al. 2015). In contrast, Lithuania's progress is more modest, though impressive given its size and economic capacity. Among the Baltic states, Lithuania is leading in renewable energy development, with Latvia heavily reliant on hydropower (about 40% of its energy mix) (Streimikiene and Klevas 2007) and Estonia still depending on oil shale, although efforts to diversify with wind and biomass are underway (Miskinis et al. 2020). Lithuania's focus on wind and biomass provides a balanced approach, but challenges remain, particularly in expanding offshore wind and solar energy capacity (Lietuvos vėjo elektrinių asociacija 2022). In summary, while Lithuania focuses on harnessing wind, biomass, and gradually increasing its solar capacity, Europe leverages its diverse geography to support a wide array of renewable technologies, bolstered by robust policy frameworks and significant investments.

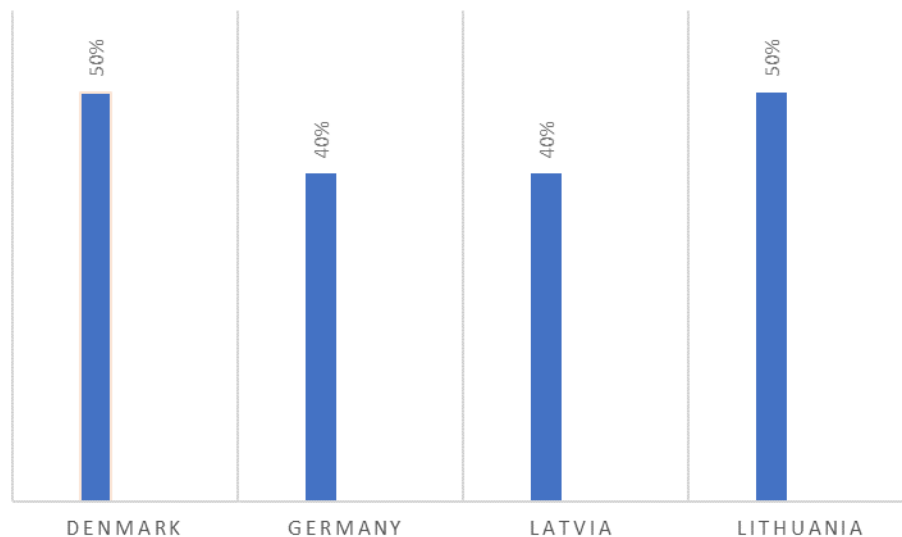


Figure 4. Electricity generation from renewable sources in 2022

Source: International Hydropower Association (IHA), Bundesnetzagentur (German Federal Network Agency), Danish Energy Agency, Eurostat

Comparing Europe's renewable energy landscape with Africa's reveals a stark contrast in progress and potential. Europe, with its advanced infrastructure and substantial financial investments, has made significant strides in renewable energy. In contrast, Africa, despite having abundant renewable resources like solar and wind, faces different challenges. In Africa, solar energy presents a significant opportunity, given the continent's high solar irradiance levels. Countries like Morocco and South Africa are leading the way, with Morocco's Noor Ouarzazate Solar Complex and South Africa's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) demonstrating substantial investments in solar power (Ministry of Youth, Culture and Communication 2016). However, the continent's overall renewable energy capacity remains underdeveloped compared to Europe's advanced infrastructure. As of 2022 (Fig.6), renewables accounted for about 21% of Africa's total energy generation, with a strong emphasis on hydroelectric power, which constitutes a large portion of the continent's

renewable energy mix (OECD 2022). Comparing Lithuania with Africa shows that Africa has significant renewable potential, particularly in solar and wind, but faces challenges such as financial constraints and infrastructure gaps (Amoah et al. 2020; Global Renewables Outlook 2020).

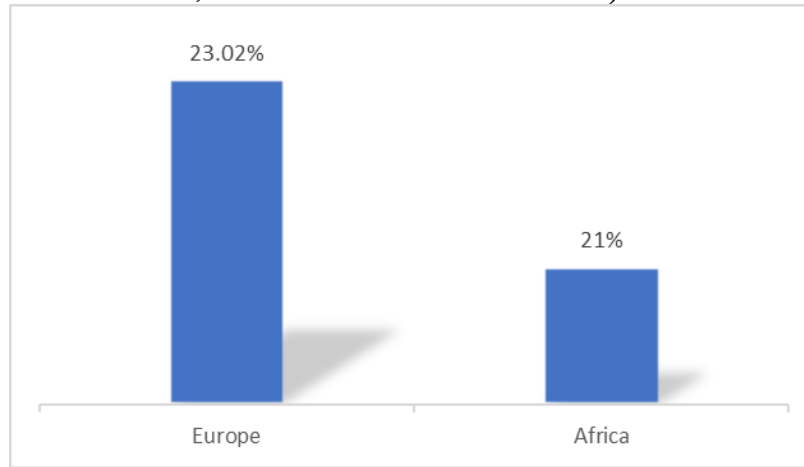


Figure 5. Europe and Africa's Renewable Energy Share of 2022
Source: Eurostat, International Renewable Energy Agency (IRENA)

Challenges in Africa include limited financial resources, inadequate infrastructure, and political instability, which can hinder the development and deployment of renewable energy projects. Additionally, many African countries face significant energy access issues, with a large portion of the population lacking reliable electricity (Gabra, Amoako, and Ampong 2023). Despite these challenges, there is a growing recognition of the potential for renewables to drive economic development and improve energy access across the continent (Juju et al. 2020). Initiatives such as the African Renewable Energy Initiative (AREI) aim to mobilize investment and support large-scale renewable energy projects, reflecting a commitment to harnessing the continent's renewable potential (Maged 2023).

Conclusions

Lithuania's advancements in renewable energy are notable, yet they must be viewed within a broader European and global context that showcases the diverse strategies and outcomes in the transition to sustainable energy. Lithuania has made significant strides, particularly in wind and biomass energy, which are crucial to its national energy strategy and reflect its commitment to reducing carbon emissions and enhancing energy security. However, its progress is part of a larger European landscape where nations have adopted varied approaches to meet ambitious climate goals. Europe's advanced renewable energy portfolio, characterized by leading technologies and extensive infrastructure investments, contrasts with the emerging but challenging renewable energy landscape in Africa. While Africa holds vast potential for solar and wind energy, its development is hindered by infrastructural limitations and financial constraints. This comparative analysis highlights the complexity of global energy transitions, emphasizing that the path to sustainability is not uniform but shaped by regional contexts and capabilities. It underscores the need for continued investment in renewable technologies, supportive policy frameworks, and strengthened international collaboration to drive progress and overcome barriers. By addressing these challenges collectively, the global community can better support diverse approaches and enhance the overall advancement of renewable energy development worldwide.

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FREE BUS TRAVEL AS A POLICY TOOL FOR IMPROVING RURAL OLDER ADULTS' ACCESS TO OPPORTUNITIES

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Abstract. In recent decades, many countries have experienced population ageing. In Estonia, for example, the share of older adults has nearly doubled from 11.6% in 1990 to 20.3% in 2023. Although most older adults live in towns and cities, an increasing number opt to age in place, including hamlets and villages in isolated areas, far from urban facilities and services. This means that most of them use their car to get around. However, life changes such as ageing and the cessation of driving can hinder older adults' access to basic amenities such as food shops and doctors' offices, putting them at risk of social exclusion. In this case, public transport remains their lifeline to friends, family, and the wider community. In this paper, we conduct ride-along interviews with non-driving older adults in an isolated rural area to examine whether the introduction of free bus travel has improved their access to urban facilities and services. Our findings suggest that while the policy has been financially, psychologically, and socially beneficial for non-driving older adults, its full accessibility benefits have not been realised due to the lack of public transport service improvements. We therefore conclude that in rural areas, free bus travel should be accompanied by other measures to ensure at least a basic level of accessibility.

Keywords: rural accessibility; basic accessibility; rural ageing; ageing in place; transport poverty; transport-related social exclusion

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1. Introduction

The global population is ageing. Around the world, the share of older adults has almost doubled between 1974 and 2024, from 5.5% to 10.3%, and is expected to reach 17% by 2050 (United Nations, 2023). In Europe, older adults already represent more than a fifth of the population; by 2050, this is expected to rise to almost 30% (Eurostat, 2024). This has led many to refer to population ageing as one of the most significant public policy challenges of the twenty-first century (Sander et al., 2015).

One of the challenges posed by population ageing is to create age-friendly neighbourhoods that facilitate ageing in place. This is especially relevant in rural areas, which tend to have proportionately more older adults than urban areas but lack the necessary amenities and services to support ageing in place (Chapman & Peace, 2008). As a result, older adults in rural areas rely on their cars to meet basic needs such as grocery shopping, getting to the doctor's office and visiting friends and family (Walsh et al., 2020). The problems, however, start when they can no longer drive a car and have to rely on others (typically, their children and neighbours). This reduces their autonomy and potential to participate in out-of-home activities, increasing the risk of social exclusion (Browning & Sims, 2007).

Public transport is generally seen as an alternative to the car when it comes to providing access to out-of-home activities. In rural areas, however, it tends to be very limited and catered to the needs of school children. Therefore, it may not meet the needs of older adults both in terms of where and when it takes them. Furthermore, public transport tends to be more expensive in places where fares are based on distance than in urban areas, where fares are usually fixed and monthly travel passes are available. This adds another barrier to public transport use among older adults in rural areas, who often have lower incomes than their urban counterparts.

In Estonia, the introduction of free bus travel in rural areas was seen as an attempt to address this problem, among others. The policy sparked much debate: while some supported the government's effort to remove one of the main barriers to public transport, others remained sceptical. Nevertheless, an apparent result was a 20% increase in patronage during the first year following the removal of fares. Additional bus services were introduced to keep up with the growing demand. However, while the increase in public transport use is evident, no research has been carried out to assess whether this increase has led to greater accessibility benefits, particularly for those who rely on it most, for instance, non-car-driving older adults.

The study presented in this paper addresses this gap by investigating the effectiveness of free bus travel in improving rural older adults' access to key opportunities and supporting ageing in place. What makes this case study unique is that it takes place in a so-called naturally occurring retirement community (hereafter NORC). Hunt & Gunter-Hunt (1986) coined the term NORC to describe retirement communities "that were not planned (...) for older adults, but over time came to house predominantly older adults". In our case study, these are hamlets and villages that have "grown old": according to the 2011 census, more than 60% of residents are over 60 years old, making this rural community a textbook example of a rural NORC. Although it is home to dozens of older adults, it lacks basic amenities such as a grocery store, pharmacy, library, and post office, among others. The nearest grocery store is a half-hour's drive away, and those without a car have to rely on their children and neighbours or take the bus to Jõhvi, a regional centre about an hour's bus ride away (see Figure 1).

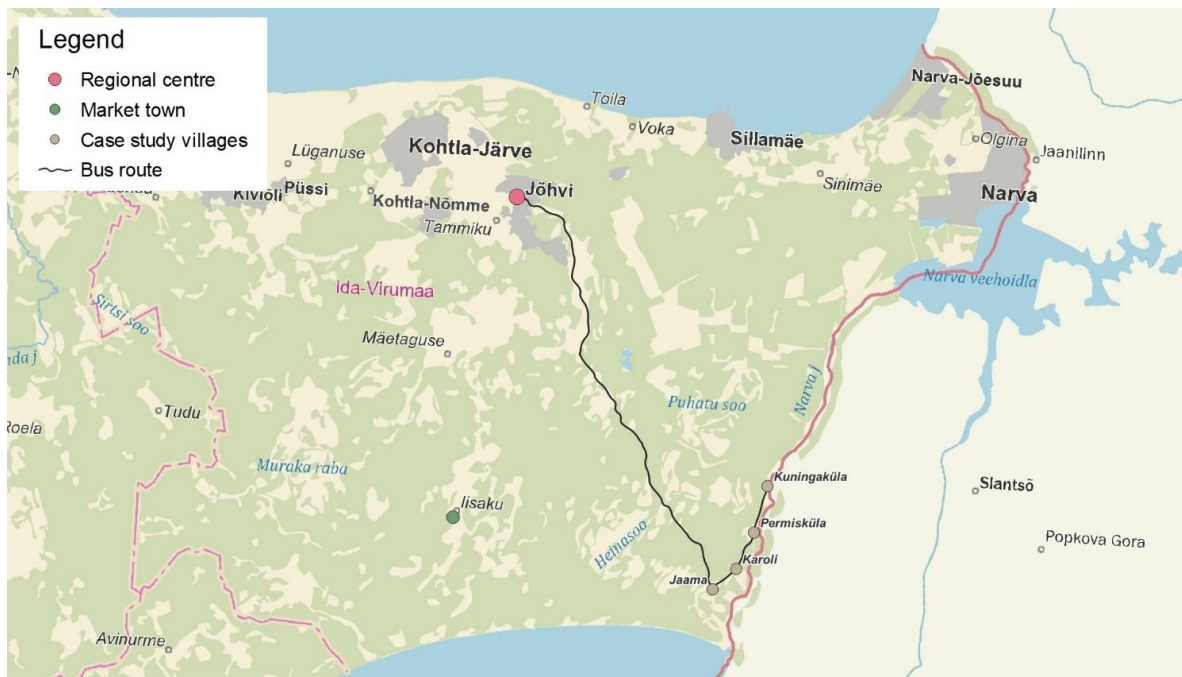


Figure 1. A map of the case study area. The nearest supermarket, pharmacy, and GP's office are located in the small market town of Lisaku (pop. 700), but the bus takes people all the way to Jõhvi, the regional centre (pop. 10 000).

The bus makes four return trips a week during the summer months (May to October) and three return trips a week in the winter (November to April). Before the removal of fares, a return ticket to Jõhvi cost 3.20 euros, which means that a single-person household could save up to 30 euros per month on shopping trips to the city twice a week (note that monthly passes were not available at the time)*. With this in mind, this paper seeks to answer the following research question: How has the introduction of free bus travel in the case study area affected non-driving older adults' access to key destinations and activities?

2. Theoretical background

2.1 On mobility and accessibility

As John Urry (2007) once observed, “it sometimes seems that all the world is on the move”. The clearest example of this can be seen in the rise of the car as the “default” mode of transport and its “overwhelming impact (...) in transforming the time-space ‘scape’ of the modern urban/suburban dweller” (Sheller & Urry, 2000). The “automobilization” of time-space did not happen overnight, though, as its foundations were laid in the second half of the twentieth century, backed by “an aggressively supportive social, political, and economic environment” (Monkkonen, 1988). In the following years, as Sassen (1996) puts it, “the urban environment, built (...) for the convenience of the car, has “unbundled” territorialities of home, work, business, and leisure that had historically been closely integrated and fragmented social practices that occurred in shared public spaces”. As a result, “much of what many people now think of as “social life” could not be undertaken without the flexibilities of the car and its availability 24 hours a day” (Urry, 2006). Therefore, “mobility”, as Bauman (1998) argues, “climbs to the rank of the uppermost among the coveted values—and the freedom to move (...) fast becomes the main stratifying factor of our late-modern or postmodern times”.

It is well established that limited mobility opportunities contribute to social exclusion (see, e.g., Delbosc & Currie, 2011; Allen & Farber, 2020; Luz & Portugal, 2022; Székely & Novotný, 2022). A widely cited 2003 report by the UK Social Exclusion Unit (hereafter SEU) highlights how “problems with transport and the location of services contribute to social exclusion by preventing people from participating in work or learning, or accessing healthcare, food shopping, and other local activities”. The report also stresses that “those living in rural areas without a car face particularly acute problems”, as “distances to key services are often greater and public transport is often infrequent or inadequate”. Furthermore, transport problems are not limited to those without a car but also affect those who have a car, but cannot afford the cost of necessary trips, leading to missed employment and other opportunities.

Similarly to the SEU report, researchers studying the links between transport disadvantage and social exclusion suggest that the latter occurs “not due to a lack of (...) opportunities, but a lack of *access* [emphasis added] to those opportunities” (Preston & Rajé, 2007). Thus, rather than examining the availability of public transport, they argue that the focus should instead be on examining “the consequences of [poor public transport availability] in terms of [people's] (in)ability to access key life-enhancing opportunities, such as employment, education, health and their supporting social networks” (Lucas, 2012). Appropriate policy measures should aim to improve people's access to key destinations and activities (that is, accessibility) rather than mobility, as improvements in mobility can, but do not necessarily, lead to improvements in accessibility (Martens & Bastiaanssen, 2014; Martens, 2016; Levine et al., 2019; Ryan & Martens, 2023; Walker, 2024). Some examples of policies and practices that should be considered include improving the level of accessibility provided by the public transport network so that people without cars could access a broader range of out-of-home activities; providing facilities and services closer to people's homes, making them accessible by walking and cycling, thus reducing the need for motorised transport; facilitating the building of social networks and social relationships within the community, thereby increasing people's social capital (see also Bourdieu, 1979).

* For context, the average old-age pension at the time was less than 500 euros per month.

2.2 On naturally occurring retirement communities

The SEU report and other authors (see, e.g., Kamruzzaman & Hine, 2011; Lange & Norman, 2018; and Dabelko-Schoeny et al., 2021) suggest that older adults in rural areas are much more likely than their urban counterparts to experience accessibility poverty. This is particularly relevant given the increasing prevalence of naturally occurring retirement communities (NORCs). Hunt & Gunter-Hunt (1986) coined this term to describe housing developments "that were not planned for older people, but which over time came to house largely older people". While NORCs share some characteristics with planned retirement communities, such as relatively small populations, they differ in age structure, funding, and size. NORCs can emerge in various ways but most commonly result from either ageing in place or in-migration of older adults, particularly young retirees. This is especially true in rural areas with abundant natural amenities (e.g., lakes, rivers, forests, and mountain ranges), which young retirees often see as "more beautiful, tranquil, or inspirational than their current, usually urban environment" (Borsdorf et al., 2012).

A rural NORC, as the name implies, is a naturally occurring retirement community located in a rural area. Based on census data from Wisconsin, Marshall & Hunt (1999) developed a typology of rural NORCs based on the characteristics of the older migrants they attract and the community features these migrants find appealing. They identified three types of rural NORCs: Amenity, Bi-Focal, and Convenience NORCs. Amenity NORCs are rich in natural amenities and tend to attract "younger, healthier, and more active retirees who move to the area to escape urban life and enjoy the natural environment". Initially, retirees in amenity NORCs are not concerned about access to urban services and facilities. Bi-Focal NORCs, on the other hand, attract retirees "seeking natural amenities but wishing to remain close to friends and family". Convenience NORCs differ from the rest by attracting retirees from nearby rural areas who "want to be near relatives, often due to recent widowhood, or because they need to be closer to town-based services such as healthcare". Based on Marshall & Hunt's (1999) typology, older adults in amenity NORCs are most vulnerable to transport-related social exclusion. Although these NORCs offer scenic views and recreational opportunities, they often lack basic amenities, such as grocery stores and public transport to nearby towns and cities. As a result, ageing in place can be particularly difficult for non-driving older adults, especially those who have recently stopped or reduced driving.

Rural NORCs are also not limited to the United States. For example, the 2021 Population and Housing Census shows that in Estonia, more than a tenth of adults over 60 years live in rural areas that meet the criteria of a rural NORC; that is, more than half of their neighbours are also over 60 years old (Statistics Estonia, 2021; Table RL003, authors' calculations). Marshall & Hunt (1999) suggest that the structural ageing of the population, combined with the growing preference of rural adults to age in place, will likely "lead to an influx of retirees into rural retirement destinations", contributing to the rise of more rural NORCs in the coming decades. This calls for a rethinking of the role of public transport in rural areas generally and NORCs particularly, both for researchers and practitioners.

3. Materials and methods

3.1. Research design

This study adopts an interpretivist perspective, recognising that "reality is constructed by individuals interacting with their social worlds" (Merriam, 1998). It, therefore, relies on "[participants'] views of the situation being studied" (Creswell, 2003). With this in mind and based on similar studies (see, e.g., Casas, 2007; Engels & Liu, 2011; and Broome et al., 2012), this study uses Stake's qualitative case study approach to address the research question.

In "The Art of Case Study Research", Stake (1995) defines a case study as "a study of the particularity and complexity of a single case, coming to understand its activity within important circumstances". In Stake's (2003) approach, "the bulk of case study work", as he puts it, "is carried out by individuals who have intrinsic interest in

the case and little interest in the advance of science". Cases are selected based on whether they are "interesting in themselves or can facilitate the understanding of something else", that is their practical relevance rather than theoretical contribution (Stake, 2006). For Stake, case study research is about "discovering and portraying the multiple views of the case" rather than seeking generalisability. Therefore, his approach relies on analytical generalisation, which requires the researcher to "specify evidence, make arguments explicit, and then allow the readers to judge the soundness of the claim" (Swanson & Holton, 2005). In doing so, it combines the strengths of both quantitative and qualitative data collection methods to create a "thick description" of each case (Stake, 1995).

To achieve this, this study employs go-along interviews (hereafter go-alongs), described by Kusenbach (2003) as "a hybrid between participant observation and interviewing". Used by scholars from a range of disciplines, including sociology (Carpiano, 2009), geography (Anderson, 2004), and public health (Garcia et al., 2012), go-alongs involve the researcher "accompanying inform-ants on (...) outings and through asking questions, listening and observing, actively exploring their subjects' stream of experiences and practices as they move through, and interact with, their physical and social environment" (Kusenbach, 2003). Go-alongs can be conducted while walking, in which case they are referred to as "walk-alongs", and while driving, cycling or using public transport, in which case they are referred to as "ride-alongs". Because of their contextual sensitivity, go-alongs are particularly suitable for exploring environmental perceptions, spatial practices, biographies, social architecture, and social domains.

Go-alongs have their strengths and limitations. Carpiano (2009) highlights two main benefits: first, go-alongs reduce the typical power dynamics between the interviewer and interviewee, which is especially important when conducting research with marginalised populations; second, they are crucial for establishing rapport with the community. Therefore, go-alongs minimise the risk of what Bourdieu (1979) refers to as "symbolic violence". However, the success of go-alongs, and especially walk-alongs, depends on several factors beyond the researcher's control, including weather conditions, the walkability of the neighbourhood, and the mobility of the participants (although these are less of an issue in ride-alongs). Furthermore, transcribing audio data from a walk-along in a busy area or a ride-along on a bumpy road can be challenging, even for the most experienced transcriptionists.

3.2. Data collection

The first stage of data collection took place on the morning departure of bus no. 546 in early 2020, just before the onset of the Covid-19 pandemic. Purposive convenience sampling was used to recruit passengers who met the following sampling criteria: permanent residents of the case study area, aged 60 and older, with no or limited access to a car. As passengers boarded the bus, potential participants were invited to share their experiences with free bus travel. Those who agreed to participate were seated in the middle of the bus, close to the voice recorder. Of the 25 passengers who boarded the bus during the ride-alongs, 18 met the sampling criteria, and 12 agreed to participate in the study (see Tables 1 and 2). Once the bus passed through the last village before reaching the main road to Jõhvi, the researcher introduced the purpose of the study and its context and assured participants of the confidentiality of the data. It was emphasised that the data would be presented in aggregate form, ensuring that individual participants could not be identified.

Table 1. An overview of the ride-alongs

	Ride-along 1	Ride-along 2	Ride-along 3
Day of the week	Wednesday	Friday	Sunday
Duration	2 hours	2 hours	1 hour ¹
Number of passengers	13	7	5
Number of passengers who met the sampling criteria	10	5	3
Number of passengers interviewed	5	4	3

¹ The third interview was shorter than the first two, as the bus used to take a different route on Sundays.

Table 2. Ride-along participants

	Ride-along(s)	Gender	Age group ²	Household size	Car availability
Participant A	1	Female	Middle-old	1	None
Participant B	1	Male	Middle-old	1	None
Participant C	1	Male	Young-old	1	None
Participant D	1 and 3 ¹	Female	Middle-old	2	Sometimes
Participant E	1	Female	Middle-old	1	None
Participant F	2	Male	Young-old	1	None
Participant G	2	Male	Young-old	1	Sometimes
Participant H	2 and 3 ¹	Female	Young-old	2	Sometimes
Participant I	2	Female	Young-old	2	Sometimes
Participant J	3	Female	Young-old	1	None

¹ Participants D and H participated in two ride-alongs.

Note: Following Zizza et al. (2009), the term “young-old” refers to individuals aged 65–74, while the term “middle-old” refers to individuals aged 75–84. ride-alongs.

3.3. Data analysis

This study follows Elo & Kyngäs' (2008) inductive approach to content analysis, which is used when “there is not enough former knowledge about the phenomenon or if this knowledge is fragmented”. After each ride-along, the recording was transcribed verbatim and supplemented with the researcher's field notes and reflections. Once all ride-alongs were completed, the transcripts were read to gain a general understanding of the participants' responses. The transcripts, along with the field notes and reflections, were then open-coded separately by two researchers to identify recurring themes related to the research question. These themes were grouped into higher-order categories (Strauss & Corbin, 1998), making the process more collaborative and allowing for researcher triangulation.

4. Results

The following section summarises the results of the ride-along interviews. A total of three ride-alongs were held with 10 unique participants (though 12 in total, as two people participated in two ride-alongs), who were encouraged to share their experiences of using public transport to reach desired destinations and activities before and after fares were removed. These interviews' key findings and implications are organised into three categories, highlighting the policy's 1) benefits, 2) drawbacks, and 3) other issues that, while not directly related to free bus travel, still limit the policy's usefulness.

4.1. Policy's benefits

Financial benefits. The most common benefit mentioned is financial support, which means that older adults have more money to spend on participating in activities rather than getting there. This, in turn, also increases their use of public transport.

Participant D, for instance, says that the removal of fares is particularly helpful when she needs to visit the doctor's office more often than usual:

RESEARCHER: So how much you used to spend on public transport?

PARTICIPANT D: Well, let's see... If I used to make four trips a month... three twenty for a return ticket, so it's about thirteen euros.

RESEARCHER: That sounds about right.

PARTICIPANT D: Yes, but if I had to go to the doctor more often or if there were other things I had to take care of, then I spent more than that... now that it's free, I'd say there's more... freedom

Similarly, Participants E and F say that after the fares were removed, they participate in out-of-home activities more often than they used to:

RESEARCHER: Would you say that public transport has become more useful to you?

PARTICIPANT E: I would say that we use the bus as much as we used to... or maybe a little bit more, not much, but certainly a little bit more than we used to (...) In the summer there are definitely more people on the bus, some go to town for no reason, there are even people I've never seen take the bus when it wasn't free... (...) and because it's free, it's full of people. (...) as for today, I see that there are quite a lot of people [on the bus], that's because Wednesday is the best day of the week to go shopping.

PARTICIPANT F: I usually go when I need to, but since it's free, I probably use it a bit more than I used to... I'd rather go to the doctor more often while I can.

PARTICIPANT E: My neighbour takes the bus once a week, or maybe even once a fortnight, she buys her groceries and she's happy with that... as for me, with my bad health, I wouldn't mind going to town a couple of times a month instead of every week, but I've got pets, I have to go every week to buy minced meat, wheat grits and everything... some people I know who go to the doctor regularly are very happy [with free bus travel], they can go to town as often as they like.

Participant G also shared that:

RESEARCHER: So, you take this bus as often as you used to?

PARTICIPANT G: Of course, I take it more often!

RESEARCHER: Is there a particular reason for that?

PARTICIPANT G: Well, I visit the city once a month, and also Kuremäe [a village halfway between the case study area and Jõhvi] (...) now I can go there more often.

RESEARCHER: But do you feel that public transport gets you where you need to go?

PARTICIPANT G: Sure, it does, why wouldn't it? But of course, the more departures, the better.

However, some participants noted that the financial benefits of free bus travel are rather modest, with Participant I jokingly calling it a "pension supplement". Participants A and B also feel that free bus travel does not improve their accessibility, as there is still only one day a week when they can go to town without having to wait too long for the bus home:

RESEARCHER: I've heard people say that they use public transport more often since it became free. Is this the case for you?

PARTICIPANT A: We only use it when we need to... to go to the doctor, for example, or to buy some food because we don't have any shops out here.

PARTICIPANT B: Some time ago the schedule was different, there used to be a bus on Friday, Saturday and Sunday, but now it's only on Wednesday, when it leaves town at a quarter past two... (...) it's convenient, you arrive in town, buy groceries and go back while the sun's still shining... so even though it's free, I only use it on Wednesdays.

PARTICIPANT C: ...Wednesday is the best, I think everyone will tell you that... because while you don't have to sit at the bus station for six hours waiting for the bus to take you back to the village, there's still enough time to go to the doctor and take care of things.

RESEARCHER: So, you don't take this bus on other days of the week?

PARTICIPANT C: No... if you only go shopping, why should you do it more often? Once a week is enough. If there's something urgent, I just get on the bus and go.

Here it is important to note that the bus only runs three times a week on Wednesdays, Fridays, and Sundays. Although it always arrives in town at 10 a.m., the departure time varies. On Fridays and Sundays, it leaves at 5:15

p.m., meaning there are roughly eight hours in town. On Wednesdays, however, it leaves earlier at 2:15 p.m., thus allowing for a much shorter stay. The Wednesday departure is the most popular among the locals, as it provides enough time for everyday activities without having to wait too long for the bus home. However, Participant B points out that even a four-hour stay in town feels too long when there is "nothing else to do there":

PARTICIPANT B: I don't feel that anything has changed for me [for the better]. I used to spend... how much... one sixty, three twenty, some twenty euros a month... that's nothing (...) after the village shop closed, I used to take the local bus to town on Thursdays, it was free and we only had to spend two hours in town... you could go to the shop, buy your food and go back home... now this bus is free, but there are four hours in town... I get the food and then there's nothing else for me to do there.

According to the participants, they use public transport mainly for grocery shopping, visiting the doctor's office, and seeing friends and relatives:

RESEARCHER: There are only four hours in town today, how will you spend them?

PARTICIPANT B: Well, I'll go to the doctor (...) and then do some shopping... what else?

PARTICIPANT C: There are crossword puzzles, of course!

PARTICIPANT B: Well, there's nothing else to do in town... I could go to the library, but I have a small library at home, so why bother? That's why I take the bus on Wednesdays.

When discussing his plans for the day, Participant G mentions that he is on his way to the food shop in Kuremäe. Getting groceries takes about half an hour, but then he has to wait around eight hours for the bus back home. Instead of waiting, he explains that he plans to take another bus to Jõhvi simply to "kill time" before taking the bus home:

RESEARCHER: What if you could visit other places besides Jõhvi?

PARTICIPANT G: Well, that would be good, I guess, but I don't really want to go anywhere else, honestly... it would be good if the bus went to Kohtla-Järve [another town close to Jõhvi], let's say, on Fridays and Sundays (...) maybe someone would take [the bus] to work, to school... but as for me, once a week is enough, I just go to Kuremäe, then I take another bus to Jõhvi, and then I come back (...) but as I said, there is a convenience store in Kuremäe, I get all my food there, so there's not much for me to do in Jõhvi except kill time.

RESEARCHER: So, you've been doing this for a while?

PARTICIPANT G: No, but now that it's free, why not.

Psychological benefits. Some participants note that since the fares were removed, public transport has become much easier to use. For instance, Participant A shares that she no longer has to withdraw money from the ATM in town before heading home, nor worry about whether the bus driver has enough change. This, as she puts it, gives her peace of mind:

PARTICIPANT A: Well, of course, it saves money... and now it's easier to take the bus, you don't have to worry about having small bills... you don't have to think "what if I only have large bills"... what if I get on the bus and the bus driver tells me "I don't have any change, look for smaller bills!" (...) When public transport wasn't free, I used to make sure that before I went back to the village, I had some money in my pocket for a trip back to town, but now my mind is free from such worries... I don't have to look for money, I don't have to count the coins... as my eyesight is not so good, it [counting the coins] was a problem for me... Once I dropped the coins in front of the bus driver and he told me to bend down and pick them up.

Social benefits. The ride-alongs also revealed that for older adults, the bus is more than just a way to get from A to B. Similarly to Green et al. (2014), it was observed that the bus acted as a kind of "Facebook on wheels", a third place where older adults from different villages could meet, chat, and gossip on their way to town (for more on third places, see Oldenburg, 1989):

RESEARCHER: So, do you always chat on the bus or is there something special going on today?

PARTICIPANT E: Of course we do!... All the latest news, from start to finish. And it would be great if we could see each other more often.

This way, removing fares made this social space more accessible for those who might have struggled to participate due to financial constraints.

4.2. Policy's drawbacks

One drawback highlighted during the ride-alongs was overcrowding. The case study area is a popular summerhouse destination, and during the warmer months, when seasonal residents arrive, the bus often becomes overcrowded, leading to conflicts over seating. This is especially the case on Wednesdays, the only day of the week when there is a four-hour stay in town.

The participants' observations are interesting, as ticket sales data do not show signs of overcrowding. Participant G explained that this is because seasonal residents usually travel light, while permanent residents often bring large shopping bags and trolleys that take up extra seats. They typically buy a week's worth of groceries, not only for themselves but also for their friends and neighbours who cannot take the bus on their own. These shopping bags and trolleys take up extra seats, but this is not reflected in the ticket sales data:

RESEARCHER: You mentioned that there are some problems with the bus in the summer. Can you tell me more about that?

PARTICIPANT G: Well, yeah... [the bus] is full of dachniks [seasonal residents] trying to squeeze in, pushing and shoving everyone and shouting that they have nowhere to sit because we're carrying too many bags.

PARTICIPANT J: On Wednesday, there are only four hours in town.

PARTICIPANT G: But what they don't understand is that [Wednesday] is the only day we can go shopping, and so we buy food for a week ahead, and not only for ourselves but for our families and neighbours who can't take the bus themselves... So of course, we carry a lot of bags, sometimes three big bags for bread, milk, something that our neighbours have asked us to bring... and of course, we put these bags on the seats, and so the dachniks [seasonal residents] are angry because they don't have a place to sit.

PARTICIPANT I: They have flats in the city, they can go there whenever they want [because they have a place to stay], but they still take the bus on Wednesday just because there're four hours in town and it's free... on Friday it's seven hours, but unlike us, they don't have to sit at the bus station all day.

Overcrowding was brought up again by another participant when discussing the free shopping bus provided by the local municipality in Vasknarva, a neighbouring village not included in the study:

RESEARCHER: What if this bus stopped in Vasknarva? Would people use it?

PARTICIPANT I: In the summer they probably would... I know some people and our [rural municipality] mayor also said that there are people who aren't registered here, who have two, sometimes three cars in their front yard, but they take the free shopping bus to Iisaku every week... I mean, it doesn't look good, they don't pay local taxes, but they use the bus for free, and sometimes there's not enough room for everyone.

Participant I's comment suggests that the local government is aware of the community's concerns about seasonal residents using the free shopping bus. Participant H even felt that seasonal residents without a "propiska" (i.e. registration) in the local municipality were 'robbing' permanent residents of local amenities, such as food shops:

RESEARCHER: Have you noticed any new people moving into the area in recent years?

PARTICIPANT H: Well, judging by the new houses, there seem to be quite a few.

RESEARCHER: Do they live here all year round or...

PARTICIPANT H: No, only in the summer; they live in the city, they don't register here, they don't pay taxes to the municipality, so there's no food shop here even in the summer.

It should be noted that here, Participants I and H are referring to a different free bus service provided by the local municipality, which serves neighbouring villages but not the case study area. The issue of overcrowding on the free bus service serving the case study area was raised only once, and no other drawbacks were mentioned.

4.3. Other issues

During the ride-alongs, participants raised concerns that, while not directly related to free bus travel, still limit its usefulness. One key issue highlighted was the poor quality of the public transport infrastructure, particularly the lack of raised kerbs at bus stops. For example, Participant A shared that, due to her mobility impairment, she finds it difficult to take the bus on her own:

PARTICIPANT A: The steps of the bus are too high for me... about five years ago I could have climbed them by myself, but now I can't take the bus by myself. (...) Not long ago, when I was getting on the bus, I asked a man standing behind me for help, but he replied: "I don't know how to!". At that point I was already holding on to the railing, trying to pull myself up, but I didn't have the strength, so I shouted: "Push me up from behind!", and he said: "I don't understand...", then I replied: "Push me up the steps, they're too high!". So he pushed me from behind and that's how I got on the bus.

Similarly, Participant D described her walk to the bus stop as "painfully long". However, when asked how far she lived from the bus stop, she said it was "about three or four houses away":

PARTICIPANT D: It would be nice if there was another bus stop in the village... today the walk to the bus stop was painful and it took me a long time to get there.

RESEARCHER: I'm sorry to hear that. But how far do you live from the bus stop?

PARTICIPANT D: Well, about three or four houses away.

RESEARCHER: Would it help if you could get off the bus closer to where you live?

PARTICIPANT D: Yes, that would be good, especially in the summer when there are even more old people out here.

Participant C summed it up as follows:

RESEARCHER: Do you find it difficult to take the bus?

PARTICIPANT C: It's fine... as long as I can walk and nothing bad happens to me... it's much more difficult for older people, so I try to help them as much as I can, carrying their bags onto the bus and so on."

In all three ride-alongs, participants expressed frustration with the long waiting times in town, particularly on Fridays and Sundays. Several mentioned that everyday activities such as grocery shopping and taking care of personal business take a couple of hours at most. Once these are taken care of, they end up waiting at the bus station for the rest of the day:

RESEARCHER: What about the time in town, is it enough for you?

PARTICIPANT E: Well, today it's four hours.

PARTICIPANT D: And that's more than enough!

PARTICIPANT E: Well, yes, there could be another day like Wednesday.

RESEARCHER: Like maybe Saturday?

PARTICIPANT E: Yes, that's right! I was going to say that... because, well... my health is very bad, I can't take all the medication with me every time I go to town... and I must sit there until five o'clock? When I arrive in town, I need an hour, maybe two, to do everything I need to do, but where do I have to sit until five o'clock? I have no acquaintances there, let alone places to pass the time... and waiting at the bus station is so exhausting, especially since the meds make me sleepy... and I want to sleep in my bed, not on the bench at the bus station... so yes, it would be helpful if there was another short day in town.

Another issue raised during the ride-alongs was access to the hospital, which is about a 10-minute drive from the bus station (or 10 to 30 minutes by public transport). Participant A, who was on her way there with a relative, described the journey as follows:

PARTICIPANT A: You know, when I call the hospital to book an appointment ... the first thing I say is "don't even look at Monday, I can't make it on Monday because there's no bus on Monday", and if there's an appointment on Wednesday, I tell them right away that "I can't get there before 11 o'clock" ... (...) Of course, it would have been more convenient if this bus went through Ahtme [the district where the hospital is located]... but now we don't know how to get from Jõhvi to Ahtme... we don't even know the timetables of the city buses, we don't know what bus goes to the hospital... maybe there is a timetable at the bus stop?

Similarly to Participant A, Participants D, F, and G also expressed concerns about getting to the hospital on Mondays, Tuesdays, and Thursdays. If they have a doctor's appointment on those days, they often have no choice but to take a taxi:

PARTICIPANT D: The thing is that I can't use this bus for anything other than going shopping. If I must go to the doctor, I must hire a car because most days of the week there's no bus. The only day when there's enough time to go to the doctor is Friday.

RESEARCHER: Have you ever had to cancel or postpone an appointment because there was no bus that day?

PARTICIPANT F: Things like that happen.

RESEARCHER: And what do you do then?

PARTICIPANT F: Well, I take a taxi.

RESEARCHER: A taxi?

PARTICIPANT F: Well, yes, because... if the doctor only sees patients on Monday, and there's no bus on Monday, you must think of something to get there.

RESEARCHER: How much does it cost to take a taxi to the hospital?

PARTICIPANT F: Well, let's say it depends on how lucky you are.

Another option is to arrive in town the night before the doctor's appointment and stay overnight:

RESEARCHER: What about visiting the hospital?

PARTICIPANT G: Well, we ask if there's an appointment on Wednesday or Friday.

RESEARCHER: And that works?

PARTICIPANT G: Well, I'd say it does, but appointments get postponed, and you have to wait longer... and if that doesn't work, then we take a taxi.

RESEARCHER: How much does that cost, if I may ask?

PARTICIPANT G: Well, the other day I had an appointment in the morning, so I took the bus to Jõhvi [to stay there overnight] and paid 35 euros for a hostel there... and if I took a taxi, it would cost me about 40 euros as well.

PARTICIPANT H: ...and if you need to go to Kuremäe, then it's 20 euros.

Overall, the findings suggest that the policy was well accepted by older adults who use public transport as their main mode of transport. All participants brought up at least one positive aspect related to free bus travel, including its financial, psychological, and social benefits. One negative aspect reported was overcrowding during the summer months, as both permanent and seasonal residents prefer to take the bus on Wednesdays, leading to conflicts over seating. This is also linked to a major issue that does not seem related to free bus travel but is mentioned throughout the ride-alongs: the limited public transport service, including long waiting times in town and no service on Mondays, Tuesdays, Thursdays, and Saturdays, which limits older adults' access to opportunities. These are discussed further in the next section.

5. Conclusions

The research reported in this paper sought to explore the impact of free bus travel on improving non-driving older adults' access to key opportunities. To achieve this, three ride-along interviews were carried out, during which older adults were encouraged to share their experiences with free bus travel and how it affected their access to various destinations and activities. The data collected from these ride-alongs were transcribed, coded, and analysed using inductive content analysis. This process identified several recurring themes, which were then grouped into higher-order categories presented in the "Results" section.

The research question was: How has the introduction of free bus travel in the case study area affected non-driving older adults' access to key opportunities?

Based on the results of the ride-along interviews, we conclude that the introduction of free bus travel in the case study area has been financially, psychologically, and socially beneficial for non-driving older adults. However, the policy's accessibility benefits have not been realised due to the lack of public transport service improvements.

First of all, it was revealed that the introduction of free bus travel had potentially substantial benefits for non-driving older adults, which can be summarised as financial, psychological, and social benefits. The financial benefits, described by one participant as a “pension supplement”, were rather straightforward: older adults saved around 30 euros a month (ca. 6% of the average pension at the time) on public transport fares, money they could then spend on other activities. This provided financial relief for older adults who were financially disadvantaged, such as those receiving the so-called survivor’s pension, which was around 200 euros at the time. The psychological benefits were closely related to the financial ones, as they provided older adults with peace of mind, knowing they no longer had to worry about having enough money for their next trip to town. This was particularly important because there were no ATMs in the case study area, and bus drivers only accepted cash. As a result, older adults had to plan their trips to town well in advance, sometimes days or weeks ahead. Since the removal of fares, using public transport involved less of what Ravensbergen et al. (2021) describe as “emotional work”, making it easier to use and allowing for more spontaneous trips. In our case, this proved particularly beneficial for older adults with cognitive impairments, e.g. due to the side effects of medications. The social benefits were mentioned less frequently, possibly because the bus acted as a “third place” well before the fares were removed. Again, it should be taken into account that there was no other “third place” in the case study area, so it makes sense that the bus would serve this function. This is in line with recent findings from Hagan (2020), who further noted that the use of the bus as a place for socialisation “may be particularly valuable for those whose life is becoming more restricted due to later-life transitions, such as poorer health and mobility, and bereavement”. Previous studies have also highlighted other benefits of free bus travel for older adults, such as lower obesity rates (Webb et al., 2012) and improved mental health (Reinhard et al., 2018), although the study participants did not mention these. However, the latter could be seen as part of the social benefits discussed above.

Nonetheless, study participants reported one negative consequence of free bus travel: overcrowding during the summer months, particularly on Wednesdays, when there is a four-hour stay in town. Although this might seem a logical consequence of free bus travel, in our case it reveals a deeper issue that free bus travel failed to address: the limited public transport service, which reduces the policy's potential accessibility benefits. According to most of the participants, free bus travel would have been more useful if there were more than three departures per week. Despite the removal of fares, many participants reported having to skip or postpone doctor's appointments and other important activities due to the limited public transport service. Furthermore, even though everyday activities such as grocery shopping usually take a couple of hours at most, they can take up to eight hours, as participants often have to wait a long time for the bus home. This means that even though free bus travel somewhat improves the spatial accessibility of urban facilities and services, it does not improve their temporal accessibility, as it still takes an unreasonable amount of time to carry out everyday activities. As participants pointed out, the bus takes them to the grocery store free of charge but leaves them there for eight hours, a disproportionately long time. This is why, even though the bus makes three trips per week, most permanent residents, as well as seasonal residents, as it turned out, prefer to take the bus on Wednesdays when there is a shorter, four-hour stay in town. Another accessibility issue that was not addressed concerns the route of the no. 546 bus, which heads straight to the bus station in Jõhvi, skipping several important destinations along the way, including the regional hospital, one of the most important destinations for older adults. As a result, reaching the regional hospital requires a transfer to Jõhvi, making the trip longer (if taking a city bus), more expensive (if taking a taxi), and more complicated (having to figure out how to get there). This can nullify the financial and psychological benefits of free bus travel. Finally, the poor quality of public transport infrastructure, particularly bus stops, makes public transport less accessible for older adults with reduced mobility. This issue is well known (see, e.g., Ravensbergen, 2021), and it is particularly pronounced in winter—when the study was carried out—when walking a few hundred metres to the bus stop can take up to half an hour. To summarise, these issues may not seem directly relevant to free bus travel, but together, they greatly impact the policy's effectiveness, including its potential accessibility benefits.

In conclusion, we offer several policy recommendations and suggest directions for future research. The findings of this study indicate that the introduction of free bus travel in the case study area provided financial,

psychological, and social benefits for non-driving older adults. However, the removal of fares alone did not significantly improve their access to urban facilities and services, as several underlying issues remained unaddressed. For example, the limited public transport service (three return trips per week) continued to limit older adults' ability to participate in the full range of potential out-of-home activities. Therefore, we strongly advise that free bus travel should be complemented by additional policy measures aimed at improving accessibility, ensuring that public transport provides "a level of access that guarantees that each member of society can fulfil his or her life opportunities" (Martens et al., 2012). Three departures per week fall below any reasonable minimum standard.

This research involved a series of ride-alongs with participants on their way to town. However, future research could expand the ride-alongs to include walk-alongs with participants once they arrive in town. As one participant noted, getting to town was the easy part; the difficult part was getting to the destination. Walk-alongs could provide valuable insights into challenges that could otherwise go unnoticed. Furthermore, it would be beneficial to include older adults who neither drive nor use public transport and rely on others, most likely their neighbours and relatives, for groceries, medications and other essentials.

While the research presented in this paper aimed to improve older adults' well-being, methodological limitations should be considered when interpreting the findings. Firstly, the modest sample size (n=12) and convenience sampling limit the generalisability of the results and the range of conclusions that can be drawn. Another limitation is the research design itself—specifically, a case study based on a rural NORC—which means the findings may only be applied to similar contexts and settings. Finally, although the implemented changes—such as an additional departure on Saturdays with a two-hour stay in town, as well as the addition of new bus stops, including one near the regional hospital—received positive feedback from the residents, no follow-up studies have been conducted to assess their long-term impact. Finally, although free bus travel was discontinued in 2024, it remains free for those under 20 and over 63.

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DEVELOPMENT OF AI IN THE CARIBBEAN: ALGORITHMS, CHALLENGES AND RECOMMENDATIONS

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Abstract. Artificial Intelligence (AI) has attracted special academic attention recently due to its potent capabilities across various application domains. Defined as the ability of computer systems to perform tasks with human-like intelligence, AI encompasses visual perception, speech recognition, decision-making, translation, and interpretation. Central to AI systems are algorithms that discover patterns and make predictions, eliminating the need for meticulous programming. The adoption of AI emerges as a pivotal tool, offering numerous advantages when harnessed and applied to detect anomalous data, which is an integral part of real-life systems. This article provides a concise overview, explicitly delving into popular AI algorithms employed in developing Anomaly Detection Systems (ADSs) applicable to Cyber-Physical Systems (CPSs), the state of AI and guidelines for adopting AI within the Caribbean region.

Keywords: Artificial Intelligence (AI); Cyber Physical Systems (CPSs); Machine Learning; Cyber Attacks; Faults; Disturbances

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JEL Classifications: O31, O33

1. Introduction

Cyber-physical systems (CPSs) can be characterized as the fusion of computational algorithms and physical components brought about by technological advancements in embedded systems, distributed systems, and advanced networking (ElBouanan et al., 2022). These systems find widespread deployment in critical infrastructures (CIs) within the Caribbean, such as gas networks, water supply, public health, transportation, and electricity generation, which are pivotal in supporting daily operations. Consequently, owing to their nature and critical importance, these systems are expected to operate seamlessly in the presence of disturbances. However, this assumption rarely holds, as CPSs comprise intricate subsystems with diverse characteristics, presenting significant challenges from a security perspective. These systems' inherent complexity and heterogeneity raise concerns regarding their vulnerability to disturbances and underscore the importance of resilient security measures. Intrinsic to these characteristics are vulnerabilities that can give rise to security threats, including the risk of cyber-attacks. Notably, cyber-attack repercussions have been observed internationally and regionally (Caribbean), specifically in the context of CPSs (Mohammed et al., 2023). Internationally, recorded cyber-attacks have demonstrated a rising trend in frequency and sophistication. Fault occurrences pose another significant challenge for Cyber-Physical Systems (CPSs), contributing to major power outages that have affected regions like the Caribbean (Mohammed et al., 2023) and on a global scale (Stefanidou et al., 2022). These faults have led to substantial disruptions, resulting in a loss of resources and potential loss of life in more severe scenarios. Therefore, cyber-attacks and fault occurrences in CPSs can be considered anomalous behaviour within such systems. Thus, this poses an ongoing challenge in anomaly detection (AD). Therefore, developing accurate Anomaly Detection Systems (ADSs) is essential for detecting the presence of anomalous behaviour and aiding in preventing such occurrences. Thus, the authors present a brief review of popular AI-based algorithms that can serve as the foundation for developing effective ADSs, which can be integrated into existing CPSs within the Caribbean region. This article focuses on three main aspects: 1) The

review of core AI strategies used for ADSs, 2) The state of AI within the Caribbean and 3) Recommendations on the way forward when harnessing AI for the Caribbean region.

2. Anomaly Detection

Anomaly Detection (AD) can be viewed as the ability to identify objects that do not possess characteristics similar to those of other data points. The process of AD has been used to investigate data identified as abnormal compared to the training data. Figure 1 highlights the AD process.

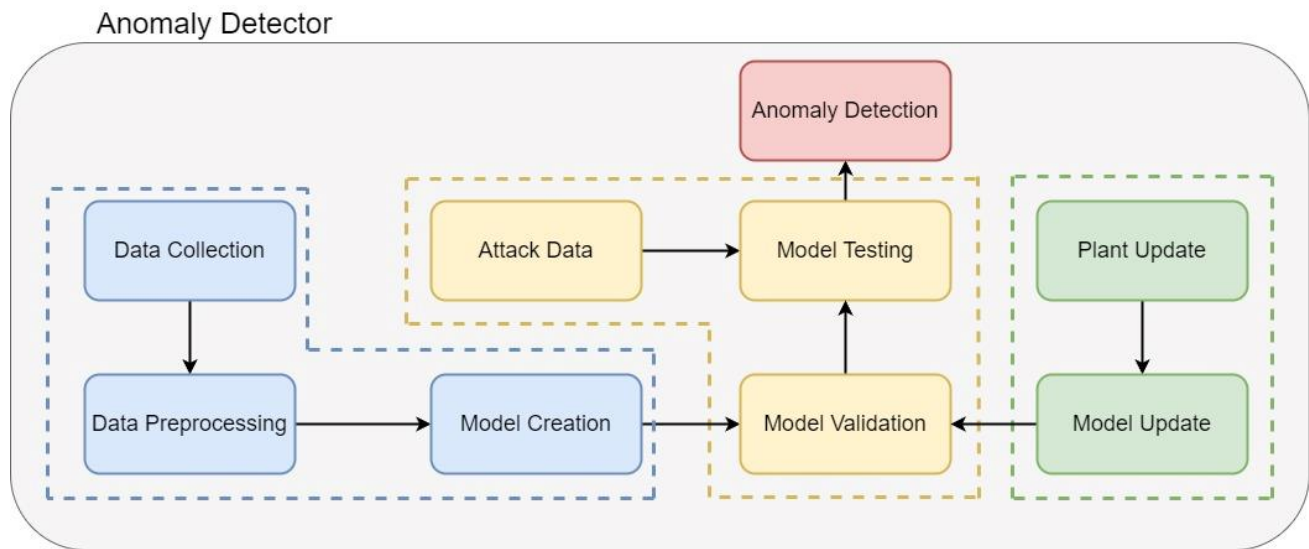


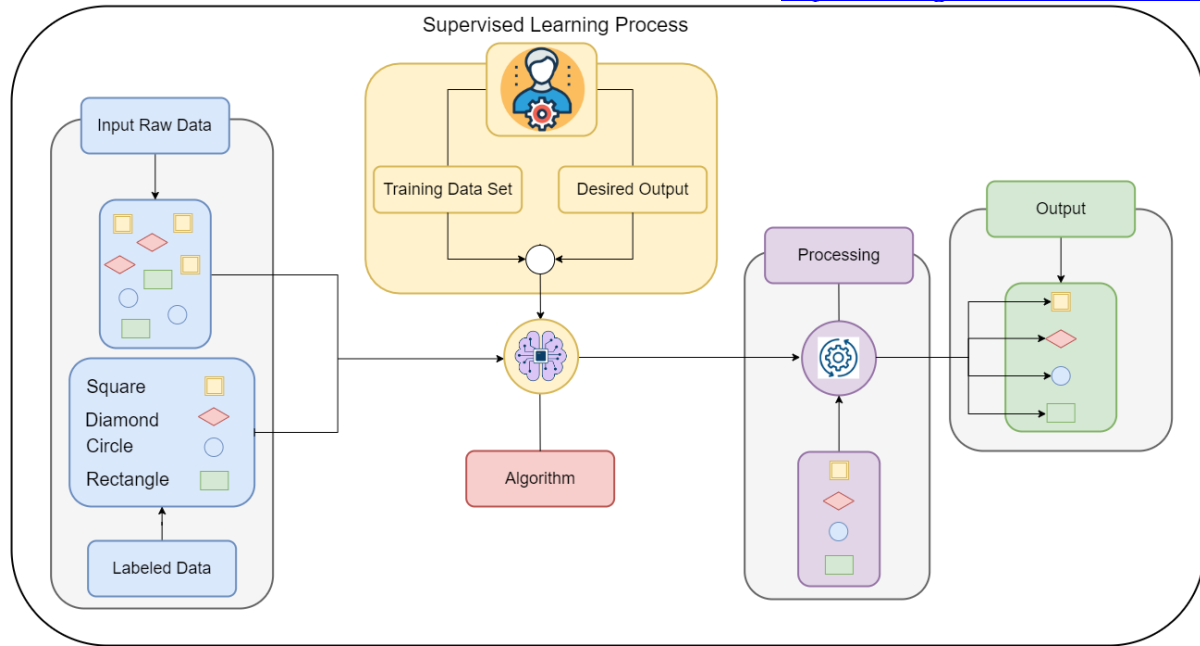
Figure 1. Anomaly Detection Process

Source: created by the authors based on literature review

The detection of anomalies is crucial to prevent the occurrence of anomalous behaviour, which can lead to the disruption of CPSs. Detection of anomalies becomes challenging when considering several factors, such as 1) inadequate anomalous data, 2) training data and 3) ever-changing environmental conditions (Natha et al., 2022). These factors must be taken into consideration. It is important to note that anomalies can be categorized into three main categories: 1) Point Anomalies, 2) Contextual Anomalies and 3) Collective Anomalies. Point anomalies can be seen as a difference at any point compared to other data flows (Jain & Kumar, 2017). Contextual anomalies can be defined as observations that can be taken as anomalous in one context but not in another, and they are accompanied by two different properties: contextual and behavioural. Lastly, collective anomalies can be seen as a group of related data instances that can be seen as anomalous compared to the entire data set (Nassif et al., 2021). The following section presents the AI algorithms typically used to develop ADSs. These include 1) Supervised Learning, 2) Semi-supervised Learning, 3) Unsupervised Learning, and 4) Deep Learning.

3. Supervised Learning Anomaly Detection (SLAD)

SLAD methods rely on information, often called the "data set," which consists of examples of input data and their corresponding desired output data. In essence, SL can be compared to a teacher-student relationship, where the training data specifies the target data set during classification for normal and anomalous data (Sowmya & Anita, 2023). SL can be broadly categorized into 1) Classification, where the output is typically a discrete variable, and 2) Regression algorithms, where the associated output is a continuous variable. Numerous common algorithms that employ this learning structure are Support Vector Machines (SVM), Decision Tree (DT), and K-Nearest Neighbour (KNN) (Siam et al., 2021). Figure 2 highlights the Supervised Learning process used within ADSs. The following methods highlight some of the typical SL algorithms used for ADSs.

**Fig. 2.** Supervised Learning Process

Source: created by the authors based on literature review

3.1. Support Vector Machine

The Support Vector Machine (SVM) was initially introduced as a kernel-based machine learning model for classification and regression tasks. Due to its discriminant power, SVMs can generate an optimal solution, contributing to their widespread popularity in AI. This method has demonstrated promising results and has been reported to outperform other supervised models. The SVM algorithm maximizes a mathematical function for a given set of data and operates based on four core concepts: 1) the separating hyperplane, 2) the maximum margin hyperplane, 3) the soft margin, and 4) the kernel function (Noble, 2006), which can affect the learning, the general performance and by extension the prediction error of the SVM anomaly detector (Siam et al., 2021). In recent times there have been several ADSs which have been proposed for time series data the optimization of feature vectors (Serkani et al., 2019), financial time series data (Shawe-Taylor & Žličar, 2015; Schmidl et al., 2022). The SVM algorithm has also been used for heartbeat time series data (Yuan et al., 2023) and an outlier detection system for network detection (Alghushairy et al., 2024). Table 1 provides an overview of the advantages and disadvantages of the SVM algorithm.

Table 1. A comparison of the SVM algorithm

Advantages of SVM	Disadvantages of SVM
Generates good results despite insufficient information about the data.	Choosing an appropriate Kernel function is difficult.
Handles nonlinear data efficiently.	Extensive memory requirement.
Solves both Classification and Regression problems.	Long training time when using large data sets.
Solves complex problems with a convenient kernel solution function.	It may be challenging to interpret and understand because of problems caused by personal factors and the weights of variables.
Relatively good scaling of high dimensional data.	

Sources: Pereira & Joshi, 2014; Marx, 2019

3.2. Decision Tree

The decision tree algorithm is used for categorical and numerical classification, representing a graph delineating decisions and their corresponding outcomes in a tree-like structure. This graphical representation comprises elements known as "nodes," consisting of three types: 1) the topmost node, designated as the root node; 2) intermediate nodes, referred to as internal nodes; and 3) leaf nodes, known as leaves. In the decision tree, the learning process unfolds from the top and is widely utilized in addressing classification problems. Notably, this algorithm is favoured for its minimal data-cleaning requirements and has gained popularity in data exploration (Patankar et al., 2016). Decision trees have been used in many ADSs to handle issues regarding anomalous financial data (Zhang, 2022), anomalous computer assessment results optimization of feature vectors (Serkani et al., 2019), network intrusion detection systems for cyber-attacks and network traffic anomalies in cellular networks (Casas, Fiadino, and D'Alconzo, 2016). Table 2 highlights some of the advantages and disadvantages of the decision tree algorithm.

Table 2. A comparison of the Decision Tree Algorithm

Advantages of the Decision Tree Algorithm	Disadvantages of the Decision Tree Algorithm
Easy to understand, very intuitive.	Overfitting, high variance algorithm. This means it can easily overfit as it has no mechanism to prevent this from creating complex decision rules.
A lower number of data preparation steps is required.	Time consuming in training phase and can be an issue if there are multiple continuous independent variables.
Redundant attributes allowing enhanced performance of the decision tree	Optimization is required; algorithm doesn't consider how recent decisions will affect stages of splitting.
Highly versatile algorithm and can perform multiple roles apart from standard predictions.	Unstable because of high variance models resulting in the accuracy of the model being affected.
Can solve nonlinear problems using complex decision boundaries.	Limited performance in regression.

Source: Patankar et al., 2016

3.2. K-Nearest Neighbour

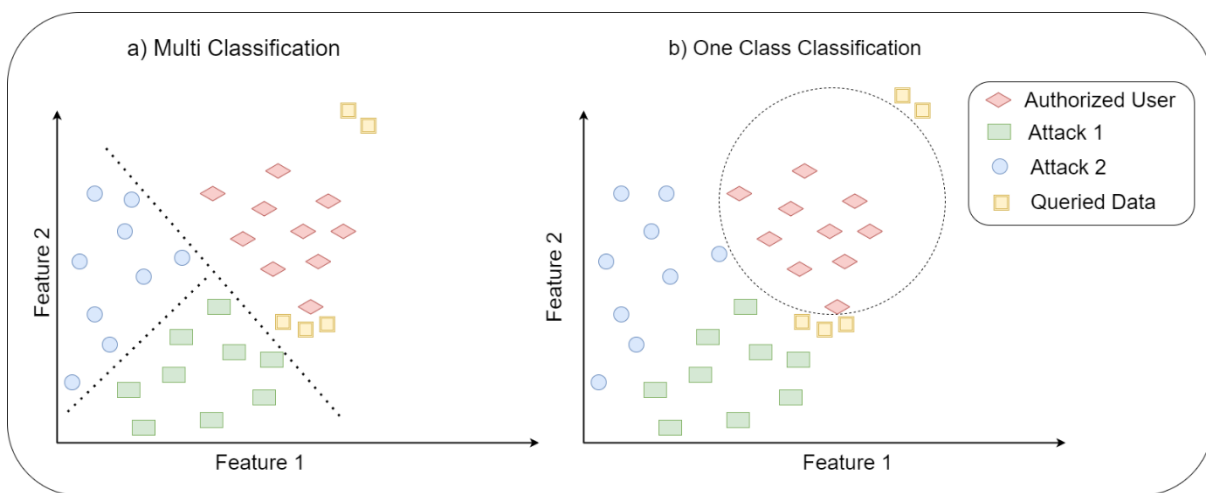
The K-Nearest Neighbour (KNN) is an algorithm known for its simplicity and effectiveness. It utilizes an input-labelled dataset, categorizing data into various classes and predicting the class of unlabelled data. KNN relies on selecting the closest neighbouring training examples for the classification process. In scenarios involving continuous data, the Euclidean distance is commonly employed to identify the nearest neighbours. When encountering new input data, KNN calculates the nearest neighbours, and the classification is determined through a majority vote. It is noteworthy that, despite its simplicity, the choice of the parameter K significantly influences the classification procedure (Taunk et al., 2019). The KNN algorithm's performance is also significantly influenced by the Euclidean distance metric and the normalization of parameters. Several methods have been proposed for KNN ADSs. The Transductive Confidence Machine KNN (TCM-KNN) algorithm has been used in network AD, highlighting its applicability using the KDD Cup 1999 dataset (Li et al., 2007). An efficient log anomaly detection method (ADM) based on improved KNN has been put forward, which handles the issue of 1) excess vector dimension, 2) unlabeled log data, and 3) an imbalance of the number of log data distorts (Ying et al., 2021). The performance of the nearest neighbour (NN) algorithm for AD has been highlighted using synthetic datasets (Gu, Akoglu and Rinaldo, 2019). A two-phased algorithm known as the one-class support vector machine (OCSVM) KNN algorithm was used to demonstrate the use of real data sets for AD (Su et al., 2015). Satellite time series anomaly detection has been proposed based on fast dynamic time warping (DTW) and improved KNN (Jrasol et al., 2023). KNN neighbours of neighbours for AD have shown enhanced performance (Nizan and Tal, 2024). Table 3 summarises the advantages and disadvantages of the KNN algorithm, offering insights into its characteristics and considerations when designing KNN ADSs.

Table 3. Comparison of KNN algorithm

Advantages of KNN	Disadvantages of KNN
Simple, comprehensible and scalable.	Expensive in determining the value of K when the dataset is large.
Computation is small compared to other algorithms.	Requires greater storage.
Effective and Efficient (Predictive Power).	Prediction phases slow for a larger dataset.
Effective for large training Data.	The computation cost is quite high.
Simple algorithm to follow and implement.	Lazy learning algorithm.

Source: Taunk et al., 2019

4. Semi-Supervised Anomaly Detection

**Figure 3.** Semi-supervised learning process

Source: created by the authors

Semi-supervised anomaly detection (SSAD) can be viewed as a method that lies between supervised and unsupervised AD. The major difference between unsupervised and supervised anomaly detection is that supervised anomaly detection uses a fully labelled dataset for training and testing, while unsupervised anomaly detection does not require a labelled dataset. This approach requires the algorithm to obtain the fundamental properties of the dataset and then score the data solely on this. Usually, this is done by some kind of density or distance estimation (Bajallan and Hashi, 2020). In SSAD, the training set is only labelled as instances of the normal class and requires no labels from the anomaly class. Figure 3 describes the semi-supervised ADM. Figure 3 highlights different data types represented by different colours. The red symbols represent an authorized user, the green and blue symbols represent anomalous data, and the brown symbols represent queried data. Multi-classification can separate the problem classes without error using established boundaries among labelled data sets. Only authorized users and attack types 1 and 2 can be detected in this method, as shown in Figure 3(a). Therefore, using the multi-classification scheme, queried data can be classified into either Authorized users or Attack data, and consequently, new types of anomalies can be classified incorrectly. However, this issue can be resolved using a one-class classification method. Setting a boundary around the entirety of the negative class ensures the classifier can distinguish patterns from an authorized user and anomalous data (Villa-Pérez et al., 2021). This type of classification can be seen in Figure 3(b). Several approaches using these techniques have been proposed (Xu et al., 2023), (Zhou et al., 2023), (Karasmannoglou, Antonakakis and Zervakis, 2023), (Baradaran and Bergevin, 2024).

5. Unsupervised Learning

Unsupervised learning uses unlabeled data, allowing users to categorize data based on similarities. This technique uses a principle called "clustering", which considers the similarities in data. The training creates a situation where hidden patterns in the unlabeled dataset can be discovered. In essence, unsupervised learning

mimics human beings through learning from previous experiences. This learning style can be compared to learning without a teacher (Siam et al., 2021) and can be seen in Figure 4.

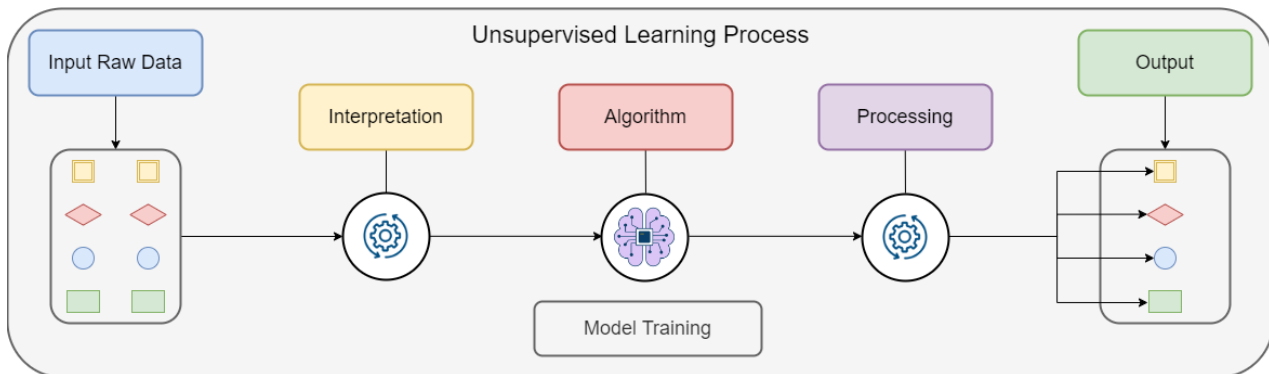


Figure 4. Unsupervised Learning Process

There are currently several popular unsupervised anomaly detection algorithms, such as 1) Nearest neighbor-based techniques, 2) Clustering-based methods, 3) Statistical algorithms and Subspace techniques. However, emphasis is placed on clustering ADMs for this section.

5.1. K means Clustering

The K-means clustering algorithm is an iterative approach that separates unlabeled data into K clusters and assigns membership for each data sample to a cluster based on similarities. The algorithm operates on the principle that data samples are allocated to the nearest centroid, making it a centroid-based method. The general flow for the K-means clustering algorithm can be described by the following four (4) points: 1) selection of K points as initialized centroids, 2) repeat the process, 3) form K clusters by assigning each point to its nearest centroid and 4) recompute the centroid for each cluster until there is no change in the centroid. For more details surrounding K means Clustering refer to (Ghosh and Dubey, 2013; Ahmed et al., 2020). Clustering can be divided into three different categories: 1) Exclusive, 2) Hierarchical and 3) Overlapping Clustering. Exclusive Clustering can be defined as a method where the data or object may only exist within a cluster. In hierarchical Clustering, this method establishes a hierarchy of clusters, which can exist as Agglomerated and divided hierarchical grouping associated with the hierarchical set. Overlapping Clustering can divide a data point into two or more groups of clusters. The following highlights some of the recent clustering ADMs which have been proposed. These methods focus on aspects such as grouping images into coherent clusters of different anomaly types (Sohn et al., 2023), using a mixed clustering approach for AD of real-time data with an emphasis on the factor of time (Mazarbhuiya & Shenify, 2023a) and an ADM for building energy consumption data, which can detect point anomalies and collective anomalies (Lei et al., 2023). Similar ADMs include an unsupervised anomaly detection algorithm (GC-ADS), which uses grid clustering and the Gaussian distribution (Zou et al., 2023), a clustering-based approach which detects real-time anomalies and handles the issue of high dimensionality of data (Mazarbhuiya & Shenify, 2023b) and an intelligent Deep Clustering-based Local Outlier Probabilities (DCLOP) approach for satellite telemetry data (Obied et al., 2023).

6. Deep Learning

Deep Learning (DL) can be seen as a complex evolution of machine learning (ML) algorithms that use layered architectures to model complex scenarios. This method uses artificial neural networks (ANNs), which mimic the human brain and produce better performance than other conventional ML techniques (Sowmya & Anita, 2023). Deep learning consists of various types of networks, such as Convolutional Neural Networks (CNNs), Restricted Boltzmann Machines (RBMs) and Recurrent Neural Networks (RNNs), each of which contains different characteristics and functionality. Essentially, these networks can learn in a supervised, semi-supervised, and unsupervised manner (Mahmud et al., 2021). The following section focuses on two DL techniques: 1) Autoencoders and 2) Long Short-Term Memory.

6.1. Autoencoders

Autoencoders can be classified as unsupervised machine learning architectures that perform both classification and address the issue of dimensionality reduction. The autoencoder network typically consists of three main components: 1) the encoder, 2) the code, and 3) the decoder. When there is an input, the encoder compresses the input, and the decoder reconstructs the compressed input. Autoencoder networks operate using the backward propagation algorithm, which helps minimize reconstruction loss. Reconstruction loss measures how close the output is to the input (Sowmya and Anita, 2023). Figure 5 highlights the structure of an Autoencoder.

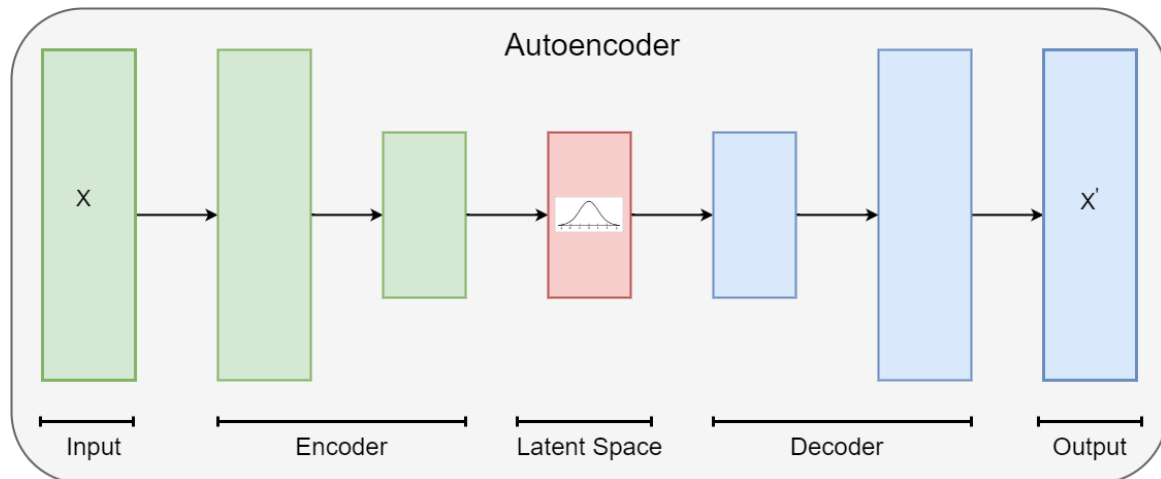


Figure 5. The Autoencoder Process

Autoencoder-based ADSs are normally trained with and are expected to recover any given input as closely as possible to the learned patterns. Thus, a situation involving a reconstruction error can be deemed an anomaly. Therefore, an auto-encoder can identify anomalies using the deviation in patterns from the training data (Song et al., 2021). There have been several autoencoder schemes which have been proposed to deal with aspects such as web attacks (Mesiar & Kolesárová, 2018), defects in concrete structures (Chow et al, 2020), visual anomaly detection (Sun, Wang, and Li, 2024), AD in cloud computing networks (Torabi et al., 2023) and fault detection (Fahmi et al., 2024).

6.2. Long Short-Term Memory (LSTM)

Recurrent deep neural networks are inherently challenging to train because of the associated exploding/vanishing gradient problem. Therefore, the LSTM model was developed to overcome these shortcomings when the issue of learning long-term dependencies is involved. The typical LSTM model comprises four (4) main components: 1) cell, 2) input gate, 3) output gate and 4) a forget gate. It is important to note that the forget gate was not initially part of the LSTM configuration but was proposed to allow the network to reset its state. The LSTM configuration contains a set of recurrently connected networks called memory blocks. The memory blocks are used to retain its state over time and regulate the flow of information. Figure 6 highlights the structure of the LSTM network configuration (Van Houdt, Mosquera and Nápoles, 2020). There have been several proposed LSTM ADMs such as convolutional long short-term memory (Conv-LSTM) which extends fully connected LSTM (FC-LSTM) to detect violent actions (Fahmi, Kashyzadeh and Ghorbani, S., 2024), fault detection utilizing LSTM with hidden dynamics and reversible instance normalization (Liu, Young, and Jafarpour, 2023) and the detection of abnormal air quality (Wei et al, 2023). Anomalous human activity detection has also been proposed using raw video streams of data facilitated by a convolutional neural network (CNN) and a bidirectional long short-term memory (Bi-LSTM) method (Kumar et al., 2023).

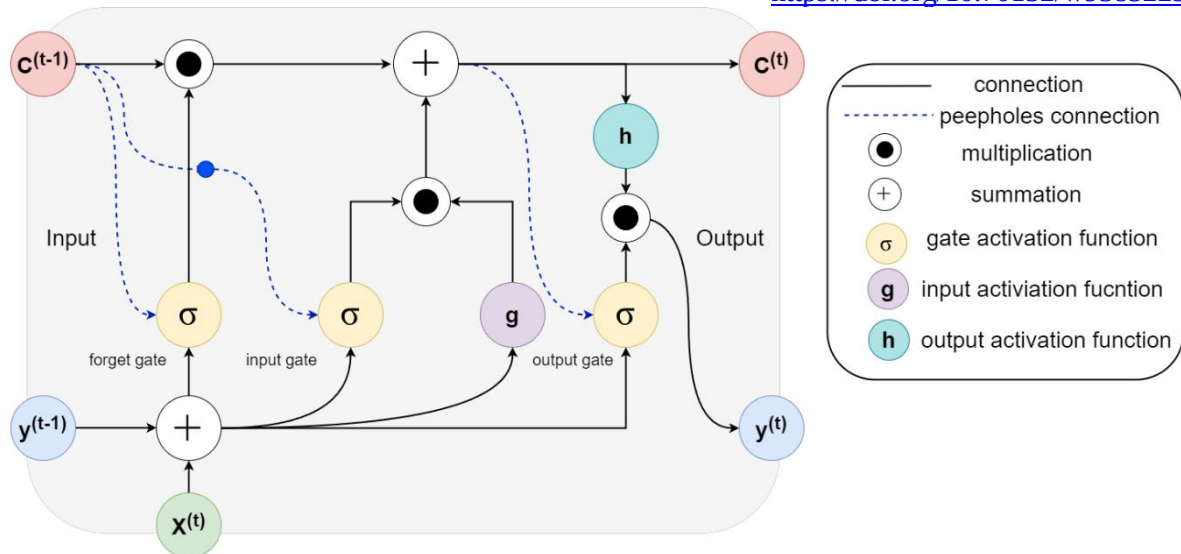


Figure 6. The Long Short-Term Memory Structure

The methods highlighted serve as an introduction to some of the critical algorithms that can be used in ADSs, tailored for various applications to ensure the detection and prevention of occurrences such as faults and cyber-attacks. Given the Caribbean's susceptible environment to faults and cyber threats, there is a demand for real-time monitoring and quick response capabilities. Implementing AI-based ADSs allows the region to manage these risks more effectively, improving its capacity to respond swiftly to disturbances that could impact CPSs and, by extension, CIs. These methods equip entities such as governments and infrastructure operators with the necessary tools to proactively identify potential threats before they can escalate into widespread failures. AI-based ADSs significantly enhance system resilience under abnormal conditions by enabling early detection and intervention. This proactive approach reduces system downtime and, in severe situations, prevents the loss of life by ensuring the continued operation of essential services. Systems such as these can improve the region's overall stability and security. Given the importance of ADSs, this raises a key question regarding the Caribbean region: What is the current state of AI within the Caribbean region? The following section addresses this question.

7. The state of AI within the Caribbean

The field of AI has been generating great interest among countries such as the United States (US) and China, competing for the top position in the global AI market. In 2017, China unveiled a plan to transform its country into a \$150 billion AI global leader, while the United States allocated \$10 billion for AI investments. However, the US has faced challenges due to limited funding. Furthermore, researchers and startup companies have been increasingly attracted to funding opportunities provided by China, impacting the strategic position of the US (Florez Zuluaga et al., 2019). While the US and China can be viewed as undoubtedly the leaders in the AI race, other countries such as the United Kingdom, France, Germany, India, Canada, and Russia are currently also showing great potential as it relates to AI initiatives (Keary, 2024).

In contrast to these global leaders, regions such as Latin America face significant challenges in AI readiness. A 2019 government AI readiness survey conducted by Oxford Insights and the International Development Research Centre (IDRC) revealed the absence of Latin American countries (LAC) being ranked amongst the top 20 countries, highlighting the Caribbean region's lack of preparedness for AI adoption (George et al., 2019). In 2023, the same study was conducted where the LAC region reported an average score of 41.50, placing it 6th among 9 surveyed regions. Figure 7 presents the Government AI readiness Index for the LAC region in 2023. It is important to note that there is a difference of 40 points recorded between the average score recorded by the LAC region and that of the North American region. There is also a major difference between the highest-ranking country within the LAC region, Brazil, with an associated score of 63.70. Haiti is recorded as the lowest-ranking country within the LAC region at a value of 21.97. This highlights the huge disparities from region to region and when comparing LAC countries within their region. Countries such as Brazil, Chile, Uruguay, Colombia,

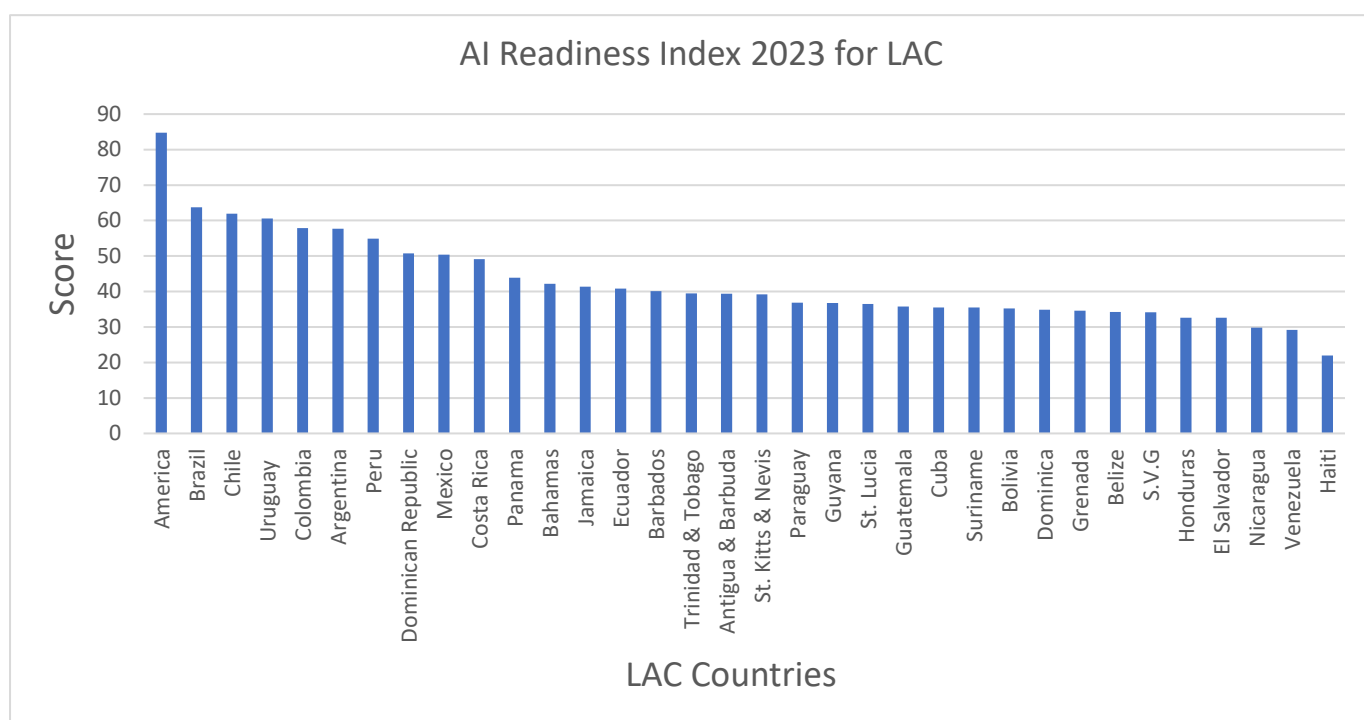
Argentina, Peru, Dominican Republic and Mexico represent 24% of the LAC with an associated score represented by the following ($50 \leq AI \text{ index score} \leq 65$). These countries represent the high-scoring nations making progress in relation to AI readiness in the region.

However, it is important to understand that much work is needed when these scores are compared to the highest-ranking nations, such as America and Canada, with associated scores of 84.80 and 77.07, respectively. The remaining 76% of LAC has an associated score of ($AI \text{ index score} < 50$) and reveals that most countries still require development in areas such as 1) Government, 2) Data and Infrastructure, 3) and the Technology sector, which requires more attention (Hankins et al., 2023).

The International Development Bank (IDB) released a report highlighting key findings from 12 LAC countries (Mexico, Costa Rica, Colombia, Ecuador, Peru, Chile, Dominican Republic, Trinidad and Tobago, Brazil, Paraguay, Uruguay, Argentina) regarding their groundwork for AI adoption. This report identified several areas requiring further attention and development, detailed in Table 4. Based on the information presented in Table 4, the Caribbean is progressing in establishing foundations aligned with government strategies, implementing digital strategies, and having open data agendas. Additionally, these countries have associated research and development and major tertiary-level institutions offering AI degrees, marking a significant step in the right direction. However, concerns exist surrounding the lack of supporting digital infrastructure, connectivity issues, and the absence of AI patents, all of which impede the region's ability to fully embrace AI (Gómez Mont et al., 2020).

In addition to the IDB report, adherence to international AI principles plays a crucial role in regional AI development. The Organization for Economic Cooperation Development (OECD) AI principles provide key benchmarks for evaluating AI research, development and deployment. These principles offer valuable insights into a country's AI landscape and help establish evidence for tracking progress. However, only seven (7) countries from the LAC region have adhered to OECD principles, with three (3) countries adhering to G20 AI principles and four (4) adhering to their country-specific principles. Table 5 presents this information in more detail. While adherence to these principles can be seen as a positive step, it alone may not be sufficient to ensure the effective deployment of AI technologies within the region. Additional concerns have been highlighted in Table 6, along with their associated ranking for each category related to the use of AI (OECD/CAF, 2022).

Recent data from 2024 indicates that AI is forecasted to contribute up to 5.4% of Latin America's GDP by 2030, compared to North America's projected 14.5%, further emphasizing that the Caribbean is lagging in AI adoption. Despite the slow uptake, the Caribbean has shown signs of technological growth, with its technological industry increasing by 5.6% since 2022. This growth is driven by the rise of technological startups in the region, valued at over US \$1 billion, offering promising potential for developing AI-related industries (Muschet & Opp, 2024). Despite progress, the slow uptake of AI in the Caribbean significantly impacts the region's ability to develop and implement sophisticated systems like ADSs, which are crucial for monitoring and safeguarding critical infrastructure. The lack of digital infrastructure, inconsistent support from local agencies, and the absence of AI research patents limit the region's capacity to build the necessary foundations for widespread AI adoption. This lag poses challenges for the development of ADS, which relies on real-time data and advanced algorithms to detect anomalies in critical sectors such as energy, transportation, and communication systems. However, with the growing number of technology startups and increasing entrepreneurial activity in the region, there is potential for the Caribbean to overcome these barriers. By strengthening digital infrastructure, investing in AI education, and fostering collaborations with international AI initiatives, the Caribbean can accelerate its progress toward developing robust ADS capabilities, ensuring the resilience of its critical systems and advancing the region's overall technological growth.

**Figure 7.** Government AI readiness Index for the LAC region 2023

Source: Hankins et al., 2023

Table 4. Major Findings from the LAC report conducted by the IDB

Number of Findings	Description of Finding
Foundations with government alignment	Most surveyed nations have established solid foundations, developing their AI systems in accordance with government efforts with a focus on connectivity, infrastructure development, national digitization strategies, open data and national AI agendas.
Digital Strategy and Open Data Agenda	All surveyed countries have a digital strategy and an open data agenda except for Trinidad and Tobago.
Supporting Digital Infrastructure	There is a lack of supporting digital infrastructure.
Connectivity	A lack of connectivity is predominant, with < 70% of the LAC population on average having internet access.
State of Cyber Security	Cybersecurity amongst these nations is making progress. However, they are ranked between 51 and 123 among 175 countries worldwide.
Research and Development	Approximately 75 % of LAC major universities have research and development for autonomous systems.
AI-related degrees	Approximately over 96% of the main universities in the LAC region offer AI degrees, with 50 % having a specialized laboratory. This is very promising for the development of skills and AI entrepreneurship. However, half of these universities are located outside the country's capital, which poses an issue in terms of knowledge dissemination and opportunities.
AI patents	The LAC region recorded the lowest level (< 1%) compared to different regions.

Table 5. LAC adherence to AI principles

LAC country establishment and adherence to the AI principles			
Country Name	OECD AI Principles	G20 AI Principles	Country Specific Principles
Argentina	✓	✓	
Barbados			
Brazil	✓	✓	
Bolivia			
Chile	✓		✓
Dominican Republic			
Colombia	✓		✓
Costa Rica	✓		
Ecuador			
Jamaica			
Mexico	✓	✓	✓
Panama			
Paraguay			
Peru	✓		
Trinidad and Tobago			
Uruguay			✓
Venezuela			

Source: the authors, based on OECD/CAF, 2022

Table 6. Major concerns and associated countries by Rank

Concern	LAC Countries	Ranking System
LAC region capacities for establishing legal and ethical frameworks for AI	Colombia, Chile, Mexico, Uruguay	Regional Leader
	Argentina, Brazil, Costa Rica, Peru	Demonstrates solid commitment
	Barbados, Ecuador, Jamaica, Panama	Demonstrates initial capacity
	Bolivia, Dominican Republic, Paraguay, Trinidad and Tobago, Venezuela	Significant effort/support advised
LAC region capacities for establishing safeguards against bias and unfairness	Colombia, Mexico, Uruguay	Regional Leader
	Argentina, Brazil, Chile, Costa Rica, Peru	Demonstrates solid commitment
	Barbados, Ecuador, Jamaica, Panama	Demonstrates initial capacity
	Bolivia, Dominican Republic, Paraguay, Trinidad and Tobago, Venezuela	Significant effort/support advised
LAC region capacities for considering the explainability of AI systems and automated decision-making	Colombia, Mexico, Uruguay	Regional Leader
	Argentina, Brazil, Chile, Costa Rica, Peru	Demonstrates solid commitment
	Barbados, Dominican Republic, Jamaica, Venezuela	Demonstrates initial capacity
	Bolivia, Ecuador, Panama, Paraguay, Trinidad and Tobago	Significant effort/support advised
LAC region capacities for promoting safety and security in public sector AI systems	Colombia, Mexico, Uruguay	Regional Leader
	Argentina, Brazil, Chile, Costa Rica, Peru	Demonstrates solid commitment
	-	Demonstrates initial capacity
	Barbados, Bolivia, Dominican Republic, Ecuador, Jamaica, Panama, Paraguay, Trinidad and Tobago, Venezuela	Significant effort/support advised

Source: the authors, based on OECD/CAF, 2022

8. Recommendations moving forward for harnessing AI within the Caribbean

AI is a powerful tool that, if harnessed correctly, can contribute holistically to the development of the Caribbean region and, by extension, LAC, leading to increased productivity and sustainability. However, achieving these outcomes is not easily accomplished. Traits such as increased productivity and sustainability can only be attained through aspects such as reflection, strategic vision, regulation, and regional coordination to create opportunities. To fully take advantage of AI, an enabling environment is crucial. This involves having suitable digital infrastructure, ensuring data availability, fostering digital skills, building innovation capacities, and promoting digital entrepreneurship. These elements collectively create the foundation for harnessing the

potential benefits of AI in the region. (ECLAC, 2023). Therefore, the authors put forward the following guidelines which can be used as key enablers for the use of AI within the Caribbean region: 1) Data usage, 2) Funding, 3) Development of internal expertise and human capital, 4) Accessing external expertise, 5) Stronger partnerships, 6) Government Involvement, 7) Development of Infrastructure, 8) Research and Development, 9) Safety and Security, 10) AI awareness.

8.1. Data Collection\Usage

Data is a crucial element for any AI project, serving as input required by machine learning algorithms to learn patterns and features. However, it's essential to recognize that not all data is equal, and steps such as pre-processing are necessary to ensure the data is accurate, reliable, and suitable for the intended application. The effectiveness of the models trained and proposed heavily depends on the quality of the data set used. AI can offer solutions to government issues and limitations related to data management, and government structures can restrict its true potential. Careful consideration of these limitations is crucial to unlock the full benefits of AI in addressing governmental challenges.

8.2. Funding for AI Projects

Funding is another critical element that is a key enabler for using AI applications in the public, private, and government sectors. It is pivotal in transitioning from concept to reality for any AI project. The availability of funds facilitates the continuous development of AI applications, enhancing their capacity to serve various industries better. Furthermore, relevant stakeholders must implement appropriate measures to manage AI funding. Complete transparency in allocating and utilizing funds is essential to ensure that resources are directed towards their intended applications. Mismanagement of funds can pose a significant challenge, potentially hindering the success of AI initiatives.

8.3. Development of AI Expertise Internally

One of a country's most valuable assets is its people. Therefore, developing skilled AI personnel and experts is vital and requires the support of upskilling and recruiting programs. Emphasis must be placed on the education system, focusing on secondary and tertiary education. At the secondary level, an introduction to AI can generate genuine interest among students who may pursue this field at a tertiary level. The education system should offer well-structured undergraduate and postgraduate degrees in AI at the tertiary level while ensuring the programs are continuously re-evaluated to provide exposure to the latest trends and technology. This allows students to study AI at the highest level, allowing them to become pioneers, entrepreneurs, and experts within the field. Moreover, in building internal capacity, governments can collaborate with the private sector to leverage their expertise and resources, strengthening these educational endeavours.

8.4. Accessing and harnessing External AI Expertise

AI is a complex field with a diverse range of experts found within the international community. Given the current AI landscape that requires substantial support, seeking relevant experts for guidance and advice is recommended. This can be facilitated through the formation of partnerships within the international community. Government involvement is crucial in this process, as governments bear the responsibility of good governance and must take a leading role in seeking necessary and relevant experts internationally and coordinating such collaborative efforts. Governments should create an environment that facilitates a seamless exchange of information between regional and international entities. This collaboration is essential to shape a landscape that is better suitable for adopting and implementing AI and leveraging the expertise and insights available globally.

8.5. Creating Stronger Partnerships for the Caribbean

The creation of local partnerships is critical for the adoption and use of AI. These partnerships should involve participation from government, public, private, and international sectors, fostering collaboration across various domains. Similarly, the government is responsible for coordinating events to ensure seamless participation from all sectors. By facilitating information sharing, these partnerships create a holistic approach that incorporates viewpoints from all sectors. This collaborative effort provides a better understanding based on past experiences with AI, ultimately contributing to more informed decision-making and effective implementation strategies.

8.6. Government Involvement/Participation

Government involvement is a critical factor in adopting and using AI, as it intersects with important issues related to governance. As discussed in points 4 and 5 previously, the government plays a central role in coordinating efforts, establishing policies, and creating an enabling environment for the effective integration of AI technologies. The active engagement of the government ensures that regulatory frameworks, ethical considerations, and strategic initiatives are aligned to harness the benefits of AI while addressing potential challenges.

8.7. Development of Infrastructure

Supporting digital infrastructure is crucial for the successful adoption and use of AI. Digital infrastructure encompasses the underlying technology and systems that facilitate the digital transformation of local societies and economies. This includes networks, servers, data centres, and other hardware and software components. A lack of supporting digital infrastructure can limit a country's success in adopting and using AI. Key elements of digital infrastructure, such as broadband networks (including optical fibre and 5G) that offer high transmission rates and volumes, reliability, and low latency, are essential for sustaining connectivity and real-time communication between the cyber and physical environments. Digital infrastructure is indispensable for achieving digital transformation initiatives like the Internet of Things (IoT), Industry 4.0, networked mobility, and cloud services (Robbins and van Wynsberghe, 2022).

8.8. Research and Development

Research and development (R&D) is key in fostering innovation and driving advancements within AI. R&D initiatives create a pathway for local talent to develop novel algorithms and models, enabling more efficient solutions to complex problems. Additionally, R&D efforts contribute to the generation of emerging technologies, the identification of existing open issues, and the ability to predict future trends in the field of AI. Investing in R&D enhances the local workforce's capabilities and positions the region at the forefront of technological advancements. It becomes a driving force for continuous improvement, ensuring that the latest research findings and innovative solutions inform the adoption and implementation of AI technologies.

8.9. Safety and Security

AI has many advantages and can be used as a powerful tool. However, understanding the ramifications of using such methods is also essential, given that AI applications are known to be susceptible to cyber-attacks, which pose a serious security concern. Inherently, AI applications are used in many real-time applications where safety is a priority. Therefore, consideration must be given to aspects such as resilience, cyber-attack detection, and isolation strategies, which must be integrated to account for abnormal behaviour when it presents itself.

8.10. AI awareness

AI awareness is essential today, given the prevalent hesitation and distrust among people. This scepticism is understandable and creates an impression that AI systems can be biased (Geoff & Ward, 2022). People must understand the benefits and disadvantages of using AI, providing them with a comprehensive view of the field. This approach allows individuals to make informed decisions based on a more nuanced understanding rather than relying on preconceived notions that may lead to inherent biases against AI. Meaningful endeavours by key stakeholders, including government, public entities, and private enterprises, are essential in providing the public with accurate and comprehensive information about AI. Such initiatives can contribute to reducing hesitancy and changing the way people currently think about AI, fostering a more informed and constructive perspective.

Conclusions

The novelty of this paper lies in its comprehensive and systemized examination of Artificial Intelligence (AI) development within the Caribbean region, offering a unique perspective on the challenges, opportunities, and practical pathways to adoption. By providing an in-depth review of popular AI algorithms tailored for Anomaly Detection Systems (ADSs) with application to Cyber-Physical Systems (CPS), the paper not only underscores the importance of these technologies in safeguarding critical infrastructure but also contextualizes their implementation within the region's technological landscape. A major contribution of this research is the

identification of ten key enablers which are designed to address the current gaps in AI readiness while providing a strategic roadmap for regional stakeholders, including governments, academic institutions, and private enterprises. Additionally, the study highlights the disparity between global leaders in AI, such as the United States and China, and the Caribbean's slower pace of adoption, emphasizing the pressing need for targeted investments and policy-driven initiatives. The emphasis on ADS as a critical tool for monitoring and protecting vital systems such as energy, water supply, and transportation further highlights the practical relevance of these findings, by focusing on region-specific challenges such as inadequate digital infrastructure, limited AI research outputs, and inconsistent policy alignment. This paper serves as a call to action for leveraging the growing technological potential in the Caribbean. It bridges the gap between theoretical AI advancements and their real-world applications in the region, providing a solid foundation for future research and development initiatives. Ultimately, this paper makes a significant contribution by laying the groundwork for a more resilient, technologically advanced Caribbean, capable of meeting the demands of an increasingly AI-driven world.

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CHALLENGES AND OPPORTUNITIES OF DIGITALIZING MOROCCO'S RENEWABLE ENERGY SECTOR*

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Abstract. This paper explores the potential of digitalization to enhance Morocco's renewable energy sector. The primary objectives are to assess the current state of digitalization within the sector, identify key challenges and opportunities, and propose recommendations for overcoming barriers to digital transformation. The study integrates a literature review with the People, Process, Technology (PPT) and Triple Bottom Line (TBL) frameworks, alongside a case study approach, expert interviews, and document analysis to gather data and draw insights. Key findings highlight the critical role of human capital, robust digital infrastructure, and a supportive regulatory environment. The research underscores that effective change management strategies are essential to overcoming resistance to change, enabling the sector to embrace digital transformation fully. By investing in skills development, building digital infrastructure, creating a supportive regulatory environment, adopting a holistic approach to sustainability, and strengthening stakeholder collaboration, Morocco can successfully navigate the challenges and capitalize on the opportunities presented by digitalization. The study concludes that the successful digitalization of Morocco's renewable energy sector requires a multi-faceted approach that addresses the economic, environmental, and social dimensions of the transition. Through the lens of Morocco's experience, this research provides valuable insights into the digital transformation of renewable energy sectors in developing countries, offering practical guidance for policymakers and industry stakeholders.

Keywords: Artificial Intelligence (AI); Cyber Physical Systems (CPSs); machine learning; cyber attacks; faults; disturbances

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1. Introduction

The transition towards a sustainable future necessitates a fundamental shift in global energy production. Renewable energy sources, such as solar and wind power, offer a promising alternative to traditional fossil fuels by reducing greenhouse gas emissions and mitigating climate change. However, integrating these renewable sources into existing energy grids poses challenges due to their inherent variability. To ensure a stable and efficient energy supply, digitalization plays a crucial role in optimizing grid management, forecasting energy production, and facilitating the wider adoption of renewable energy solutions.

Digitalization in the energy sector offers well-explored opportunities for enhanced efficiency, better integration of renewable energy, effective demand-side management, and increased transparency in decision-making, etc. For instance, smart grids equipped with real-time data analysis can optimize energy distribution, reduce transmission losses, enhance grid stability, and facilitate a greater incorporation of renewable sources. Digital tools, such as smart meters featuring time-based pricing, can incentivize reduced consumption during peak hours, thereby alleviating strain on the grid. This approach can lead to significant reductions in energy waste across various sectors. Moreover, digital platforms empower consumers with greater control over their energy usage, enabling services like mobile apps for meter readings, bill payments, and the management of connected home devices for energy-efficient operation.

However, digital transformation in the energy sector also presents typical challenges. A more digitalized grid is susceptible to cyberattacks, making the investment in robust cybersecurity measures essential to protect critical infrastructure, albeit at a high cost. The collection and analysis of energy consumption data also raise privacy concerns. To maintain consumer trust, clear regulations and stringent data security protocols must be established. Furthermore, digitalization demands investment in new technologies and infrastructure, such as smart meters and communication networks, which can pose significant challenges for developing countries, including Morocco. Additionally, digital transformation requires a workforce skilled in using digital tools, data analysis, cybersecurity, and digital grid management. Consequently, investment in training and education is vital to equip the workforce with the necessary skills.

Despite the recognized importance of both renewable energy and digitalization, research exploring their intersection within the specific context of Morocco remains limited. Existing literature offers a broad picture of global trends or focuses on developed economies. There is a scarcity of information regarding the current digitalization status within Morocco's renewable energy sector. This lack of data makes it difficult to assess the specific challenges and opportunities this North African country faces.

Furthermore, current research on digitalization in the energy sector often adopts a fragmented approach, focusing on isolated aspects like on specific technologies or applications. This approach, while valuable, fails to capture the holistic picture of the sector as an ecosystem from the management point of view. A comprehensive understanding requires examining the digitalization process within a broader theoretical framework, considering not just technological advancements but also the interplay between various ecosystem factors, like resources, processes, policy and regulations, etc.

Therefore, to effectively address the knowledge gap and pave the way for future research, this study adopts a descriptive case study approach. By developing a robust theoretical framework, the study aims to investigate the challenges and opportunities associated with the digitalization of Morocco's renewable energy sector. This case study focuses on the Moroccan renewable energy sector, examining the challenges and opportunities of digitalization within this context. While the findings of this research may have broader implications, the scope of this study is primarily limited to the Moroccan experience. By concentrating on this specific case, the research aims to provide in-depth insights into the factors influencing the digital transformation of the renewable energy sector in a developing country context.

2. Utilizing Digital Technology for the Energy Transition

The global energy landscape is undergoing a transformation, shifting away from a heavy reliance on fossil fuels toward cleaner and more sustainable energy sources (International Renewable Energy Agency – IRENA, 2023). This transition is driven by a combination of factors, including the depletion of fossil fuel reserves, growing environmental concerns, and the political imperative driven by the worldwide organizations to mitigate climate change (Dwivedi et al., 2022; Wang & Azam, 2024). Morocco has positioned itself as a leader in this global transition, with ambitious targets for renewable energy integration (Fragkos, 2023). The country's abundant solar and wind resources, coupled with supportive government policies, have created a favorable environment for the development of the renewable energy sector (Kousksou et al., 2015; Fragkos, 2023).

Digitalization, on the other hand, is the integration of digital technologies across all aspects of society and the economy. This includes the adoption, application, and utilization of digital tools, leading to new business models, economic transformation, and a fundamentally altered socioeconomic environment (Gradillas & Thomas, 2023). For organizations, digitalization signifies a modernization. It involves infusing digital tools across all organizational functions, from management to customer service. It needs to be emphasized that digitalization stands as the most significant vector of innovation impacting science, technology, business, and governance (OECD, 2020). It drives the creation of new business models and fosters digital engagements. By effectively leveraging digitalization's potential, advancements in various mentioned fields can be accelerated. This holds the potential to improve living standards, enhance environmental protection, and inform policymaking, ultimately influencing economic landscapes.

As digital technologies permeate various fields, the renewable energy sector, in particular, stands to benefit immensely from digitalization. The International Energy Agency (IEA) recognizes digital technologies as a game-changer for the renewable energy sector (Sung et al., 2021). They emphasize how these technologies can unlock several key opportunities. For instance, digital tools can help integrate more renewable energy sources into the grid by managing their variability and ensuring system reliability. Additionally, digitalization can optimize energy consumption in buildings and industries, leading to significant efficiency gains. The IEA highlights that these advancements, coupled with data analysis and smart grids, can pave the way for a more sustainable and efficient energy future.

Digitalization in the energy sector goes beyond simply boosting reliability and efficiency. It also empowers consumers to become active participants in the market (Varela, 2017). Smart meters provide real-time usage data, enabling informed energy choices and even potentially facilitating peer-to-peer energy trading. This digital transformation also fosters the emergence of new players in the energy market. Innovative startups can leverage digital platforms to offer disruptive services, such as decentralized energy solutions or personalized energy management tools. Furthermore, digitalization fuels the development of entirely new products and services, such as smart appliances that automatically adjust energy consumption or AI-powered energy management systems for businesses. The vast amount of data generated by these technologies paves the way for data-driven business models. This allows energy providers to personalize offerings, predict demand fluctuations, and optimize resource allocation, ultimately leading to a more efficient and responsive energy sector.

The inquiry will now examine some of the key technologies used in the digitalization of the energy sector. According to the literature (Varela, 2017; Asif, 2022; Idries et al., 2022; Juszczak & Shahzad, 2022; Motlagh et al., 2020; Pandey et al., 2023; Pugna et al., 2022; Rizvi, 2019; Singh et al., 2022), the energy sector leverages a range of technologies such as artificial intelligence (AI), big data, internet of things (IoT), cloud computing, blockchain to accelerate the sustainable energy transition through digital transformation (Table 1).

Artificial intelligence (AI) and its subfield machine-learning (ML) are revolutionizing renewable energy by modeling, monitoring, and forecasting both production and consumption (Asif, 2022). This fosters a more sustainable transition through optimized resource allocation and improved grid management. Big data and tools in data analytics enable the analysis of massive datasets from smart meters, sensors, and weather patterns (Pugna et al., 2022). This analysis leads to deeper insights into renewable energy production and consumption. By understanding these patterns, companies can optimize energy generation, predict demand fluctuations, and

improve grid integration. Ultimately, big data empowers a more efficient and data-driven approach to renewable energy solutions.

Table 1. Key digital technologies used in the energy sector

Technology	Description	Application Examples	Explanation
Artificial Intelligence (AI) and Machine Learning (ML)	AI uses algorithms to mimic human intelligence, while ML allows machines to learn from data without explicit programming.	Demand forecasting	AI predicts energy demand fluctuations, enabling efficient resource allocation and grid management.
		Renewable energy integration	AI optimizes the integration of variable renewable sources like solar and wind into the grid.
		Predictive maintenance	ML identifies potential equipment failures in wind turbines or solar panels, enabling preventative maintenance.
		Automated energy trading	AI algorithms can participate in energy markets, optimizing buying and selling decisions.
Big Data and Data Analytics	This involves collecting, storing, and analyzing large datasets to uncover hidden patterns and insights.	Smart grid optimization	Analyzing data from sensors and smart meters helps optimize grid operations, improve efficiency, and minimize energy losses.
		Customer behavior analysis	Data analytics helps understand energy consumption patterns, enabling personalized energy plans and targeted energy-saving initiatives.
		Risk assessment	Analyzing historical data helps predict weather patterns and potential grid disruptions, allowing for proactive measures.
Internet of Things (IoT)	A network of physical devices embedded with sensors that collect and exchange data.	Smart meters	IoT-enabled meters provide real-time energy consumption data to consumers, empowering informed energy choices.
		Smart grid management	Sensors monitor and report on grid conditions, enabling real-time adjustments and improved reliability.
		Renewable energy monitoring	IoT sensors track performance and health of solar panels, wind turbines, and other renewable energy assets.
		Distributed energy management	IoT connects distributed energy resources like rooftop solar panels, enabling efficient control and integration with the grid.
Cloud Computing	Provides on-demand access to computing resources like storage, servers, and software over the internet.	Data storage and analysis	Cloud platforms offer scalable storage and processing power for massive datasets generated by the renewable energy sector.
		Remote monitoring and control	Cloud-based systems enable real-time monitoring and control of distributed energy resources and smart grid infrastructure.
		Advanced analytics and AI development	Cloud computing provides the resources and infrastructure for running complex AI algorithms and big data analysis tools.
Blockchain	A secure, distributed ledger technology that facilitates transparent and verifiable transactions.	Peer-to-peer energy trading	Blockchain can enable secure and transparent peer-to-peer trading between consumers with renewable energy sources.
		Renewable energy certificates (RECs)	Blockchain can track and verify the ownership of RECs, ensuring authenticity and preventing fraud.
		Decentralized grid management	Blockchain can support decentralized energy models where consumers can buy and sell energy directly from each other.

Source: created by the authors based on Asif (2022), Idries et al. (2022), Juszczuk & Shahzad (2022), Motlagh et al. (2020), Pandey et al. (2023), Pugna et al. (2022), Rizvi (2019), Singh et al. (2022), and Varela (2017).

IoT technology is a game-changer for renewable energy. The network of connected devices enabled by this technology fosters the creation an “Internet of Energy” for optimizing production, distribution, and consumption (Motlagh et al., 2020; Simion et al., 2023; Varela, 2017). The benefits of cloud computing are also being harnessed in the renewable energy sector. Energy companies are integrating cloud-based solutions into their operations, enabling a more efficient and data-driven approach (Pandey et al., 2023). The cloud's scalability allows for streamlined data analysis and resource allocation, while also facilitating remote monitoring of renewable energy systems. Additionally, the cloud's vast storage capacity unlocks the potential of big data, allowing companies to extract valuable insights for better decision-making. Finally, blockchain, initially popularized for its secure transactions in the financial sector, is now gaining traction in the renewable energy sector. This technology facilitates secure peer-to-peer energy trading and transparent record-keeping for renewable energy certificates (Idries et al., 2022; Juszczuk & Shahzad, 2022). By doing so, blockchain paves the way for innovative digital business models and services within the energy landscape.

While not strictly classified as “digital technologies” themselves, robotics and automation solutions also play a crucial role in the digitalization of the renewable energy sector (Rizvi, 2019; Simion et al., 2023). They are being strategically implemented, particularly in areas like energy distribution automation and field operations.

This integration allows for enhanced efficiency and data collection. For example, robots can be deployed for automated inspection and maintenance of wind turbines or solar panels, improving safety, and reducing downtime. Similarly, drones equipped with sensors can be used to collect data on grid infrastructure, facilitating predictive maintenance and optimizing resource allocation. Combined with digital technologies like AI and data analytics, robotics and automation become powerful tools that ensure the smooth functioning of renewable energy systems.

Digitalization is widely recognized as a key catalyst for accelerating the energy sector's transition to a more sustainable model (Ersoy et al., 2022). As previously discussed, various digital technologies, such as AI, big data, IoT, cloud computing, and blockchain, are transforming how energy is produced, managed, and consumed within the renewable energy sector. To effectively leverage these digital advancements, a comprehensive understanding of the current state of the digitalization of Morocco's renewable energy sector is crucial. This understanding should encompass both the challenges and opportunities that exist. The investigation necessitates a structured approach to data collection and analysis. A theoretical framework will be employed to achieve this. The following sections will outline this framework, detailing the methodologies and data collection strategies employed to analyze the current state of the sector and its ongoing digital transformation.

3. Theoretical Framework

Case studies delve deeply into specific contexts, aiming to understand complex phenomena within a particular setting (Swanborn, 2018). To achieve this, a well-defined theoretical framework serves as the cornerstone of the analysis (Collins & Stockton, 2018). This framework outlines the key concepts, theories, and models that will guide the research process. It acts as a lens through which the researcher examines the case study, ensuring a systematic and focused approach. By establishing a theoretical framework, the case study gains a stronger foundation, allowing for a more insightful and meaningful interpretation of the data collected.

For a comprehensive analysis of the opportunities and challenges surrounding the digitalization of Morocco's renewable energy sector, this study will employ two complementary frameworks: the People, Process, Technology (PPT) framework and the Triple Bottom Line (TBL) framework. This integrated approach, as recommended by Machado et al. (2024), can offer a richer understanding of the complex phenomena involved in the transformation studied. These phenomena encompass multiple goals, diverse stakeholders, the challenges of organizational change, and technology integration – all crucial aspects for successful digitalization in the renewable energy sector. Ultimately, by integrating the PPT and TBL frameworks, this study can more effectively investigate the potential benefits and challenges associated with digitalizing Morocco's renewable energy sector.

The People, Process, Technology (PPT) framework, originating in the 1960s from the field of business management, offers a practical lens for analyzing change initiatives (Simon, 2021). It emphasizes the need for a well-balanced interplay between three key elements: People, Process, and Technology. The “People” aspect focuses on the skills, knowledge, and leadership required to implement change effectively. “Process” examines the existing workflows and ensures their compatibility with new technologies. Finally, “Technology” considers the selection and implementation of appropriate digital tools to support the transformation.

In the context of Morocco's renewable energy sector digitalization, the PPT framework can serve as a valuable tool for identifying potential gaps and areas for improvement. By analyzing the capabilities of the workforce, the efficiency of current processes, and the suitability of planned technological solutions, the PPT framework can guide the development of a comprehensive digitalization strategy. This ensures that Morocco leverages the full potential of digital technologies to achieve its renewable energy goals.

The Triple Bottom Line (TBL) framework, encompassing Economic, Environmental, and Social dimensions – also sometimes referred to as 3Ps of Sustainability (People, Planet, Profit) – emerged in the mid-1990s as a response to the growing emphasis on corporate social responsibility. While its exact origin can be traced back to the work of various thought leaders and publications, John Elkington (Elkington, 1998) is widely credited with popularizing the concept. The TBL framework is commonly used to assess the social, environmental, and financial impacts of an organization's activities. The “Economic” dimension focuses on financial performance

and viability, considering factors like profitability, resource efficiency, and impact on the local and global economy. The “Environmental” dimension assesses the organization’s impact on the natural environment, taking into account factors like pollution, resource depletion, and climate change. The “Social” dimension examines the effects on people and society, including labor practices, community development, and human rights. The TBL framework encourages consideration of these three dimensions simultaneously, aiming for a balance between financial success, environmental responsibility, and social well-being. It promotes a more holistic approach to decision-making, ensuring long-term sustainability.

In the context of Morocco’s renewable energy sector and its digitalization, the TBL framework can provide a necessary lens for assessing the initiatives’ long-term impact. Evaluating the social impact on local communities – including job creation, training opportunities, and potential disruptions – ensures a more comprehensive approach. Additionally, it prompts consideration of the environmental impact of digital technologies on resource consumption, waste generation, and the potential for lifecycle assessments. This broader perspective enables policymakers and stakeholders to make informed decisions that not only achieve renewable energy goals but also promote social equity, environmental responsibility, and a balanced transition within Morocco.

Further, the two established frameworks – PPT and TBL – are merged to create a comprehensive analytical matrix (Table 2). By combining these frameworks, the key clusters within the resulting matrix are identified.

Table 2. Leveraging a combined (PPT and TBL) framework for data collection matrix

TBL \ PPT	People <i>Skills and training needed for workforce and consumers</i>	Process <i>Seamlines and optimization of existing processes</i>	Technology <i>Specific technologies that can be leveraged</i>
Economic <i>Economic benefits and costs associated</i>	Upskilling the workforce with digital knowledge can lead to increased efficiency, potentially lowering operational costs and improving productivity.	Optimizing processes through digital tools can lead to significant cost savings, improved resource allocation, and potentially lower energy prices for consumers.	Investing in digital technologies can lead to long-term cost savings through increased efficiency and potentially open new markets for innovative renewable energy solutions.
	Job displacement might occur if digitalization automates existing tasks, impacting some workers' economic security.	Implementing new digital processes can be expensive, with upfront costs in infrastructure and software potentially creating financial strain.	The upfront investment in digital technologies can be significant, possibly impacting short-term financial stability.
Environmental <i>Optimization of energy production and distribution, minimizing environmental footprint</i>	A digitally skilled workforce and consumers can be trained to operate and maintain renewable energy systems more effectively, potentially reducing energy waste.	Digital tools can help optimize energy production and distribution, minimizing waste and maximizing resource utilization.	Technologies (smart grids) can optimize renewable energy production and distribution, leading to reduced greenhouse gas emissions.
	If digital training programs are not widely accessible, it could create a skills gap hindering optimal environmental performance.	Lack of standardization and interoperability, leading to inefficient implementation of digital processes might result in increased energy consumption for data centers and computing needs.	Manufacturing and disposal of digital technologies can create an environmental footprint, so responsible lifecycle management is crucial.
Social <i>Impact on communities and stakeholders</i>	Digital skills development can empower workers, offering opportunities for career advancement within the renewable energy sector.	Streamlining processes through digitalization can improve overall system reliability, security standards, potentially leading to fewer disruptions and improved renewable energy accessibility for communities.	Digital technologies can facilitate the development of innovative renewable energy solutions and new business models, potentially creating new markets and new jobs, ultimately improving living standards.
	Digital training programs might inadvertently exclude certain demographic groups due to accessibility issues,	If digitalization leads to job losses, it could have a negative social impact on affected communities.	Digital technology access might be uneven across different regions, potentially

TBL \ PPT	People <i>Skills and training needed for workforce and consumers</i>	Process <i>Seamlines and optimization of existing processes</i>	Technology <i>Specific technologies that can be leveraged</i>
	exacerbating social inequalities.		exacerbating existing inequalities.

Source: created by the authors

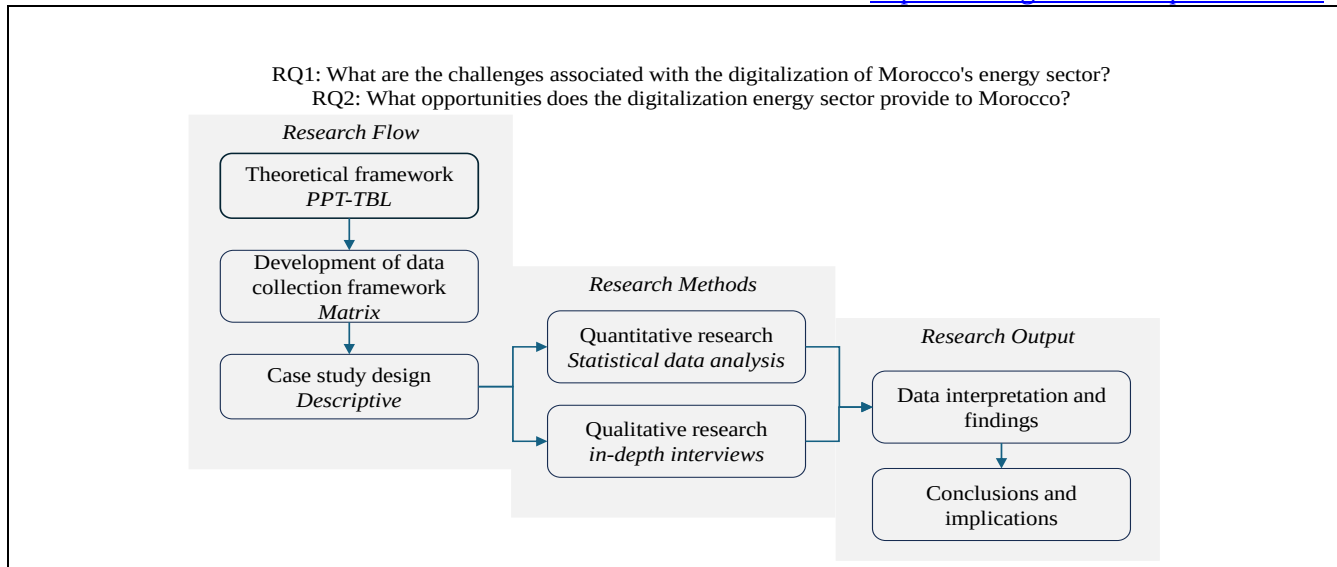
The transition to renewable energy presents a crucial opportunity for Morocco. However, digitalization, a key driver of this shift, can generate conflicting outcomes. Analyzing this process through the combined lens of the PPT and TBL frameworks (Table 2) reveals these potential contradictions. On the one hand, digitalization offers economic benefits. Optimizing processes (PPT) through data-driven decision making (TBL-Economic) can lead to cost savings. Technology (PPT) like sensor networks can improve energy production and distribution efficiency (TBL-Economic & Environmental). However, these advancements might come at the cost of job displacement (PPT-People & TBL-Social). Training existing employees or hiring new specialists with digital skills (PPT-People) could lead to short-term economic burdens (TBL-Economic). The environmental impact of digitalization also presents a complex picture. Digital tools for optimizing energy production (PPT-Process) can significantly reduce waste (TBL-Environment). However, the environmental footprint of the technology itself (e.g., manufacturing sensors, energy-hungry data centers, etc.) needs careful consideration (TBL-Environment). Additionally, ensuring accessibility to digital training for all employees (PPT-People & TBL-Social) is crucial to prevent exacerbating social inequalities.

The analysis conducted through the combined application of the PPT and TBL models highlights the importance of a nuanced strategy for digitalizing Morocco's renewable energy sector. Simply embracing technological advancements or economical pursuits without considering the potential downsides could lead to unintended consequences. Having established a theoretical framework to guide the analysis, the following section outlines the research methodology employed to investigate the challenges and opportunities of digitalizing Morocco's renewable energy sector.

4. Methodology

This research has adopted a descriptive case study method to investigate the challenges and opportunities associated with the digitalization of Morocco's renewable energy sector. The ability to investigate instances of the phenomenon being studied in depth, and to employ multiple sources of evidence, makes case study design a useful tool for descriptive studies where the focus is on specific situation or context (Rose et al., 2024). A descriptive case study is a case study whose purpose is to describe a phenomenon (the “case”) in its real-world context (Yin, 2018). The “case” may be an individual, or it can be some event or entity other than a single individual, and it can include a variety of topics, such as small groups, communities, decisions, programs, organizational change, etc. The appropriate case might be a country's economy, an industry in the world marketplace, an economic policy, or the trade or capital flow between countries (Yin, 2018). Thus, the unit of analysis for our case study is derived from the research aim – the digitalization of Morocco's renewable energy sector.

The unit of analysis is related to the research question. The selection of a descriptive case study is guided by the main empirical research question, which was formulated as follows – what are the prerequisites for the digitalization of Morocco's energy sector? To provide a structured approach to the research, the main research question is divided into two sub-questions: 1) what are the challenges associated with the digitalization of Morocco's energy sector? 2) what opportunities does the digitalization of energy sector provide to Morocco? These sub-questions permit a more detailed and comprehensive description of the research topic. Moreover, a linear-analytic research design was applied to ensure research rigor (see Figure 1).

**Figure 1.** Methodology of the research

Source: created by authors

A linear-analytic research design requires to follow the sequence of the research: it starts with the issue being studied and a review of the relevant literature, then proceed to cover the methods used, the data collected, and the data analysis and findings, ending with the conclusions and their implications (Yin, 2018).

Literature review can reveal important insights into the development of the research topic. Reviewing a particular (stream of) literature is essentially learning about the history, the present state, and the potential future developments of a specific realm (Michailova, 2023). A literature review revealed the key stakeholders in Morocco's renewable energy sector:

Government and Regulatory Institutions

This group, encompassing entities responsible for shaping the digitalization landscape through relevant policies, regulations, and investment plans, establishes the policy framework for renewable energy development and digitalization.

International Organizations

International organizations play a crucial role in supporting Morocco's digitalization efforts. They offer expertise and support for renewable energy initiatives by providing technical assistance, financial resources, and knowledge sharing. These contributions empower Morocco to achieve its economic, environmental, and social goals.

Private Companies

This category comprises energy and IT companies that act as the driving force behind digitalizing the renewable energy sector. They achieve this by developing, implementing, and investing in cutting-edge digital technologies within the sector.

Research Institutions and Academia

Universities and research institutions play a vital role in supporting the successful digitalization of the renewable energy sector. They achieve this by generating knowledge, developing innovative solutions, and training the future workforce.

Community and Consumers

The digitalization of the renewable energy sector directly impacts two key stakeholder groups: local communities residing near renewable energy projects and the general public who consume the generated energy.

Table 3 summarizes potential data contributions from the identified stakeholders within the context of the established theoretical framework.

Table 3. Key stakeholder groups and data contributions

Stakeholder Group	Data Contributions	Relevance to integrated PPT-TBL framework
Government and Regulatory Institutions	<i>Existing regulations and policies</i> This data will help identify potential hurdles or areas where adjustments might be necessary to facilitate the smooth integration of digital technologies within the sector.	Process (PPT), Economic (TBL)
	<i>Investment incentives</i> Understanding the existing and potential investment incentives offered by the government can inform strategies for attracting private sector participation in digitalization efforts.	Economic (TBL)
	<i>Potential roadblocks for digital transformation</i> By identifying potential roadblocks, such as infrastructure limitations or regulatory gaps, stakeholders can develop solutions and mitigate these challenges.	Process (PPT), Economic (TBL), Technology (PPT) (if infrastructure related)
	<i>Social concerns</i> Data from government agencies can offer insights into potential social concerns related to digitalization, such as job displacement or data privacy issues. Understanding these concerns allows for proactive measures to address them and ensure public acceptance.	Social (TBL)
	<i>Environmental regulations and monitoring</i> Government data on existing environmental regulations and monitoring practices can inform how digital solutions can be leveraged to ensure the environmental sustainability of the digitalized renewable energy sector.	Environmental (TBL)
International Organizations	<i>Technical assistance and expertise</i> International organizations can provide direct technical assistance by deploying experts to work alongside Moroccan counterparts on specific digitalization projects within the renewable energy sector.	Technology (PPT)
	<i>Financial resources or instruments</i> They can offer access to a variety of financial instruments such as grants, loans, or blended finance mechanisms to support investment in digital infrastructure and technology development for renewable energy.	Economic (TBL)
	<i>Knowledge sharing and best practices</i> International organizations can facilitate the creation of knowledge exchange platforms that connect Moroccan stakeholders with experts and practitioners from other countries who have successfully implemented digital solutions in the renewable energy sector. These platforms can foster collaboration, knowledge sharing, and the transfer of best practices. This could involve best practices for waste management associated with digital technologies, life-cycle assessments of different solutions, or promoting energy efficiency through digital tools.	Process (PPT), Environmental (TBL)
Private Companies	<i>Workforce Skills and Training Needs</i> Companies can contribute data on the specific skills and expertise required within their organizations to successfully implement digital solutions for renewable energy projects. This might include information on technical skillsets, data analysis capabilities, or project management expertise.	People (PPT)
	<i>Data management practices and cybersecurity considerations</i> Data on the challenges companies face when integrating digital solutions with existing infrastructure is crucial. This could involve aspects like data compatibility, cybersecurity concerns, or the need for upgrades to existing equipment.	Process (PPT), Technology (PPT)
	<i>Innovation and New Business Models</i> Companies are encouraged to share data on their ideas for innovative digital solutions and potential new business models with respective revenue streams within the digitalized renewable energy sector. This could involve novel applications of existing technologies, data-driven service offerings, or entirely new approaches to energy production or distribution.	Economic (TBL), Technology (PPT)
	<i>Investment plans for renewable energy integration</i> Data on how companies plan to integrate renewable energy sources into their digital solutions can contribute to the environmental dimension. This could involve information on using digital tools to manage and optimize the integration of renewable energy sources like solar or wind power.	Economic (TBL) Process (PPT)

Stakeholder Group	Data Contributions	Relevance to integrated PPT-TBL framework
	<i>Return on Investment (ROI) Expectations</i> Companies can provide data on their anticipated ROI for various digitalization projects. This data can help assess the financial feasibility of different technological solutions and identify areas where incentives or policy adjustments might be needed to support wider adoption.	Economic (TBL)
	<i>Data on the environmental impact of new technologies</i> Companies can provide data on the life-cycle assessments (LCA) of the digital solutions they propose to implement. LCAs evaluate the environmental footprint of a product or service throughout its life cycle, from resource extraction to disposal. This data can help assess the environmental impact of different digitalization options and identify solutions with a lower environmental footprint.	Environmental (BTL)
	<i>Data on waste management practices</i> Information on how companies plan to manage and dispose of any electronic waste generated by the new digital technologies can be valuable. Responsible waste management practices are crucial for minimizing the environmental impact of digitalization.	Environmental (TBL), Process (PPT)
	<i>Data on energy efficiency improvements</i> Companies can provide data on the potential energy efficiency gains expected from their proposed digitalization solutions. This could involve information on how digital tools can optimize energy production, distribution, and consumption, ultimately reducing the environmental impact of the renewable energy sector.	Environmental (TBL)
	<i>Social Responsibility Initiatives</i> Data on existing or planned social responsibility initiatives related to digitalization can be valuable. This might include data on workforce training programs, community engagement efforts, or plans to address potential job displacement or skill gaps arising from digital transformation.	People (PPT), Social (TBL)
Research Institutions and Academia	<i>Collaboration with industry</i> Data on existing or planned collaborative efforts between research institutions and industry stakeholders (including private companies) can be beneficial. This could involve collaborative research projects, joint development of practical solutions, or student internship programs that bridge the gap between theory and real-world application.	Process (PPT)
	<i>Development of environmentally sustainable digital solutions</i> Data on research efforts focused on developing or adapting digital solutions that minimize environmental impact can be valuable. This could involve research on energy-efficient hardware and software for digital technologies used in the renewable energy sector or exploring the use of recycled materials in these technologies.	Environmental (TBL), Technology (PPT)
	<i>Open-Source Technology Development</i> Data on research efforts related to the development and adaptation of open-source digital technologies suitable for the Moroccan renewable energy sector can be valuable. This information can inform companies about potential solutions that are readily available and adaptable to their specific needs.	Technology (PPT), Process (PPT)
	<i>Skills Gap Analysis</i> Research institutions can contribute data on their assessments of existing skill gaps within the workforce relevant to the digitalization of the renewable energy sector. This data can help identify areas where curriculum development or targeted training programs are needed to equip future generations with the necessary skills.	People (PPT)
	<i>Research on economic modeling for digitalization of renewable energy sector</i> Research institutions can contribute data on their existing or planned research addressing economic models for digitalization within the renewable energy sector. This could include data on cost-effectiveness analysis of different technological solutions or potential financial benefits for both companies and consumers.	Economic (TBL)
	<i>Social impact assessments</i> Data on existing or planned research methodologies for assessing the social impacts of digitalization on the renewable energy sector can be insightful. This could involve frameworks for evaluating potential job displacement, skills gaps, or the need for social safety nets during the transition.	Social (TBL)

Stakeholder Group	Data Contributions	Relevance to integrated PPT-TBL framework
	<i>Research on the environmental sustainability and environmental impact of digital renewable energy solutions</i> Research institutions can contribute data on the environmental impact of different digital solutions being considered for the renewable energy sector. This could involve life-cycle assessments (LCA) of specific technologies, comparative analyses of environmental footprints, or research on potential environmental risks associated with digitalization (e.g., e-waste management), frameworks for evaluating the environmental impact of different solutions or tools to measure the effectiveness of environmental risk mitigation strategies.	Environmental (TBL)
Community and Consumers	<i>Existing skills and knowledge within the community</i> Data on existing levels of digital literacy and access to technology within the communities served by private companies can be helpful. This could involve information on internet penetration, smartphone ownership, or comfort levels with using digital tools.	People (PPT)
	<i>Concerns about job displacement or traditional energy use</i> Data on community concerns regarding potential job displacement or changes in traditional energy use patterns can be informative. Additionally, understanding their expectations for increased participation in decision-making processes around digitalization can be valuable.	Social (TBL), Economic (TBL), Process (PPT)
	<i>Energy Conservation Practices</i> Data on existing energy consumption patterns and community attitudes towards energy conservation can be helpful. This could involve information on preferred communication channels for energy-saving tips or willingness to participate in demand-response programs facilitated by digital technologies.	Environmental (TBL), Process (PPT)
	<i>Access to technology and affordability concerns</i> Data on potential social equity concerns arising from digitalization can be valuable. This might involve concerns about unequal access to information or potential benefits within the community, particularly for low-income residents.	Social (TBL), Economic (TBL), Technology (PPT)

Source: created by the authors based on Bahgat (2013), Bakkari et al. (2024), Bouabid et al. (2019), Cantoni & Rignall (2019), Choukri et al. (2017), Fragkos (2023), Kousksou et al. (2015), Moore (2021), Plank et al. (2023), and Schinko et al. (2019).

To gather data for this study, a mixed-methods approach was employed, allowing for the triangulation of findings. A combination of qualitative (in-depth interview) and quantitative (statistical data analysis) methods permits the describe the energy sector situation in Morocco as well as gain insights associated with the digitalization of Morocco's energy sector. In-depth interviews are useful for deriving detailed information or to get insights into the lived experience of participants (Rose et al., 2024). According to De Massis & Kotlar (2014), interviews are often the primary data source in case studies, as they are a targeted, insightful, and highly efficient means of collecting empirical data. The in-depth interviews were conducted with five key experts representing Government and Regulatory Institutions, International Organizations, Research Institutions and Academia, and Private Companies. These interviews provided rich qualitative data on the sector's dynamics and informed the subsequent analysis. Additionally, a thorough analysis of relevant documents, including reports, strategies, and policies, was undertaken to supplement the interview data. To provide a broader context, secondary data, such as statistical information on Morocco's energy and digital landscape, was incorporated into the analysis. This triangulation of data collection methods enhanced the credibility and robustness of the research findings.

While pre-established theoretical frameworks, such as the PPT and BTL models, provide a valuable structure for analysis, it was essential to maintain methodological flexibility to capture the nuances of stakeholder perspectives. As suggested by grounded theory (Charmaz & Thornberg, 2021), allowing for emergent themes can enrich the research findings. By developing a set of initial guiding questions based on the chosen framework and remaining open to unforeseen insights, researchers could more effectively address the research objectives. During in-depth interviews conducted in English and French with stakeholder representatives, researchers adapted their questioning style based on the conversation's flow and the representative's insights. This flexibility allowed for deeper exploration of unforeseen issues or perspectives that emerged during the interview. Similarly, when analyzing reports and documents, the investigation was not limited to the initial

guiding questions. Instead, framework analysis was used to reveal new aspects or viewpoints not anticipated initially. The obtained data were carefully systematized to derive findings and draw conclusions.

5. Results

The following sub-sections present the findings of the research on the challenges and opportunities associated with digitalizing Morocco's renewable energy sector. By examining the country's energy landscape, stakeholder perspectives, and other relevant data, the study provides a foundation for understanding the current state of the sector and identifying key factors influencing its development.

Morocco's Energy Landscape

Morocco is experiencing a rapidly growing population, industrial development, and urbanization. These factors are driving a significant increase in the country's energy consumption. However, there was a slight decrease of 1.4% in total energy consumption in 2022, following an 8% increase in 2021 (Enerdata, 2024). Despite some fluctuation, Morocco relies heavily on imported hydrocarbons to meet its energy needs. Currently, the country imports approximately 90% of its energy needs (International Trade Administration – ITA, 2024).

Morocco uses six main resources for its energy supply: oil, coal, natural gas, hydropower, wind, and solar. Oil remains the dominant source, accounting for 56% in 2021, followed by coal (38.8%) (Figure 1). While oil consumption has been relatively stable since 2011, coal use has steadily increased by 43% between 2011 and 2021 (Figure 2). Conversely, renewable energy sources like wind and solar are experiencing significant growth. Their production has jumped from 2,372 TJ in 2010 to 37,370 TJ in 2021, a fifteenfold increase.

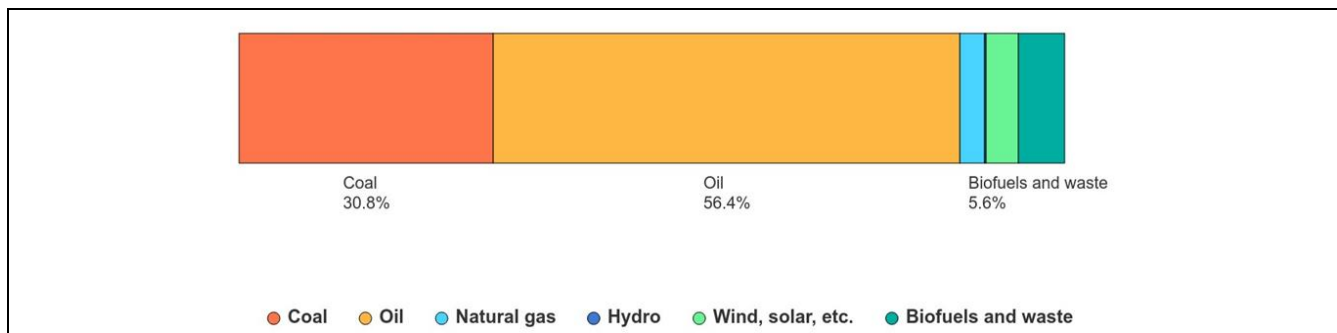


Figure 2. Total energy supply in Morocco during 2021
Source: International Energy Agency – IEA (2024)

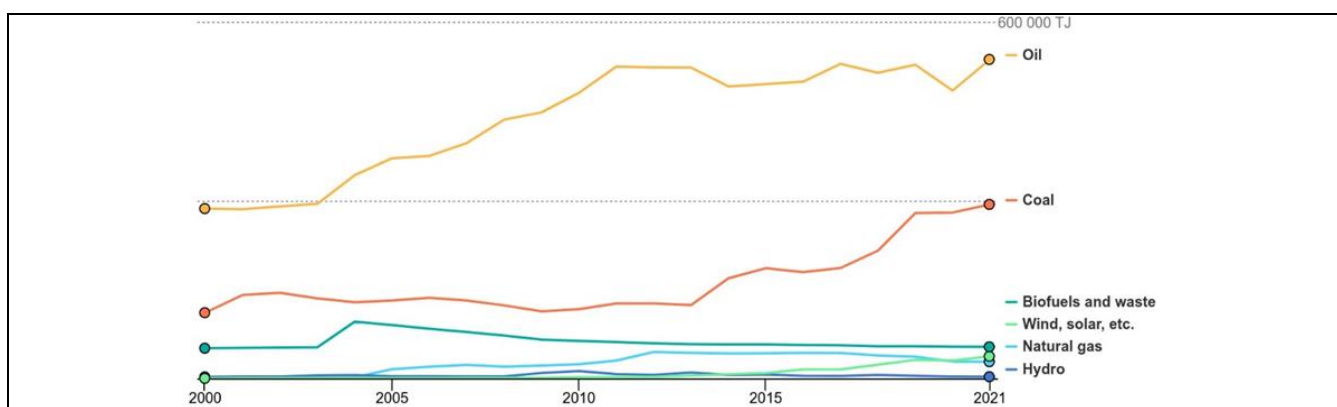


Figure 3. Evolution of total energy supply in Morocco (2000–2021)
Source: International Energy Agency – IEA (2024)

Recognizing the need for energy security and environmental sustainability, the Moroccan government aims to reduce dependence on imported fossil fuels and increase renewable energy use. This aligns with their commitment to the Paris COP21 agreement and Nationally Determined Contributions (NDCs). To achieve this, Morocco has launched several initiatives to boost the use of renewable energy sources for electricity production (Ministry of Energy Transition and Sustainable Development – METSD, 2024).

By 2022, Morocco had a total installed power capacity of 10,830 MW, with renewables contributing 38% (4,031 MW) according to the Ministry of Energy Transition and Sustainable Development – METSD (2024). This includes wind power (13.48%), hydropower (16.70%), and solar power (7.82%). This growth continued by the end of 2023, with the National Office of Electricity and Drinking Water – ONEE (2024) reporting a total installed power capacity of 11,474 MW. Notably, green installed power reached 4,672 MW, representing a 15.9% increase from 2022. This clean installed power is the result of 38 wind energy sub-projects, 23 hydropower sub-projects, and 19 photovoltaic plant sub-projects across different regions of Morocco (Ministry of Energy Transition and Sustainable Development – METSD, 2024).

Morocco's abundant renewable resources and favorable investment climate make it an attractive destination for international investors. Its impressive ranking of 2nd in Ernst & Young's Renewable Energy Country Attractiveness Index (RECAI) (Ernst & Young, 2023), specifically in the normalized index, underscores its significant potential in the renewable energy sector. The RECAI evaluates countries based on market attractiveness, technology-specific scores, and global market trends, adjusting for economic size to highlight exceptional performance in smaller markets. This high ranking reflects Morocco's robust policy support, favorable investment climate, and successful deployment of renewable energy projects, positioning it as a leading market for renewable energy investment and development. Consequently, the quality of renewable resources and the supportive investment climate have led to a significant drop in wind and solar power costs, making them competitive with fossil fuel-based electricity.

Morocco has experienced increasing electricity consumption in recent years, with figures indicating a steady growth trend (Rahhou, 2024). While total primary energy consumption has historically increased by 5% annually since 2004, Morocco aims to reduce consumption by 15% from 2016 levels by 2030 through energy efficiency measures (International Trade Administration – ITA, 2024). In 2022, the country's electricity production mix was diverse, with coal leading at 37.25%, followed by hydroelectricity (16.70%), natural gas (17.72%), wind (13.48%), solar (7.82%), and fuel oil (7.03%) (International Trade Administration – ITA, 2024).

Renewable Energy Integration

Morocco's energy sector has historically relied heavily on imported fossil fuels, leading to significant economic vulnerabilities. However, the country possesses abundant solar and wind resources, presenting a compelling opportunity to diversify its energy mix and enhance energy security.

In response to the energy crisis and the growing global focus on climate change, Morocco launched a comprehensive renewable energy program in 2009 (Alami, 2021). The Moroccan Solar Plan (MSP) emerged as a flagship initiative, aiming to develop large-scale solar power projects (Anouar, 2022; NDC Partnership, 2016). Furthermore, the country has set ambitious targets for increasing the share of renewable energy in its electricity mix, with a goal of exceeding 52% by 2030. With this strategy, Morocco aims to position itself as a key electricity hub for North and West Africa, leveraging its renewable energy initiatives to enhance regional energy connectivity and sustainability (Simpara, 2024; World Economic Forum, 2024).

To achieve these targets, the Moroccan government has established a supportive policy framework and initiated institutional reforms to implement the national energy strategy. Key reforms include the creation of the National Regulatory Authority (ANRE) and the Moroccan Agency for Sustainable Energy (MASEN), both of which play significant roles in developing renewable energy projects. The Moroccan Agency for Energy Efficiency (AMEE) is now responsible for implementing energy efficiency programs. Additionally, the Institute for Research in Solar Energy and Renewable Energies (IRESEN) conducts extensive research, development, and innovation activities in collaboration with the private sector. These efforts aim to ensure rapid technology transfer and translate research results into innovative products in renewable energies, energy efficiency, and new energy sources (Centre National pour la Recherche Scientifique et Technique – CNRST, 2021). Collectively, these institutions are crucial in driving renewable energy investments and facilitating the integration of renewable energy sources into the grid.

The development of renewable energy projects is primarily driven by the MSP, which is part of Morocco's energy strategy focusing on REs and sustainable development. Several other strategies and roadmaps support

Morocco's energy transition, including the Long-Term Low Emissions Development Strategy (LT-LEDS) Morocco 2050, Office of Electricity and Drinking Water (ONEE) Production Master Plan for 2040, PtX Roadmap, Biomass Energy Valorisation (VEB) Strategy, Roadmap for the Exploitation of Marine Energies, Cluster Green H2, National Sustainable Development Strategy (SNDD), National Energy Efficiency Strategy 2030, updated NDCs, National Climate Plan (PCN), Green Economy Strategy, National Water Plan 2050, and Morocco Vision 2050.

While the focus has primarily been on solar and wind energy, Morocco is also exploring the potential of other renewable sources, such as hydropower and biomass. Recent political debates indicate that Morocco also plans to develop a green hydrogen economy. The country aims to become an exporter of green hydrogen and its derivatives in the future, addressing domestic market needs, particularly the production of green ammonia. Energy partnerships with European countries and international hydrogen agreements underline the political support for developing a green hydrogen sector in Morocco.

Additionally, the announcement of the European Union (EU) and Morocco to establish a "Green Partnership" highlights the intentions to cooperate in advancing the energy transition (European Commission, 2021). The Moroccan government has expressed the intention to integrate more renewable energy sources into the energy mix, aiming for more than 52% renewable energy share in the capacity mix by 2030 (International Energy Agency – IEA, 2019). This share includes 20% from solar energy, 20% from wind energy, and 12% from hydro energy.

The energy transition is accompanied by many initiatives of National Center for Scientific and Technique Research (NCSTR), as encouraging Moroccan's researchers to develop studies, research and patents linked to renewable energy. According to the International Renewable Energy Agency – IRENA (2024), there has been a significant increase in patent filings in Morocco following its commitment to renewable energy in 2009. The report highlights that out of the 364 patents filed in the field of renewable energy between 2009 and 2020, 159 originated from Morocco, with the remaining patents primarily filed by European countries such as Spain (41), France (35), and Germany (31).

Morocco's Digital Landscape

Morocco's digital landscape has undergone significant transformations in recent years, driven by investments in infrastructure, government policies, and increased access to technology, according to the 2023 data of the globally recognized Network Readiness Index (NRI). This composite index is published annually by the World Economic Forum (WEF) in collaboration with academic institutions (European Commission, 2023; Portulans Institute, 2024). It aims to measure the degree of readiness of countries to exploit opportunities offered by information and communications technology (ICT). The Network Readiness Index (NRI) focuses on four key dimensions: technology, individuals, governance, and impact. Each pillar is comprised of three sub-pillars, supported by 58 indicators. These indicators encompass topics such as emerging technologies like artificial intelligence (AI) and the Internet of Things (IoT), as well as the role of digital transformation in advancing the Sustainable Development Goals (SDGs).

Morocco has traditionally occupied a mid-range position within the global NRI rankings, however, there has been a notable shift in its ranking in recent years. In an effort to align with emerging technologies and enhance its economic competitiveness, Morocco established the Digital Development Agency (ADD) in 2017. This autonomous public institution is responsible for driving the country's digital transformation and fostering digital literacy. In 2023 the country is positioned 77th out of a sample of 134 countries (Portulans Institute, 2023). Morocco has shown steady progress in improving its digital infrastructure and technological capabilities reaching the 72nd out of the 134 economies included in the NRI 2023 (Figure 4), but challenges remain in areas such as digital literacy, and e-participation.

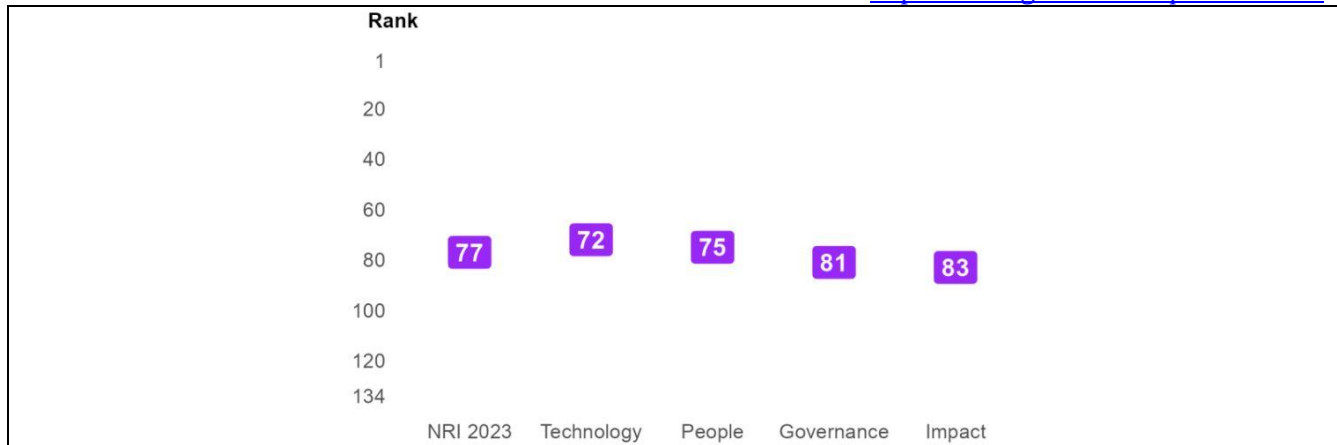


Figure 4. Morocco global NRI ranking, overall and by pillar

Source: Portulans Institute (2023)

Morocco's performance in the Technology pillar of the 2023 Network Readiness Index (NRI) is marked by significant progress. Morocco's solid foundation in digital infrastructure is evident in its high rankings for "International Internet bandwidth" (21st) and "FTTH/building Internet subscriptions" (43rd). This indicates a robust connectivity landscape that supports digital innovation and economic growth. The country's investment in emerging technologies is demonstrated by its strong performance in "AI scientific publications" (27th). This suggests a growing focus on research and development in cutting-edge technologies, positioning Morocco for future competitiveness.

Morocco has made significant progress in expanding mobile network coverage and improving international internet bandwidth. According to the country's Ministry of Economy and Finance (Simpara, 2023), the number of mobile subscriptions reached approximately 55.9 million in 2023, representing a penetration rate of 150.9%. This surpasses the penetration rate of developed countries and confirms Morocco's strong position in mobile telecommunications (26th). Despite improvements, fixed broadband subscriptions remain relatively low compared to some other countries in the region. This can hinder the adoption of data-intensive services and limit the potential for digital transformation. While mobile tariffs have decreased, the cost of mobile handsets and, in some cases, fixed broadband subscriptions can still be a barrier to access for certain segments of the population. The country's efforts to develop local digital content, including mobile applications, have been limited compared to other MENA nations. This impacts the diversity and relevance of digital services available to Moroccan users.

In the People Pillar, Morocco's performance reflects both progress and areas needing further development. This pillar assesses the readiness of individuals, businesses, and governments to use and benefit from ICT. Morocco has made significant strides in increasing internet access among its population. The country has a high percentage of individuals using the internet, which is a positive indicator of digital inclusion. According to the International Telecommunication Union (2023) estimates, 91% of the population was using the internet in 2022. This growth is driven by several factors, including improved infrastructure, and rising smartphone adoption. While internet penetration is high overall, there is a slight gender gap, with 90% of male and 86% of female populations using the internet in 2021. This suggests that efforts to bridge the digital divide should continue to ensure equal access for all. Internet usage is highest among younger age groups, with 99% of 15-24-year-olds and 85% of 25-74-year-olds online in 2021. However, internet penetration among the elderly (75+) remains relatively low at 28%, indicating a need for targeted initiatives to improve digital inclusion for older populations. Despite improvements, there is still a need to enhance digital skills and literacy across the broader population. The low ranking of "Government online services" (102nd) suggest that the extent to which a country's government has implemented and effectively delivered public services through digital channels is not satisfactory. The low ranking in "Knowledge intensive employment" (111th) indicates challenges in transitioning towards a knowledge-based economy, which is essential for long-term competitiveness. This suggests that both basic digital literacy and more advanced technical skills necessary for the workforce. Overall, Morocco's global ranking in the People Pillar indicates that while there has been progress, there is still room for improvement to match the leading countries in digital readiness.

In the Governance Pillar, Morocco demonstrates a mix of strengths and areas needing improvement. The country scores well in several key indicators, reflecting its commitment to enhancing digital governance and public services. The country's efforts to improve e-government services are evident in its strong ranking for “E-commerce legislation” (1st) and “Privacy protection by law content” (46th). These indicators demonstrate a supportive legal and regulatory framework for digital development. Though the regulatory environment in Morocco is improved to support digital transformation, the low ranking in “E-Participation” (111th) suggests opportunities for improving citizen engagement and participation in digital governance. There is a need to improve digital skills and literacy among government employees and the general population. The low ranking in “Online access to financial account” (124th) highlights challenges in promoting financial inclusion through digital channels, which can limit economic opportunities for many citizens.

Morocco's performance in the Impact pillar reflects its efforts to leverage digital technology for economic growth and social development. Morocco's strong ranking in “High-tech and medium-high-tech manufacturing” (23rd) indicates a growing capacity for technological innovation and industrial competitiveness. However, the country's performance in “High-tech exports” (83rd) suggests that there is room for improvement in leveraging digital technology to drive exports and foreign exchange earnings. Regarding the progress in areas related to the Sustainable Development Goals (SDGs), Morocco's commitment to sustainable development is demonstrated by its ranking for “SDG 7: Affordable and Clean Energy” (40th). However, challenges persist in achieving quality education (72nd) highlighting the need for improvements in educational systems to equip the population with the necessary digital skills. In general, Morocco's global ranking in the Impact Pillar indicates that while there has been progress, there is still room for improvement to match the leading countries in harnessing the full potential of ICT for sustainable development.

In conclusion, Morocco's digital landscape has evolved significantly, with notable strengths in digital infrastructure, emerging technologies, and necessary legislation for e-services. However, addressing challenges in education, knowledge-intensive employment, and e-participation is essential for building a more inclusive and competitive digital ecosystem.

Stakeholder Perspectives

This section presents key findings from expert interviews conducted to gain insights into the challenges and opportunities associated with Morocco's renewable energy transition.

Morocco's commitment to sustainability and renewable energy, as evidenced by the establishment of the Ministry of Energy Transition and Sustainable Development (METSD) and associated agencies. While this signifies a positive step, experts highlight the gap between ambitious goals and concrete achievements. Widespread energy waste, as highlighted by one expert's observation of “...a lot of energy being wasted...”, underscores the urgent need for efficiency improvements. To address these challenges, experts advocate for the accelerated deployment of smart grid infrastructure. This, they argue, is crucial for optimizing energy distribution, reducing waste, and facilitating the integration of renewable energy sources into the market. However, the centralized nature of Morocco's current energy system, as noted by experts, presents significant obstacles to this transition, requiring both technological and regulatory advancements.

The absence of robust smart grid infrastructure, coupled with a lack of comprehensive regulatory frameworks governing energy markets and pricing, poses significant challenges to Morocco's energy transition. As emphasized by experts, these deficiencies are particularly critical given the energy sector's pivotal role in the national economy. Furthermore, the limited availability of comprehensive economic and investment return models, as noted by one expert, who stated “economic and investment return models are not widely publicized, suggesting they might not be fully developed,” creates uncertainty for potential investors. To compound these issues, regulatory delays in adopting smart grid frameworks exacerbate investor concerns and hinder overall progress.

Morocco has actively sought international partnerships to advance its renewable energy agenda. While collaboration with foreign entities has been pursued through various projects, concerns have been raised regarding the nature of these partnerships. Experts have highlighted that foreign organizations often prioritize technology transfer rather than knowledge sharing, as evidenced by the statement: “foreign organizations often

prioritize importing and implementing their own technologies, with a focus on taking away the generated energy.” Furthermore, the lack of open-source technology sharing has been identified as a critical barrier to local capacity building, as emphasized by the expert's observation: “the technologies brought in by foreign partners are not open-source, meaning there is limited sharing of expertise with local stakeholders.”

Morocco boasts a strong intellectual foundation for driving innovation in the renewable energy sector, with numerous universities capable of conducting cutting-edge research. This potential is evidenced by the proliferation of renewable energy projects incorporating digital technologies. However, challenges persist in harnessing this capacity effectively. As highlighted by experts, fragmented digitalization initiatives, exemplified by the observation “...fragmented green energy sector digitalization initiatives...”, hinder the development of a unified national strategy. This lack of coordination among academia, industry, and government, coupled with a skills gap, has impeded progress. The expert noted the need for “...new competences and processes...” required for smart grid technologies, highlighting the need for targeted skills development and training programs.

Effective communication and collaboration are essential for driving innovation and policymaking in the energy sector. As one expert noted, “...lack of communication... with those who make decisions...” hinders progress. A lack of coordination among academia, industry, and government stakeholders, as evidenced by fragmented initiatives pursued by individual actors, has led to inefficiencies and missed opportunities, as highlighted by experts.

Long-term sustainability is often overlooked in the pursuit of rapid renewable energy development. Experts emphasize a tendency towards short-term thinking, as evidenced by the statement “...sustainability... is viewed narrowly...”. This neglects the critical issue of end-of-life management for renewable technologies, such as the disposal of solar panels and batteries. Additionally, the renewable energy sector has experienced political interference, hindering its responsible development. As one expert noted, “the current development of wind farms often leads to the emergence of unsustainable infrastructure and service providers in their vicinity.” This highlights the need for a holistic approach that considers both environmental and economic impacts.

Moroccan consumers, both residential and industrial, face significant challenges in optimizing energy consumption. A lack of real-time data, as highlighted by experts, hinders their ability to identify and address energy inefficiencies. The transition to a digitalized energy system necessitates significant behavioral changes and skill development across all stakeholder groups. This includes households, industries, and energy producers.

For instance, households will require training in utilizing smart meters to monitor and manage energy consumption effectively. Industries must enhance their data analysis capabilities to optimize operations and reduce energy waste. Energy producers will need to adapt to the dynamic nature of a smart grid and integrate renewable energy sources seamlessly. As one expert noted, “...resistance to change... new competences and processes...” will be a key challenge in overcoming these hurdles.

This underscores the need for stakeholders' education and awareness campaigns. By explaining the benefits of smart grids, such as potential cost savings and a more sustainable energy future, these campaigns can empower the stakeholders to actively participate in the energy transition.

While large corporations in Morocco have made significant strides in digital transformation, small and medium-sized enterprises (SMEs) face distinct challenges. As noted by experts, the primary obstacle for SMEs is not financial constraints but rather a reluctance to adopt new technologies and processes. The expert emphasized: “the main challenge is not the availability of funding but rather the reluctance of SMEs to change, adapt their processes, and acquire the necessary skills to utilize digital and smart technologies effectively.”

Despite the establishment of two energy innovation clusters, their impact on fostering industry collaboration has been limited. As one expert stated, “the two energy innovation clusters have not been able to fully bridge the gap and foster the necessary synergies among industry stakeholders.” Furthermore, regional disparities in development levels have hindered progress. As noted by experts, “there is a noticeable gap in the level of development between different regions, with some being far more advanced than others.”

On a positive note, the role of academia in promoting collaboration is acknowledged. Experts recognize the efforts of universities in fostering knowledge sharing and cooperation among industry stakeholders, as evidenced by the statement: “academia is actively working to enhance collaboration and knowledge sharing among various players in the energy sector.”

The expert perspectives presented in this section have provided valuable insights into the complexities and challenges associated with Morocco's renewable energy transition. The findings underscore the need for a comprehensive and multi-faceted approach to address the identified issues. The following discussion section will delve deeper into these challenges, explore potential solutions, and propose recommendations for policymakers, industry stakeholders, and researchers to advance Morocco's renewable energy agenda.

Discussion

This study aimed to assess the challenges and opportunities associated with digitalizing Morocco's renewable energy sector. By combining expert interviews with an analysis of secondary data, including statistics and relevant documents, this research sought to identify the current state of the sector and to understand the factors influencing its development. The following discussion delves deeper into the findings, analyzing them through the lens of the People, Process, Technology (PPT) and Bottom Triple Line (BTL) frameworks to elucidate the complexities and implications of digital transformation.

People: The Human Factor in Digital Transformation

The successful digitalization of Morocco's renewable energy sector is contingent upon a skilled and adaptable workforce. A significant skills gap, as highlighted by experts, exists within the sector, hindering its ability to fully harness the potential of emerging technologies. Upgrading the skills of both the existing workforce and consumers is paramount to ensuring a smooth transition to a digitalized energy landscape.

While digitalization offers numerous opportunities for innovation and efficiency, it also carries the risk of job displacement. As automation and artificial intelligence become increasingly prevalent, certain roles within the energy sector may become redundant. Therefore, it is essential to implement comprehensive retraining and upskilling programs to equip displaced workers with the necessary competencies for emerging roles.

Equitable access to digital training programs is crucial to prevent exacerbating existing social inequalities. Targeted initiatives should be implemented to ensure that all segments of the population, including individuals from rural areas, have the opportunity to acquire the digital skills required for the renewable energy sector.

Process: Optimizing Efficiency Through Digitalization

Digital technologies offer immense potential for optimizing processes within the renewable energy sector. By streamlining operations, reducing manual interventions, and enhancing data-driven decision-making, digital tools can significantly enhance efficiency. For instance, automation of routine tasks, such as data entry and report generation, can free up human resources for more strategic activities. Additionally, digital platforms can facilitate seamless communication and collaboration among stakeholders, accelerating project timelines and reducing costs.

However, the implementation of new digital processes is not without its challenges. Resistance to change, coupled with the need for substantial investments in technology and training, hinders the adoption. Furthermore, ensuring interoperability between different digital systems is crucial to avoid creating new inefficiencies. To overcome these challenges, a phased approach to digital transformation is essential, along with robust change management strategies.

Technology: Enablers of the Energy Transition

Digital technologies are emerging as indispensable tools for driving the energy transition. Technologies such as artificial intelligence, big data analytics, the Internet of Things (IoT), and blockchain offer unprecedented opportunities to optimize energy production, distribution, and consumption. For instance, AI-powered predictive analytics can enhance renewable energy forecasting, enabling grid operators to better integrate variable energy sources. IoT devices can facilitate real-time monitoring of energy systems, enabling efficient

troubleshooting and maintenance. Blockchain technology has the potential to revolutionize energy trading by creating transparent and secure peer-to-peer energy markets.

While the adoption of these technologies promises substantial benefits, it also comes with associated costs and potential environmental impacts. The initial investment in digital infrastructure and the ongoing expenses for data management and cybersecurity can be significant. However, these costs can be offset by increased efficiency, reduced operational expenses, and new revenue streams. Furthermore, the environmental impact of digital technologies, particularly in terms of energy consumption for data centers and the production of electronic devices, must be carefully considered and mitigated through sustainable practices.

Economic Implications of Digitalization in the Renewable Energy Sector

The integration of digital technologies into the renewable energy sector holds significant potential for economic benefits. By streamlining operations, reducing costs, and enabling data-driven decision-making, digitalization can enhance the sector's overall efficiency and profitability. For instance, the optimization of energy distribution and consumption patterns through digital platforms can lead to substantial cost savings for both energy providers and consumers. Moreover, the development of new digital solutions and services can create job opportunities and stimulate economic growth.

However, the transition to a digitalized energy system also involves economic risks and challenges. The initial investment in digital infrastructure and workforce training can be substantial, potentially impacting short-term financial performance. Additionally, the potential for job displacement due to automation must be carefully considered to mitigate negative social and economic consequences. To maximize the economic benefits of digitalization while minimizing risks, it is essential to develop strategies for managing costs, mitigating risks, and fostering innovation.

Social Implications of Digitalization

The social implications of digitalization in Morocco's renewable energy sector are multifaceted and require careful consideration. While digital technologies offer the potential to empower individuals and communities, the country's socio-economic landscape presents significant challenges. High illiteracy rates, particularly in rural areas, coupled with regional disparities in development, create a complex environment for digital inclusion.

To maximize the social benefits of digitalization, targeted interventions are necessary to bridge the digital divide. This includes investing in digital literacy programs, expanding internet access, and developing culturally appropriate digital tools.

Moreover, the fear of job displacement due to automation is prevalent among the workforce. This social anxiety poses a dilemma for policymakers, who must balance the benefits of digitalization with the need to protect vulnerable population. While new job opportunities may emerge in the digital economy, it is crucial to implement effective retraining and upskilling programs to mitigate the negative social impacts of this transition. By addressing these challenges and ensuring equitable access to digital technologies, Morocco can harness the full potential of digitalization to create a more inclusive and sustainable society.

Environmental Implications of Digitalization

The environmental impact of digitalization in the renewable energy sector is a complex issue with both positive and negative dimensions. On the one hand, digital technologies offer significant potential for reducing the environmental footprint of the energy sector. By optimizing energy production and distribution, digital tools can contribute to minimizing waste and maximizing resource efficiency. For instance, smart grids can enable the integration of renewable energy sources, reduce energy losses, and optimize grid operations.

However, the growing reliance on digital technologies also raises environmental concerns. The energy consumption associated with data centers and the production of electronic devices can contribute to greenhouse gas emissions. Additionally, the disposal of electronic waste, if not managed properly, can have detrimental effects on the environment. To mitigate these negative impacts, it is crucial to adopt sustainable practices in the design, production, and disposal of digital technologies.

To fully realize the environmental benefits of digitalization while minimizing its drawbacks, a holistic approach is necessary. This includes promoting energy efficiency in data centers, encouraging the reuse and recycling of electronic waste, and supporting research and development of low-carbon digital technologies.

Overall Assessment and Recommendations

The digital transformation of Morocco's renewable energy sector presents both significant challenges and opportunities. While the analysis through the PPT and BTL frameworks highlights the potential benefits of digitalization in terms of efficiency, economic growth, and environmental sustainability, it also underscores the importance of addressing key challenges such as skills gaps, infrastructure limitations, and social inequalities.

To fully realize the potential of digitalization, a comprehensive and coordinated approach is essential. This includes investing in human capital development, further building robust digital infrastructure, and creating supportive regulatory frameworks. Additionally, it is crucial to prioritize research and development in emerging digital technologies and to further foster collaboration among government, industry, and academia.

Crucially, successful implementation necessitates a robust change management strategy. Overcoming resistance to change, fostering a culture of innovation, and ensuring stakeholder buy-in will be critical to the overall success of the digital transformation. By adopting a holistic perspective and addressing the identified challenges, including the effective management of change, Morocco can position itself as a leader in the renewable energy transition and reap the rewards of a digitalized energy sector.

Conclusions

This case study aimed to identify the challenges (RQ1) and opportunities (RQ2) associated with digitalizing Morocco's renewable energy sector. By examining the perspectives of key stakeholders and analyzing relevant data, the study sought to understand the sector's digitalization prerequisites and to identify strategies for overcoming barriers to digital transformation.

The research findings underscore the significant potential of digitalization in driving Morocco's renewable energy transition. While the country has demonstrated a strong commitment to renewable energy, the realization of its full potential is hindered by several challenges. Firstly, the study highlights the critical role of human capital in the digitalization process. A skilled workforce is essential for the successful implementation and operation of digital technologies. However, the current skills gap, particularly in relation to digital competencies, poses a significant barrier to progress. This is further compounded by the uneven distribution of digital skills across the population, with certain demographics, such as youth and women, facing greater challenges. Secondly, the importance of robust digital infrastructure and supportive regulatory frameworks is evident. The absence of these elements impedes the effective integration of renewable energy sources and the optimization of energy systems. Additionally, the lack of interoperability between different digital systems can hinder the overall efficiency of the energy sector. Thirdly, the study emphasizes the need for a holistic approach to digitalization that considers both economic and environmental implications. While digital technologies offer opportunities for cost reduction and efficiency gains, their impact on jobs, social equity, and the environment must be carefully managed. The potential for job displacement due to automation, as well as the environmental consequences of digital technologies, require careful consideration and mitigation strategies. Finally, the research underscores the importance of effective change management and stakeholder engagement in driving digital transformation. Overcoming resistance to change, fostering collaboration among various stakeholders, and ensuring equitable access to digital technologies are crucial for realizing the full potential of digitalization.

The findings of this study underscore the complex interplay of technological, economic, social, and environmental factors in the digitalization of Morocco's renewable energy sector.

Economically, the transition to a digitalized energy system offers opportunities for economic growth, job creation, and increased efficiency. However, the initial investments in digital infrastructure and workforce development may pose challenges for some stakeholders. It is essential to develop strategies to mitigate these costs and maximize the economic benefits of digitalization.

Environmentally, digital technologies present both opportunities and risks. While they can contribute to the optimization of energy production and distribution, reducing overall environmental impact, their own energy consumption and waste generation must be carefully managed. A circular economy approach, emphasizing the reuse and recycling of electronic waste, is crucial to minimize the ecological footprint of digitalization.

Socially, the implications of digitalization are far-reaching. While digital technologies can enhance access to energy services and create new economic opportunities, they also risk exacerbating existing inequalities. Efforts to bridge the digital divide, invest in digital literacy, and ensure equitable access to the benefits of digitalization are essential to achieve a just and inclusive energy transition.

Based on the findings of this study, several key recommendations emerge for advancing Morocco's renewable energy transition through digitalization. Firstly, investing in human capital development is paramount. This includes targeted training programs to equip the workforce with the necessary digital skills, as well as initiatives to bridge the digital divide. By fostering a digitally literate population, Morocco can maximize the potential benefits of digital technologies. Secondly, building a robust digital infrastructure is essential for enabling the effective integration of renewable energy sources. This requires significant investments in smart grid technologies, data centers, and high-speed internet connectivity. Thirdly, a supportive regulatory environment is crucial for stimulating innovation and investment in the renewable energy sector. Streamlining regulatory processes, creating incentives for digital adoption, and establishing clear guidelines for data privacy and security are essential for unlocking the full potential of digitalization. Fourthly, a holistic approach to sustainability is required. While digital technologies offer numerous benefits, their environmental impacts must be carefully managed. Promoting circular economy principles, investing in clean energy for data centers, and encouraging the development of sustainable digital technologies are essential steps. Finally, strengthening the collaboration among government, industry, academia, and civil society is vital for successful digital transformation. By working together, stakeholders can address challenges, share knowledge, and accelerate the transition to a sustainable energy future.

This study has made significant contributions to the understanding of the challenges and opportunities associated with digitalizing Morocco's renewable energy sector. By examining the perspectives of key stakeholders and analyzing relevant data, the research provided a nuanced understanding of the sector's dynamics.

While the study offers valuable insights, further research is needed to explore specific aspects of the digitalization process in greater depth. For example, in-depth case studies of successful digitalization initiatives could provide valuable lessons for other developing countries. Additionally, long-term monitoring and evaluation of the impacts of digitalization on Morocco's energy sector are essential to inform ongoing policy and decision-making.

In conclusion, the successful digitalization of Morocco's renewable energy sector requires a multi-faceted approach that addresses the economic, environmental, and social dimensions of the transition. By addressing the identified challenges and capitalizing on the opportunities presented by digitalization, Morocco can position itself as a leader in the global renewable energy transition.

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CUSTOMER PERCEPTION OF GREEN MARKETING IN THE SOUTH AFRICAN RETAIL SECTOR

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Abstract. Green marketing has recently become essential to companies as environmental relevance grows worldwide. Green marketing implies focusing on developing a company's strategy in creating products, promotion, and distribution concerning ecological balance in conserving natural resources. This study assessed customer perception of green marketing within the South African retail sector. A descriptive, quantitative, and cross-sectional design was adopted for the study. Data were derived from a simple random sample of 150 respondents using a self-administered structured questionnaire. Data analysis was done through descriptive statistics using the Statistical Package for Social Sciences. This study observed green marketing variables such as eco-labelling, environmental aspects, and green advertisement affect customers' purchasing behaviour. These findings could assist companies and marketing practitioners who wish to exploit environmentally sensitive consumers. In this regard, it is crucial for firms to actively assume green marketing strategies as one of the methods of adjusting to changeable customer sentiments. This study has contributed to literature on green marketing from the developing world with specific reference to the retail sector in South Africa.

Keywords: green marketing; consumer purchasing behaviour; green advertising; eco-labelling

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1. Introduction

The retail industry has, over recent years, undergone a significant transition towards sustainability. Hence, green marketing today is one of the most valuable brand strategies for engaging with environmentally conscious consumers (Papadas, 2021). With its rich biodiversity and unmatched socio-economic challenges in South Africa, green marketing has emerged as an essential competitive differentiator and a moral imperative. More and more often, consumers are aware of the environmental impact of their purchasing decisions, and retailers are increasingly tasked to revise their marketing activities in line with these changing perceptions. Green marketing ensures awareness among people regarding natural, environmentally friendly products and services. This strategy also motivates consumers to make ecologically responsible purchase decisions. Although it has gained momentum over the years, a total dearth of understanding still prevails concerning the impact that green marketing has on consumer buying behaviour in the retail sector of South Africa. The retail sector in South Africa presents a diverse consumer demographic, variable levels of environmental awareness, and an equally complex socio-economic environment (van Valkengoed et al., 2022).

Increasingly, with urgent issues like climate change, resource depletion, and social inequalities dominating public debates, sustainability in retail has become recognised. At the same time, looking at such challenges, green marketing can be regarded as strategic and defined as attempts to market a product or service due to its environmental advantages. South African government implements policies and initiatives geared toward attaining sustainability across various spheres. This pushes retailers to adopt greener methods, but whether such

initiatives bear fruit depends on consumers' perceptions and acceptance of such green marketing messages. Therefore, with retailers trying to gain the confidence of a loyal customer base in an ever-changing marketplace, it will be essential to understand if South African consumers believe green marketing reflects a commitment to sustainability or is only a marketing ploy. The current study focuses on customer perception of green marketing and purchasing behaviour in South Africa. Thus, by gaining a deeper understanding of these perceptions, retailers can more effectively tailor their strategies to align with consumer expectations and contribute to a more sustainable future.

2. Literature Review

Theory of Planned Behaviour

The Theory of Planned Behaviour (TPB) represents a psychological construct to elucidate the connections among individuals' beliefs, attitudes, intentions, and behaviours. Formulated by Ajzen (1991), this framework asserts that a person's intention to engage in a particular behaviour is shaped by three primary factors: their attitudes concerning the behaviour, the subjective norms surrounding it, and their perceived control over the behaviour in question. Especially in green marketing, TPB would be beneficial in explaining to a great extent how consumers form perceptions of eco-friendly products and consequently make purchasing decisions. In the South African retail environment, consumers have become increasingly exposed to green marketing campaigns promoting environmentally sustainable products. For example, if consumers think buying eco-friendly products contributes positively to environmental conservation, they are more likely to form positive attitudes, affecting their purchase intentions. Subjective norms also play a vital role in affecting consumer behaviour in this regard. Consumers may feel a sense of responsibility to purchase eco-friendly products, not just for self-satisfaction but also to align themselves with the ideals shared by their social circles. In addition, the perceived behavioural control—the ease or difficulty of actually performing the behaviour—will influence consumers' willingness to demonstrate sustainable purchasing behaviour.

Green Marketing

Green marketing refers to marketing products by highlighting their environmental benefits. Green marketing entails making environmental claims about the attributes and characteristics of the products or the operational processes, policies, and systems of the companies that produce or sell them (Nekmahmud, & Fekete-Farkas, 2020). Chen and Chai (2019) build on this definition by incorporating the actions taken by enterprises in being sensitive to environmental issues, which ends in offering products or services that are friendly to nature with one primary objective: to satisfy the needs of the customer and the community. Due to the growing awareness of environmental issues, green marketing has become prominent in the retail sector. Green marketing involves the practices and strategies used by firms to advertise products and services that are environmentally friendly. Under this concept is the promotion of not only eco-sensitive products but also the general commitment of a brand to sustainability in all aspects of its operations (Ogiemwonyi et al., 2023). Increased awareness of South African consumers regarding their environmental footprint makes understanding customer perception of green marketing a very instrumental tool for retailers to remain competitive in the dynamic marketplace.

Ecolabelling

Eco-labelling is a certification process that indicates a product's adherence to specified environmental standards. In South Africa, eco-labelling is very important, as consumers often do not possess adequate information regarding the sustainability features of products. Well-recognised ecological labels may increase consumers' confidence and impact purchase decisions since they assure that the product has met specific environmental criteria (Dangelico & Vocalelli, 2017). However, the success of ecolabelling depends on consumers' knowledge and understanding of the labels. Research by Peattie and Crane (2005) has indicated that although eco-labels change consumer preference, effectiveness on this account depends on the extent of consumer knowledge of what the labels mean and what effect they carry. Hence, retailers should invest in educational campaigns to raise awareness of eco-labels and their function in driving sustainable consumption.

Environmental Aspects

Product environmental characteristics refer to specific features and benefits that make a product more sustainable. This includes aspects such as the materials used to produce the product, energy efficiency,

recyclability, and the overall ecological footprint of the product (Bennett & Rundle-Thiele, 2019; Irfan & Bryla, 2025). In South Africa, where water scarcity and proper waste disposal are paramount, consumers are very conscious of the environmental impacts of their buying behaviour. Retailers who clearly and effectively communicate the ecological benefits of their offerings, such as reduced carbon emissions, sustainable sourcing, or inclusion of recycled materials, can gain considerable trust and loyalty among customers. A substantial body of research indicates that consumers prefer products with superior environmental outcomes because they align more closely with their values and lifestyle preferences (Haws et al., 2019; Alhemimah et al., 2025). Regarding this factor, transparency in sourcing and manufacturing products becomes crucial. Brands showing their commitment to sustainability through complete product descriptions, certifications, and narratives can develop more profound relationships with environmentally conscious consumers.

Green Advertising

Green advertisements play a significant role in forming consumer perceptions towards green marketing. Promotion strategies adopted by retailers for their green products significantly influence customers' attitudes and behaviours. Most successful green ads generally show authenticity and transparency by showing real benefits that bestow meaning on consumers. For example, advertising campaigns that show the monetary benefits of energy-efficient appliances or the health benefits of organic products are very effective at capturing consumer attention. Given South Africa's mixed market and different levels of awareness among consumers about environmental issues, targeted advertising is necessary. Retailers can now reach a younger and more environmentally conscious consumer base through digital platforms and social media used for green advertising—likely to support sustainable practices (Haws et al., 2019; Wagdi et al., 2022).

The effectiveness of green advertisements is greatly dependent on credibility. Consumers have increasingly become cynical about "greenwashing," where companies exaggerate or lie about the environmental benefits of their products to lure customers (Peattie & Crane, 2005). Retailers must thus ensure that authentic practices support their green marketing messages and clearly and truthfully communicate efforts on sustainability. This practice not only enables the development of trust but also solidifies brand loyalty with consumers whose purchases are guided by considerations for sustainability. A set of interrelated variables, including eco-labelling, the environmental features of a product, and green advertising, significantly influence customer perception of green marketing in the South African retail sector. As consumers become more environmentally conscious, retailers must adapt their marketing activities accordingly. Thus, increasing eco-label awareness among retailers and adequately conveying the environmental benefits of products through authentic green advertising is crucial for retailers to build positive consumer perceptions. Not only does this nurture a big leap in brand loyalty, but it also contributes to creating a better retail ecosystem in South Africa, thus reconciling corporate practices with heightened expectations for environmentally conscious consumption.

Consumer Purchasing Behaviour

Consumer purchasing behaviour refers to people's cognitive processes and activities when making decisions, acquiring, and using goods or services. These are influenced by various factors, such as psychological, social, cultural, and economic factors combined, in shaping consumer preferences and decisions (Kotler et al., 2020). The study of consumer buying behaviour within the context of green marketing in the South African retail industry relates to one of the most important things retailers must consider in properly reaching environmentally concerned consumers. Recent studies show that environmental consciousness and concern among consumers significantly influence purchasing behaviour in South Africa. Consumers, with the increasing visibility of ecological problems such as climate change and pollution, are now more inclined to support brands showing a commitment to sustainability (Mackenzie & McMillan, 2021). Retailers able to communicate the environmental benefits of their products are likely to affect consumer perception and alter purchasing decisions positively.

The importance of marketing communication in affecting consumer behaviour is vast. Effective green marketing strategies that focus on the ecological impact of the product are likely to resonate with consumers, cultivating responsibility and encouraging them to buy in an environmentally friendly manner (Peattie & Crane, 2019). Companies ought to be transparent and be able to prove the product's sustainability to earn trust and tap into purchasing behaviour. Environmental awareness and effective marketing strategies greatly influence consumers'

buying behaviour in the South African retail industry. In understanding this, retailers could develop focused green marketing initiatives involving consumers, eventually driving sustainable purchases.

3. Methodology

This research employed a descriptive quantitative and cross-sectional research design. A descriptive research design is a type of research in which a researcher observes and describes the behavioural characteristics of the people for whom the study is carried out. This research design often addresses the issues regarding the ongoing situation and provides a clear and detailed account of the specific aspect. This type of design can be implemented using several methods, such as questionnaires, observation, or case study methods. Descriptive research characterises the situation, population or phenomenon of interest. Quantitative research, however, is a methodology focused on empiricism and deduction. This method entails collecting and analysing previously coveted numbers systematically. It seeks to test the propositions developed, analyse, compare, project and make informed guesses about the future based on past experiences. This research aims to measure variables, their interrelations, causation and the aggregation of their manifestations through time. Results-oriented quantitative research uses different approaches, including surveys, experiments, and statistical treatment of data (Hair et al., 2019; Sekaran & Bougie, 2016).

A simple random sampling method was used to choose 150 respondents out of the population. Simple random sampling is a probabilistic sampling approach that allows the selection of a respondent or individual from a population. While utilising this approach, a representative sample free of prejudice would be found, allowing the study results to apply to a larger audience. One benefit of simple random sampling is that it heightens the accuracy of the per cent sample and lowers the chances of bias within the sample. Data collection was done using a close-ended self-administered questionnaire. A five-point Likert scale was used in this study, where '1' meant 'Strongly Agree' and '5' meant 'Strongly Disagree'. Descriptive statistics were used to analyse data. Descriptive statistics is summarising and presenting data in a way that is easy to understand without making inferences or generalisations beyond the sample. The analysis included the computation of statistical measures such as means, standard deviations, frequencies and percentages. These measures were used to describe the data's central tendency, variability and distribution (Field, 2018). Means were used to ascertain the level of agreement in interpreting results. Thus, where the mean scores are lower, it implies strong agreement with the statement, while higher mean scores indicate strong disagreement. SPSS software was used for the analysis.

4. Results

This study sought to understand customer perception of green advertisements, eco-labels, consumer purchasing behaviour and environmental aspects. One sample T-test was done to determine if there was a significant agreement or disagreement in each item. The average agreement scale is tested against the central score of '3' to decide if it significantly differs from '3'. The results are judged to be significant when $p < .05$. The mean values for all variables in the study are below 3.0, suggesting that, on average, the sample respondents tend to agree more closely on all the questions presented in the questionnaire. The standard deviation values for all variables are below 1, indicating consistency and minimal variation in responses, thereby supporting the normality of the data utilised (Bell et al., 2019).

Green Advertisement

Table 1 presents the respondent's level of agreement on the statement measuring green advertising. The mean score ($M=1.987$, $SD=.9863$) falls below 3, indicating an agreement. On average, respondents agree that they are often exposed to green advertisements. The extremely low p-value ($t(148) = 24.586$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that green advertisements help enhance environmental awareness. Similarly, the mean score ($M=1.743$, $SD=.8738$) falls below 3, indicating an agreement. On average, respondents agree that they are often exposed to green advertisements. The extremely low p-value ($t(148) = 24.270$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that green advertisements help enhance environmental awareness.

The mean score ($M=1.845$, $SD=.9089$) falls below 3, indicating an agreement. Respondents agree that green advertisements accurately reflect a brand's environmental effort. The extremely low p-value ($t(148) = 24.691$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that green advertisements accurately reflect a brand's environmental effort. Similarly, the mean score ($M=1.765$, $SD=.9255$) falls below 3, indicating an agreement. On average, respondents agree that green advertisements are necessary for environmental awareness. The extremely low p-value ($t(148) = 23.279$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that green advertisements are necessary for environmental awareness.

The statement with the most agreement was 5. The mean score ($M=1.743$, $SD=.8738$) falls below 3, indicating an agreement. On average, respondents agree that green advertisements help enhance environmental awareness. The extremely low p-value ($t(148) = 24.270$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that green advertisements help enhance environmental awareness. The mean value measured for all the Items was below 3, which indicates a significant agreement. On average, the respondents agreed with all the statements measuring green advertisements.

Table 1. Green Advertisements

Construct	N	Mean	Std. Deviation	t	df	p
I am often exposed to green advertisements	1	1.987	.9863	24.586	148	.000
Green advertisements help enhance environmental awareness	2	1.743	.8738	24.270	147	.000
Green advertisements accurately reflect a brand's environmental effort	3	1.845	.9089	24.691	147	.000
Green advertisements are necessary for environmental awareness	4	1.765	.9255	23.279	148	.000
I am sceptical of green advertising	5	2.593	1.1637	26.833	144	.000

Eco-labelling

Table 2 presents the respondent's level of agreement on the statement measuring eco-labelling. The mean score ($M=2.383$, $SD=.10565$) falls below 3, indicating an agreement. On average, respondents agree that they always buy eco-labelled products. The extremely low p-value ($t(148) = 27.528$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that they always buy eco-labelled products. The statement with the most agreement was 2. The mean score ($M=2.289$, $SD= 1.0546$) falls below 3, indicating an agreement. On average, respondents always notice whether the product carries eco-labels or not. The extremely low p-value ($t(148) = 26.490$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent's respondent always notices whether the product carries eco-labels.

The mean score ($M=2.872$, $SD=.12578$) falls below 3, indicating an agreement. On average, respondents agree that they postpone their purchase if an eco-label product is unavailable. The extremely low p-value ($t(148) = 27.775$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that if an eco-label product is unavailable, they postpone their purchase. Similarly, the mean score ($M=2.483$, $SD=1.2336$) falls below 3, indicating an agreement. On average, respondents agree they are willing to pay extra for eco-labelled products. The extremely low p-value ($t(148) = 24.572$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that they are willing to pay an extra amount for eco-labelled products. The mean score ($M=2.664$, $SD=1.2171$) falls below 3, indicating an agreement. Respondents agree they spend time searching for eco-labelled products before purchasing. The extremely low p-value ($t(148) = 26.723$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that they spend time searching for eco-labelled products before making purchases. The mean value measured for all the Items was below 3, which indicates a significant agreement. On average, the respondents significantly agreed with all the statements measuring eco-labels.

Table 2. Eco-labelling

Eco-labelling	N	Mean	Std. Deviation	t	df	p
I always buy eco-labelled products	1	2.383	1.0565	27.528	148	<.000
I always notice whether the product carries eco-labels or not	2	2.289	1.0546	26.490	148	<.000
if an eco-label product is not available, I postpone my purchase	3	2.872	1.2578	27.775	147	<.000
I am willing to pay an extra amount for eco-labelled products	4	2.483	1.2336	24.572	148	<.000
I spend time searching for eco-labelled products before making purchases	5	2.664	1.2171	26.723	148	<.000

Consumer Purchasing Behaviour

Table 3 presents the respondent's level of agreement on the statement measuring consumer purchasing behaviour. The mean score ($M=2.142$, $SD=1.0691$) falls below 3, indicating an agreement. On average, respondents agree that when they learn about a product's harmful impact on the environment, they stop buying it. The extremely low p-value ($t(148)=24.373$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that when they learn about the negative and harmful impact a product has on the environment, they stop buying it. The statement with the most agreement was 2. The mean score ($M=1.899$, $SD=.9312$) falls below 3, indicating an agreement. On average, in the case of an alternative, respondents prefer products that cause less pollution. The extremely low p-value ($t(148)=24.804$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that in case there is an alternative, respondents prefer products which cause less pollution.

The mean score ($M=1.899$, $SD=.9312$) falls below 3, indicating an agreement. On average, respondents agree that if there is an alternative, they prefer products which cause less pollution. The extremely low p-value ($t(148)=24.804$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that in case there is an alternative, they prefer products which cause less pollution. Similarly, the mean score ($M=2.272$, $SD=.9901$) falls below 3, indicating an agreement. Respondents agree they change products when not complying with the ecological conditions/rules. The extremely low p-value ($t(148)=27.824$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that they change products when they do not comply with the ecological conditions/rules.

Additionally, respondents also show significant agreement regarding thinking that green marketing practices positively affect my perception of the brand, with a mean score ($M=2.131$, $SD=.92991$) falling below 3. The low p-value ($t(148)=27.596$; $p=0.000$) reinforces the statistical significance of this inclination, emphasising that respondents think that green marketing practices positively affect my perception of the brand. Similarly, the mean score ($M=2.020$, $SD=.9614$) falls below 3, indicating an agreement. On average, respondents agree that knowing a product can be recycled, reused, or repaired after use is a reason to buy these products. The extremely low p-value ($t(148)=25.480$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that knowing a product can be recycled, reused, or repaired after use is a reason for them to buy these particular products.

Finally, the mean score ($M=1.993$, $SD=.9312$) falls below 3, indicating an agreement. On average, respondents agree that they like buying products which can be recycled. The extremely low p-value ($t(148)=25.119$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that they like buying recycled products. Similarly, the mean score ($M=2.238$, $SD=1.0748$) falls below 3, indicating an agreement. On average, respondents agree that they always buy energy-efficient products. The extremely low p-value ($t(148)=25.246$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that the respondent agrees that they always buy energy-efficient products.

Table 3. Consumer Purchasing Behaviour

Consumer Purchasing Behaviour	N	Mean	Std. Deviation	t	df	p
When I learn about the harmful impact a product has on the environment, I stop buying it	1	2.142	1.0691	24.373	147	<.000
In case there is an alternative, I prefer products which cause less pollution	2	1.899	.9312	24.804	147	<.000
When choosing between two products, I always buy the one which has the minimum impact on people and the environment	3	1.932	.9147	25.515	145	<.000
I change products when they do not comply with the ecological conditions/rules	4	2.272	.9901	27.824	146	<.000
I think green marketing practices positively affect my perception of the brand	5	2.131	.9299	27.596	144	<.000
Knowing a product can be recycled, reused, or repaired after use is a reason for me to buy these products	6	2.020	.9614	25.480	146	<.000
I like buying products which can be recycled	7	1.993	.9654	25.119	147	<.000
I always buy energy-efficient products	8	2.238	1.0748	25.246	146	<.000

4.3.4 Environmental Aspects

Table 4 presents the respondents' level of agreement on the statement measuring eco-labelling. The statement with the most agreement was 1. The mean score ($M=1.980$, $SD=.9406$) falls below 3, indicating an agreement. On average, respondents think that green products provide higher quality than regular ones. The extremely low p-value ($t(148) = 25.694$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that respondents think that green products provide higher quality than regular ones. Similarly, the mean score ($M=2.142$, $SD=.9259$) falls below 3, indicating an agreement. On average, respondents have more knowledge about recycling than an average person. The extremely low p-value ($t(148) = 28.143$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that respondents have more knowledge about recycling than an average person.

Finally, the mean score ($M=2.286$, $SD=1.0403$) falls below 3, indicating an agreement. On average, respondents know where to find products that create less waste. The extremely low p-value ($t(148) = 26.640$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that respondents know where they can find products that create less wastage. Similarly, the mean score ($M=2.151$, $SD=.9989$) falls below 3, indicating an agreement. On average, respondents know the sustainability symbols used on product packages. The extremely low p-value ($t(148) = 26.015$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that respondents know the sustainability symbols used on product packages.

Table 4. Environmental aspects

Environmental aspects	N	Mean	Std. Deviation	t	df	P
I think that green products provide higher quality than regular ones with the same characteristics	1	1.980	.9406	25.694	148	<.000
I have more knowledge about recycling than an average person	2	2.142	.9259	28.143	147	<.000
I know where I can find products that create less wastage	3	2.286	1.0403	26.640	146	<.000
I know the sustainability symbols used on product packages	4	2.151	.9989	26.015	145	<.000
I am deeply knowledgeable about environmental and social issues	5	1.987	.9623	25.285	149	<.000

Additionally, the mean score ($M=1.987$, $SD= 0.9623$) falls below 3, indicating an agreement. On average, respondents know the sustainability symbols used on product packages. The extremely low p-value ($t(148) = 25.285$; $p=0.000$) reinforces the statistical significance of this agreement, suggesting that respondents know the sustainability symbols used on product packages. The mean value measured for all the Items was below 3, which indicates a significant agreement. On average, the respondents agreed with all the statements measuring environmental aspects.

Conclusions

This study evaluated customer perception of green marketing in South African retail. Based on the findings of this study, businesses operating in the retail industry should actively embrace green marketing strategies that emphasise the eco-friendly attributes of their products and services. These strategies should promote sustainability, resource conservation, and environmentally responsible production practices. By implementing green marketing campaigns effectively, companies can enhance their reputation, foster consumer loyalty, and set themselves apart from competitors. For instance, eco-labelling, especially when endorsed by third-party certification, is essential in ensuring customers of the authentic eco-friendliness of items. Businesses must get eco-certifications for their environmentally sustainable products to establish consumer confidence and credibility. These certificates alleviate scepticism and bolster the credibility of environmentally beneficial assertions. Recognising the impact of reference groups, such as colleagues, friends, and family, on consumer purchase behaviour is essential. Companies may use this effect by generating favourable word-of-mouth marketing via reference organisations that advocate for eco-friendly products. The significance of social influence must not be overlooked when appealing to environmentally-conscious consumers.

Green advertising, which effectively communicates the environmental benefits of products, should be an integral part of a company's marketing strategy. Such advertising should highlight reduced ecological impact, resource conservation, sustainable production practices, and a company's commitment to sustainability. Well-executed green advertising can strengthen a company's image, boost consumer loyalty, and address environmental concerns effectively. To elicit positive customer reactions to green marketing initiatives, management should enhance consumer education and knowledge about environmental problems. Enhancing environmental literacy and raising awareness of sustainable practices can significantly impact customers who understand environmental issues. Green marketing tactics must be customised to cater to consumers with differing environmental awareness. Effective green marketing recognises the knowledge and awareness of the target audience, aiming to engage both individuals who are well-versed in sustainability and those less knowledgeable about environmental concerns.

The study's scope is limited to the specific context of the retail shop. Unique features of this retail environment, including store size, location, and customer demographics, may not represent other retail settings in South Africa or elsewhere. However, this study's findings may help benchmark with other retail stores with a similar management architecture. Future research should consider evaluating customer perception of green marketing using a qualitative study to understand their perspective and experiences better.

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RENEWABLE ENERGY CLUSTERS: THE CASES OF LEADING COUNTRIES, LESSONS APPLICABLE TO MOROCCO*

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Abstract. Environmental issues have grown from marginal concerns to one of the biggest global challenges for economies and societies. The easiest, quickest and most effective way of driving down greenhouse gas emissions and the best chance to stop climate change's process is by moving to an energy system based on renewables. The development of renewable energy clusters is one of the factors that promote renewable energy production. The primary aim of this paper is to offer valuable insights, catering to the needs of both researchers and practitioners, regarding conditions that supported or hindered the expansion of renewable energy clusters in the leading renewable energy-producing countries, i.e., to present the case study's research on renewable energy clusters. Using statistics and archival analysis, an overview of leading countries in renewable energy and the experience associated with the performance of renewable energy clusters will be provided. The research results and insights apply to the Moroccan case to boost the development of Moroccan renewable energy clusters and economic and political decision-making.

Keywords: clusters; renewable energy; leading countries

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1. Introduction

It is recognized globally that renewable energy is crucial as fossil fuels decline and demand rises (Baus, 2017). The global energy requirements are ever-increasing, and primarily fossil fuels are utilized for energy production. At the same time as fossil fuels are running out, pollution levels worldwide have been elevated to unsafe levels due to the conventional energy production processes. Of all the different approaches to curb pollution, globally, renewable energy is seen as the most potent one (Sudhakar et al., 2017). In a report published by the United Nations, it is stated that if the world's energy sector is not changed, it will be impossible to improve the standard of living in some parts of the world while at the same time being able to decrease CO² emissions. The energy sector must urgently change globally, so most countries must invest heavily in renewable energy development.

Morocco has swiftly emerged as one of the most rapidly flourishing hubs for renewable energy across the entire globe. All credit goes to the proactive stance on climate change adopted by the visionary King Mohammed VI. In the early 2000s, the Moroccan government not only formulated impactful policies but also introduced incentivizing measures to foster the growth and development of renewable energies, with a specific emphasis on solar power. The Moroccan government has embraced a comprehensive and well-coordinated approach to promote and facilitate the adoption of green energies, involving various levels of governance and institutions. The development of renewable energy clusters is one of the factors that promote renewable energy production.

The primary aim of this paper is to offer valuable insights, catering to the needs of both researchers and practitioners, regarding conditions that supported or hindered the expansion of renewable energy clusters in the top renewable energy-producing nations. The research results and insights can be applied to the Moroccan case to boost the development of Moroccan renewable energy clusters and economic and political decision-making.

To achieve the goal, the following tasks were formulated:

- 1) identify the leading countries in the production of renewable energy;
- 2) review the situation of energy from renewable sources in each country;
- 3) gather information about the experience of creating and operating clusters and the encouraging and hindering factors.

2. Renewable energy clusters: concept and role

In business, clusters refer to geographic concentrations of interconnected companies, suppliers, service providers, and associated institutions in a particular field. These clusters can enhance the competitive advantage of the entities involved through various means, such as fostering innovation, driving productivity, and encouraging new business formations.

Key aspects of business clusters include geographic proximity, specialization in a particular industry or sector; the proximity of firms allows for a blend of competition and collaboration, often leading to higher levels of innovation and efficiency; entities within a cluster can share resources such as specialized labour pools, suppliers, and infrastructure, which can reduce costs and improve efficiency; clusters promote the exchange of ideas and expertise, leading to increased innovation and the development of new technologies and processes; universities, research institutions, trade associations, and government agencies often play key roles in supporting and sustaining clusters through research, training, and policy support; clusters can drive regional economic growth by creating jobs, attracting investment, and fostering the development of new businesses.

Examples of well-known business clusters include Silicon Valley in California for the technology sector, Hollywood for the film industry, and the financial district in New York City for finance and banking (Porter, 1998).

In Polish law, according to the definition specified in art. 2 (15A) of the RES Act, an energy cluster is a civil law contract of a group of stakeholders concluded to accomplish a specific economic objective in the energy context, primarily in the field of electric power generation; a form of contract - entered into in order to strengthen cooperation in the field of electricity management over a large administrative area, covering up to five municipalities or one county. The cooperation includes 1) generation, 2) storage, 3) demand balancing, 4) trading, and 5) distribution - of electricity or fuels (Green Encyclopedia, 2024).

The fact that the contract is a civil law agreement means that such a cluster may comprise companies, research institutes, foundations, local government units and individuals. This provides an unprecedented capability to build complex logistic chains that could support the RES power delivery process.

Bare definitions will not help you understand the structure of a cluster. The whole concept is to combine, at the local level, the means for the generation and consumption of power in order to ensure the maximum transmission of energy among the cluster components and, at the same time, to minimize outbound and inbound transmission. Considering the economics of the entire undertaking, the cluster should be as self-sufficient as possible. Here, an example may be the cooperation of once isolated power-generating entities operating independently, such as owners of wind turbines and solar panels and local consumers, to adjust the generation profile to the consumption profile. The aim of a project is to best match both these profiles (Trendy w energetyce, 2018).

3. The case study of top countries for renewable energy production: energy clusters experiences, public policies and regulatory framework

3.1. Methodology of case study

It was decided to use the best practices of leading countries in the field of sustainable energy production and energy clusters to gain practical insights applicable to Morocco. The first step to achieving the goal is to identify the countries with the largest renewable electricity production based on statistical analysis. In the subsequent analysis of archival data, the experience of renewable energy clusters operating in leading countries will be reflected. Answer the question: How have past and current government policies and local conditions supported or hindered the expansion of a particular energy cluster?

3.2. Leading countries for renewable energy production

Different organizations measure the progress of renewable energy production differently; however, the lists of leading countries based on specific rankings can often be surprising in their differences. In order to find out the leaders of renewable energy production, it is worth examining the results of the evaluation and ranking of different organizations.

Two years ago, the Climate Council (2022) announced that 11 countries were leading the charge on renewable energy. Sweden: In 2012, Sweden reached their target of 50% renewable energy 8 years ahead of schedule. This puts them right on track to achieve their 2040 goal of 100% fossil-free renewable electricity production. They use their natural resources to combine wind, bioenergy, solar, and even body heat. In Stockholm, for example, body heat from commuters passing through the central station is used to heat a nearby building. Costa Rica: In 2022, Costa Rica produced a whopping 98% of its electricity from renewable sources for over eight years in a row. Costa Rica also holds the world record for most consecutive days using solely renewable energy – 300 in 2018 and breaking their record of 299 days in 2015. Costa Rica combines hydro, geothermal, wind, biomass and solar power to get the job done. In some years, they have even been able to export the excess power they have generated to countries in Central America's regional electricity market, such as Guatemala, Nicaragua, Panama, Honduras, and El Salvador. United Kingdom: The UK is the global leader in offshore wind energy. It has more capacity installed than any other country, with offshore wind powering over 7.5 million homes. A plan to increase this fourfold by 2030 will go a long way to the government's plan to decarbonize its power system by 2035.

Iceland: The land of fire and ice has unique access to a range of renewable resources. In 2015, hydropower and geothermal power combined provided almost 100% of Iceland's electricity production. Geothermal power heats 9 out of 10 homes, and Iceland is among the world's top ten global producers of geothermal energy. The UN has even suggested their transition could provide a model for other countries to make the switch. Germany: In 2022, Germany's new government set their self-described "most significant energy policy reform in decades" during their first 100 days in government. What's so special about it? Renewables sit at the centre, with targets of 80% renewable power by 2030 and close to 100% by 2035. Renewables accounted for 46.9% of German power consumption in 2022 (a 4.9% increase from 2021) and it looks like it's only going up from here. Uruguay: Since 2007, Uruguay has undergone a renewable energy revolution. Back then, imported fossil fuels provided more than a third of energy generation, but decades of transformation have resulted in Uruguay generating 91% of all its electricity from renewable sources in 2022. Between 2013 and 2018, Uruguay increased its wind power from 1% to 34% of its electricity mix in five years – the fastest any country has achieved. The majority of this comes from hydropower, complemented by wind, solar and biofuels. In some years, Uruguay will generate much renewable energy to export to its South American neighbours, Argentina and Brazil. And they're still on the lookout for extra ways to put it to use. Kenya: Kenya is home to Lake Turkana Wind Power Project, Africa's largest wind farm. With over 310 MW of capacity – enough to supply energy to one million homes. The project also attracted the largest private investment in Kenya's history \$650 million. Africa has huge renewable energy potential – home to 60% of the best solar resources globally, however, the continent receives less than 3% of energy investments worldwide. China: it appears the world's largest carbon emitter can also be a leader in renewable energy. It may seem counter-intuitive, but China is the global renewable energy leader, hosting nearly half its total operating wind and solar capacity. China is on track to double its utility-scale solar and wind power capacity, shattering the central government's ambitious 2030 target of 1,200 GW five years ahead of schedule. They're also the biggest investor in renewable energy worldwide, where nearly half of the world's low-carbon spending took place in China in 2022 (US\$546 billion). Now, they need to get those emissions down. Morocco: Morocco has harnessed the power of its ample sun supply to become a world leader in solar energy. It's home to the world's biggest concentrated solar farm, the Noor-Ouarzazate complex in the Sahara Desert, which has a capacity of 580 MW. The farm is the size of 3,500 football fields and generates enough electricity to power a city twice the size of Marrakesh. New Zealand is doing great things about renewables. 84% of New Zealand's electricity usage is renewable. New Zealand has set a target for 50% of total energy consumption from renewable sources by 2035, and 100% renewable electricity by 2030. Norway: As of 2016, 98% of electricity generation in Norway came from renewables, with hydropower leading the charge. They've been harnessing power from rivers and waterfalls since the late 1800s, so it's easy to see how this natural resource has been a critical part of Norway's power profile. Over the years, they've also added thermal and wind energy to the mix.

According to The World Economic Forum (2024), advanced economies are generally the top performers in the Energy Transition Index (ETI), with Sweden, Denmark, Finland and Switzerland leading the rankings. France, meanwhile, has entered the top five performers due to its effective energy efficiency policies, resulting in a 12% reduction in energy intensity. France is followed by Norway, Iceland, Austria, Estonia and the Netherlands in the Energy Transition Index (ETI). The top 10 countries collectively only represent 2% of the global population and contribute just 1% of energy-related CO2 emissions. Still, the report shows that major emerging economies like China and Brazil have also made significant progress. It highlights that China commissioned as much solar photovoltaic (PV) capacity in 2023 as the entire world did in 2022. Meanwhile, Brazil's long-term plan for hydropower and biofuels has been key in attracting investment.

Common characteristics of the top performers include enhanced energy security through a diverse mix of sources, improved energy intensity, an increasing share of clean energy, a carbon pricing mechanism and a supportive regulatory environment.

Statistical Review of World Energy provided by Ember (2024), Energy Institute – (Our World in Data, 2024a) may seem very informative at the beginning (Fig. 1); however, when contrasted with other statistical data, the situation becomes more explicit and more reflective of reality. It shows how much energy different countries produce from various energy sources. However, all countries are presented here as equals, although, for example, China produces 22 times more renewable energy.

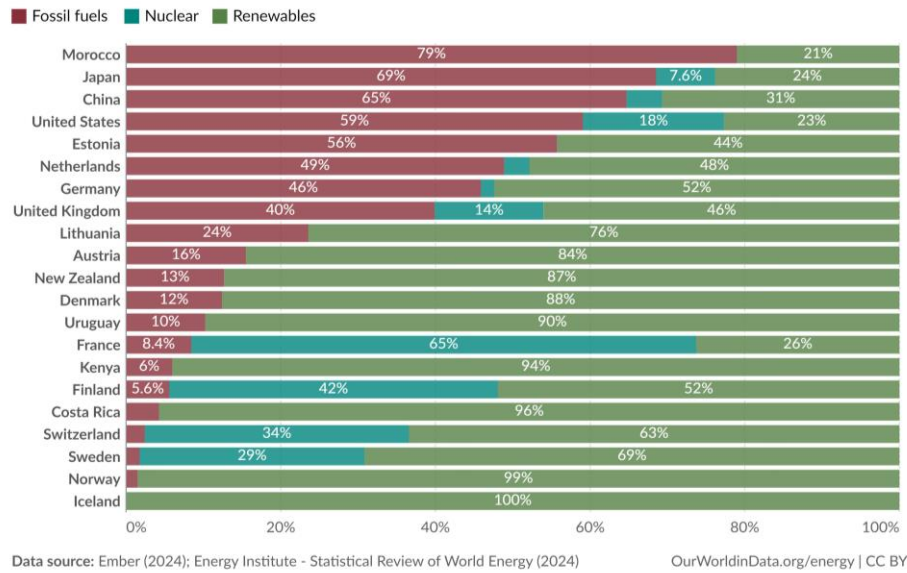


Figure 1. Electricity generation from fossil fuels, nuclear and renewables, 2023
Source: (Our World in Data, 2024a)

In 2022, China installed roughly as much solar capacity as the rest of the world combined, then doubled additional solar in 2023 (Hilton, 2024). Currently, China produces 31% of global renewable electricity, followed by the United States (11%), Brazil (6.4%), Canada (5.4%) and India (3.9%) (IRENA, 2024).

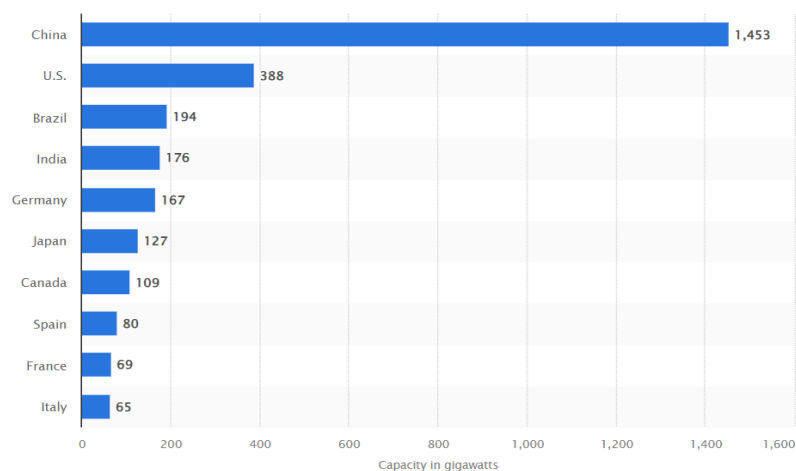


Figure 2. Leading countries in installed renewable energy capacity worldwide in 2023 (in gigawatts).
Source: (IRENA, 2024)

China was the leader in renewable energy installations, with a capacity of around 1,453 gigawatts. The U.S., in second place, had a capacity of around 388 gigawatts. Renewable energy is essential in addressing climate change and mitigating the consequences of this phenomenon.

3.3. The renewable energy generation and clusters performance in China

3.3.1. Overview of renewable energy generation in China

Hydroelectricity is China's largest renewable energy source and the second after coal. According to the International Hydropower Association, China is the world's largest producer of hydroelectricity. In 2024, China's installed hydroelectric capacity was 426 GW (IHA, 2024).

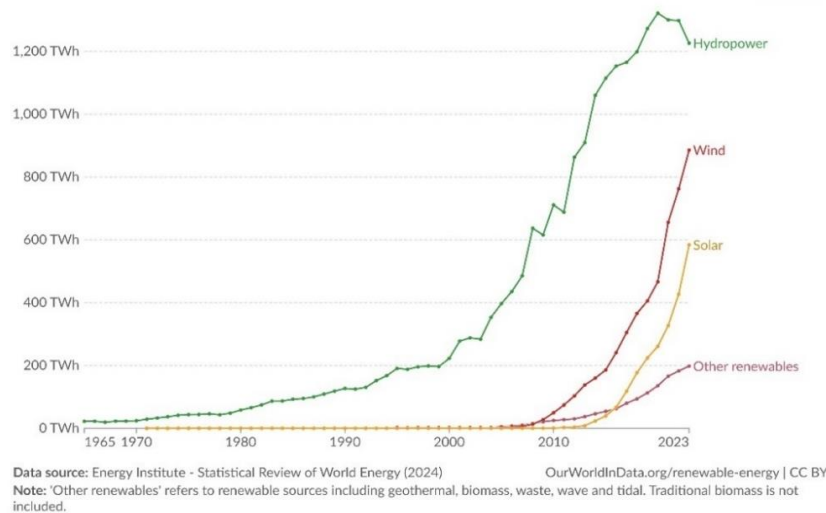


Figure 3. Renewable energy generation China

Source: (Our World in Data, 2024b)

After 2009, China began to carry out extensive wind and solar energy demonstration projects coordinated by the National Development and Reform Commission. These projects used the "flat-plate mechanism," which involved subsidies from the central government, concessions in the transmission grid, feed-in tariffs, tax incentives, and other supportive measures.

3.3.2. Renewable energy clusters in China

In 2015, China announced the "Enhanced Actions and Measures on Climate Change", which has set the goal of lowering carbon dioxide emissions per unit of GDP by 60 to 65% from the 2005 level. Achieving this goal necessitates fundamental changes in current coal-based energy systems. In January 2017, the Chinese government published the "13th Five-Year Development Plan for Renewable Energy (2016–2020)", and it is estimated that till 2020, a total investment of 2.5 trillion CNY (about US\$0.4 trillion) will be allocated to developing renewable energy. Against this background, China's much more rapid transition toward renewable energy-based energy systems is seemingly taking shape (Fuller & Guo, 2017; Huang & Liu, 2017; Su & Fan, 2022).

Regarding Dong et al. (2016) from the geographical distribution, it was concluded that after several years of development, in general, there were four renewable energy clusters formed: (1) Bohai rim areas, including Beijing, Tianjin, Hebei, Shandong, etc; (2) Yangtze River Delta region, includes Shanghai, Jiangsu, Zhejiang, Fujian, etc; (3) Middle China region, includes Henan, Jiangxi, etc; (4) Western China region, includes Sichuan, Inner Mongolia, Xinjiang, Gansu, etc. Two clusters are located in eastern China, one in central China and one in

western China. Among the above regions, Jiangsu presented the highest output value, mainly due to the highly developed solar PV industry. Zhejiang, Sichuan, Shandong, Hebei, and Beijing also have high output values. Those regions were also industrially developed areas (coastal eastern regions with higher GDP per capita and industries).

Jiangsu Solar PV Clusters: The Chinese province of Jiangsu is a leading global manufacturer of solar PV cells and modules driven by supportive government policies. Jiangsu has solar PV production plants that have among the largest capacity in the world and an extensive supply chain of supplier companies and raw materials inputs. Jiangsu is an emerging technology centre, with R&D conducted by universities, firms, and government laboratories. The province has several science parks with solar PV companies and R&D firms. The massive increase in global demand for solar PV after the mid-2000s, resulting from the rapid expansion of PV deployment in Germany and other countries, including China, led to the rapid growth of the Jiangsu manufacturing cluster, which had much lower labour costs than developed countries. The provincial government provided subsidies for land, installation of factories, electricity, and finance. Jiangsu also rapidly scaled its manufacturing capacity and built an extensive domestic supply chain. However, the glut in solar PV manufacturing in 2011 led to financial difficulties, bankruptcy, and consolidation of the PV manufacturing industry in Jiangsu. In addition, the United States and the European Union imposed anti-dumping tariffs on imports of solar PV products from China beginning in 2012, adversely affecting Jiangsu-based manufacturers. Following a two-year slump, the Jiangsu solar PV manufacturing cluster began to recover, helped by the growing demand for solar PV installations in China (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

Another case is the development of the wind power industry in Jiangsu province. He et al. (2016) gave a detailed discussion on wind industry clusters in Jiangsu province. Specifically, three clusters within Jiangsu province have emerged: Yancheng, Nantong, and Lianyungang. During the evolution process of the three clusters, a relatively complete wind power equipment industry has taken shape, including blades, gearboxes, generators, bearings, towers, and control systems (Huang & Liu, 2017). The rich labour, agricultural, and mineral resources in this area provide a labour force and raw materials for industrial development. Furthermore, the three-dimensional traffic network, which is a combination of railway, highway, port and air, has initially formed, which can provide convenient transportation conditions for the industry. In addition, Jiangsu coastal area also possesses the largest offshore radial sandbanks in the world. About 70 radial sandbank fan-shapely distribute off the mid-coastline of Jiangsu. Among these sandbanks, there are about 1300 km² of offshore shallows, where the average wind speed is 8.4 m/s at 70 m high, and the density of effective wind energy at 70 m is above 400 W/m²; thus, the wind energy can be used to generate power all year around. Jiangsu province severely lacks conventional energy; coal reserves are limited and unevenly distributed. Jiangsu power grid is a pure thermal power grid, with the installed capacity in 2013 being about 76,200 MW, and the power plants within the grid are mainly coal-fired ones, with a single power supply structure; meanwhile, the coal production capacity of Jiangsu is limited, about 80% of the coal demand depends on its allocation and transportation from outside the province. In recent years, electric power companies of Jiangsu have invested 700 million yuan in the construction of wind power integration projects and carried out a number of technical research. The local power grid can absorb 100% of wind power generated, but certain bureaucratic obstacles and lack of investment hinder the development of this project. The excessive intervention by the local government, development issues with wind-power component enterprises, insufficient independent technology innovation, and an imperfect cluster development environment have hindered healthy cluster development (He et al., 2016).

The following case for solar energy development is Shandong province, where a well-known industry cluster has been formed. It is home to Himin, the world's largest solar water heaters manufacturer. In 2013, there were more than 300 solar water heaters manufacturers in Shandong, with an annual output of more than 10 million heaters, comprising over 40% of the total production output of the country. The solar thermal power industry has established a complete industry chain covering the production of silica sand, rough pipe, vacuum tubes, heat

collectors, and heat collecting systems. Half of the ten representative solar water heaters enterprises in China are located in Shandong province. A strong industrial foundation plays an imperative role in promoting the use of solar energy. The application of solar energy is very advanced in many cities in Shandong province, such as Rizhao and Dezhou. Solar energy penetrates local people's everyday lives and is widely applied in other industries such as paper making, machinery, and textiles.

3.4. Renewable energy generation and cluster performance in the USA

3.4.1. Overview of renewable energy generation in the USA

In 2023, about 4,178 billion kWh (or about 4.18 trillion kWh) of electricity was generated at utility-scale electricity generation facilities in the United States. About 60% of this electricity generation was from fossil fuels—coal, natural gas, petroleum, and other gases. About 19% was from nuclear energy, and about 21% was from renewable energy sources. Renewables: Wind – 10.2%; Hydropower – 5.7 5.7%; Solar - 3.9%; Biomass – 1,1%; Geothermal - 0.4%. The U.S. Energy Information Administration estimates that an additional 73.62 billion kWh of electricity generation was from small-scale solar photovoltaic systems in 2023 (EIA, 2024).

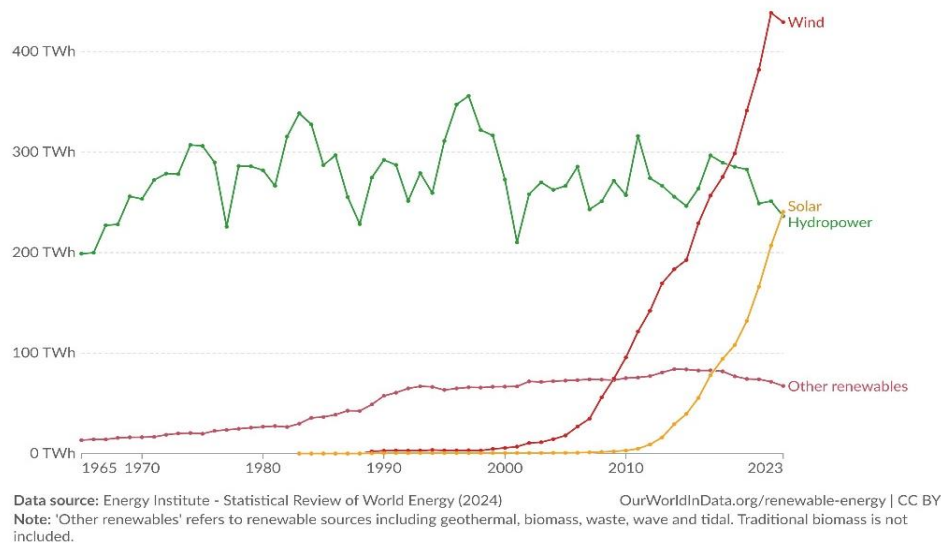


Figure 3. Renewable energy generation. United States
Source: (Our World in Data, 2024e)

Currently, six U.S. cities are already running on 100% renewable electricity: Aspen, Burlington, Georgetown, Greensburg, Rock Port, and Kodiak Island. These cities are all at the forefront of the clean energy initiative (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

3.4.2. Renewable Energy Clusters in USA

California's solar PV innovation cluster is a leading-edge technology cluster that currently has no associated large-scale manufacturing. The cluster originated more than four decades ago, driven by state government policies supporting solar. California is a leader in solar PV electricity generation, with a 5% share of global solar PV cumulative capacity installed as of 2015. Input of the California Research Centers and Silicon Valley's venture capital investment in solar PV technologies encouraged the establishment of renewable energy clusters. However, California's current PV manufacturing activity is limited to small-scale fabrication of prototypes of next-generation solar PV technologies. Although several multinational solar PV companies have offices in California, their solar PV manufacturing primarily occurs offshore in Asian countries.

California's more than 40-year-old solar PV cluster had a global first-mover advantage driven mainly by concerted and supportive policies by the state government. The state government has provided a number of market-based and financial incentives over the last four decades to encourage residential and commercial solar PV installation. The federal government's investment tax credit also stimulated the installation of solar PV. California became a major solar PV manufacturing centre in the 1980s and 1990s when the United States was a major global solar PV manufacturer. Starting in the early 2000s, California lost market share to other countries and U.S. states as PV manufacturing outside of California dramatically increased. California also did not provide sufficient incentives to manufacturers to maintain its solar PV manufacturing base. Several other U.S. states provided more appealing tax and other financial incentives. They successfully attracted solar PV manufacturing with manufacturing centres in Washington, Oregon, Michigan, and Mississippi, with the bulk of global manufacturing in Asian countries (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

The Great Lakes region comprises eight U.S. states - Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin—and the Canadian province of Ontario. The Great Lakes region has substantial wind energy capacity, with a 4% global share of cumulative installed capacity. The innovation cluster comprises research institutes, universities, and industries that perform or fund wind energy R&D and technological development. The U.S. Department of Energy has funded wind R&D activities in several Great Lakes states. Western University in Ottawa has the world's most advanced wind tunnel. The Great Lakes manufacturing cluster primarily manufactures wind subcomponents that supply assembly plants of the main components—blades, nacelles, and towers—located in several states, including Texas, Iowa, and Colorado, and in other countries (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

Key technology demand-side policies that have supported this wind cluster include the renewable portfolio standards adopted by the eight Great Lakes states and other U.S. states, as well as Ottawa's 2009–2013 feed-in tariff program. Government policies that encourage manufacturing have included the U.S. government's investment tax credit and, various tax incentives and other programs implemented by the Great Lakes states during and following the 2008–2009 recession. Ottawa's feed-in-tariff program had a domestic content requirement that spurred the construction of wind manufacturing plants. Some wind components (blades, towers) are large and challenging to transport thus providing an incentive to be made within the country of installation; however, the subcomponents within the nacelle are more easily transported and the retention of the manufacturing of these technologies appears to be supported by a strong cluster of skilled labour and relevant supply chains. The Great Lakes region's pre-eminence in other manufacturing industries—automotive, fabricated metal parts, and machinery manufacturing—played a key role in the development of the wind industry through the transfer of technology, use of skilled labour from these industries, and use or conversion of plants in these industries (Fuller & Guo, 2017; Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

3.5. The renewable energy generation and clusters performance in Germany

3.5.1. Overview of renewable energy sources in Germany

Renewable energy in Germany is mainly based on wind and biomass, plus solar and hydro. Germany had the world's largest photovoltaic installed capacity until 2014; as of 2023, it has over 82 GW. It is also the world's third country by installed total wind power capacity, 64 GW in 2021 (59 GW in 2018) and second for offshore wind, with over 7 GW. Germany has been called "the world's first major renewable energy economy".

Germany has been the global pioneer in applying renewable energy and environmental technologies for decades. In 2019, 46% of the country's electricity mix came from wind, solar, biomass and hydroelectric sources. That's up 5.6 percentage points over 2018.

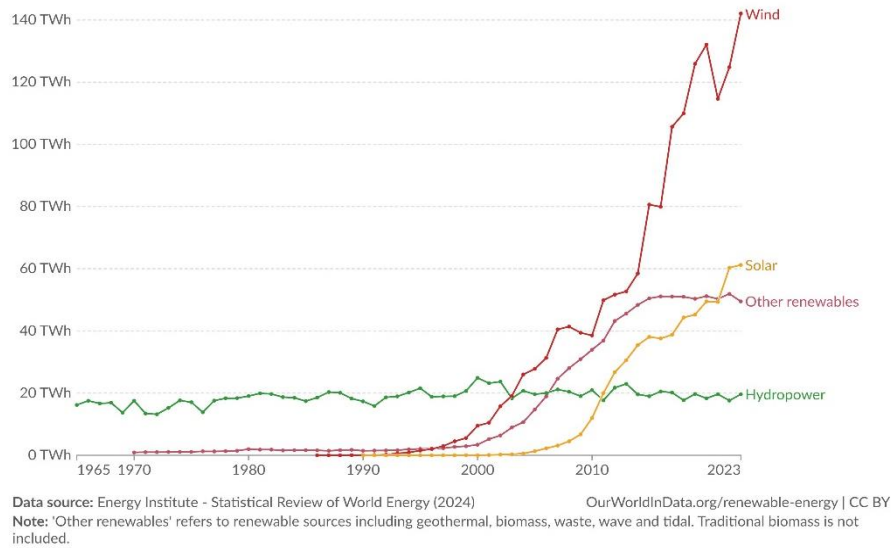


Figure 4. Renewable energy generation. Germany
 Source: (Our World in Data, 2024c)

The bulk of the clean power came from onshore and offshore wind capacity (24.4%), followed by solar (9%) and biomass (8.7%), with the remainder stemming from hydropower. All in all, 238.37 terawatt hours of electricity were generated by all renewable technologies.

3.5.2. Renewable Energy Clusters in Germany

Research and innovation in the energy sector in Germany are a high priority. As a result, the Federal government spent around 1.22 billion Eur on research, development of new technologies, and demonstration of pilot projects (Singh et al., 2023). Northwest Germany, including the states of Niedersachsen, Nordrhein-Westfalen, Sachsen Anhalt, and Schleswig-Holstein, is a leading wind turbine innovation cluster that benefited from supportive government policies. Germany today is a leading country in wind energy generation, with a global share of 10% of cumulative installed capacity (REN21, 2017). Germany has had long-term, consistent, and supportive policies that made it an early leader in wind capacity and generation and wind technology manufacturing. Most of these government policies have been on the demand side (such as feed-in tariffs), with coordination by federal and state governments and cooperation and input from labour and industry. The wind innovation cluster emerged as the number of wind turbine installations increased rapidly, starting in the 1980s. Turbine manufacturers, wind farm operators, and research institutions agglomerated in a strong cluster in northwest Germany.

Energy clusters in Germany are organized in a top-to-bottom approach (Singh et al., 2023). Germany's wind turbine innovation cluster is a network of large German and foreign corporations, small and medium-sized firms, federal and state government agencies, and various research organizations. The government's demand-side policies combined with government-sponsored economic development in key states with existing but declining industry sectors spurred an increase in wind manufacturing and led to the build-up of an extensive supply chain of subcomponents that utilized and transferred skills and equipment from Germany's turbine and machine-building manufacturing industries. This cluster is a major global producer with highly productive and technologically sophisticated firms that manufacture the main components - blades, nacelles, and towers - and an extensive supply chain of firms that manufacture subcomponents. Technology transfer and use of skilled labour, equipment, and plants from Germany's turbine and machine-building manufacturing industries played a key role in the success of this cluster. Germany is a major exporter of wind turbine components, especially throughout Europe, attesting to

its high-quality advanced technology and the global competitiveness of its industry. Germany is a major player in the technology and manufacturing of offshore wind turbines that are concentrated in the Baltic and North Sea (Hill & Engel-Cox, 2017; Jägersberg & Ure, 2017).

3.6. The renewable energy generation and clusters performance in Morocco

3.6.1. Overview of renewable energy sources in Morocco

Morocco is considered a "high-risk, low-capacity country" as it suffers from significant climatic, political and institutional vulnerabilities (Ainou et al., 2022). Morocco experiences relatively large territorial disparities in terms of access to energy resources as it possesses very limited fossil resources (already imported at a 97% rate in 2012) versus a high degree of solar irradiance, wind speed and biomass availability. This situation has led Morocco to develop diverse energy options, including large renewable power projects. Since 2009 this growing sector has emerged as complex a green business cluster in Morocco with a faster-than-average economic growth rate (Amungo, 2020; Benida et al., 2023; Boukhars, 2021; Boulakhbar et al., 2020; El Hafdaoui et al., 2024; El Iysaouy et al., 2019; Fragkos, 2023; Haddad et al., 2022; Kettani et al., 2021; Mahdavi & Vera, 2023; Nakach et al., 2023; Sellers et al., 2015; Vidican, 2015; Zemlickienė et al., 2024).

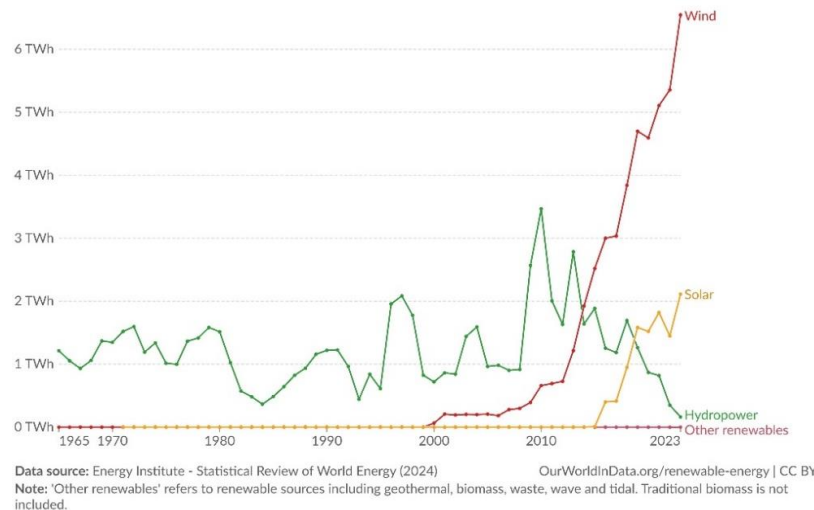


Figure 5. Renewable energy generation, Morocco

Source: (Our World in Data, 2024d)

Morocco still faces fundamental challenges – its geographical position in a warming hotspot makes it vulnerable to the impacts of climate change. This vulnerability manifests itself in the lack of water and the disappearance of rivers, which affects the decrease in the electricity produced by hydroelectric power plants, as shown in Figure 5.

3.6.2. Renewable energy clusters in Morocco

Initially, Morocco engaged in cluster development policy through the Pacte National pour l'Emergence Industrielle. In 2009, this pact aimed to develop 15 national cluster initiatives. Today, Morocco's cluster program consists of the "Stratégie Maroc Innovation" program, which seeks to improve R&D and promote innovation targeting triple-helix agents.

The cluster program combines a top-down and bottom-up approach: state support and, at the same time, initiating cluster competition. Further cluster organizations are promoted by other stakeholders, such as the solar cluster or the Industrial Cluster for Environmental Services (CISE). Additionally, Morocco will actively pursue an industrial

policy plan ("Plan D'accélération industrielle") until 2020, which includes the development of cluster organizations and cluster policy (ECCP, n.d.).

Morocco is actively developing renewable energy clusters to leverage its abundant solar and wind resources. Here are some key initiatives and developments:

Cluster ENR: This renewable energy and climate innovation centre fosters innovation and capacity building in the renewable energy sector. It has been recognized internationally, winning the Emirates Energy Award for its efforts in education and capacity building (IEA, n.d.).

Noor Solar Complex: Located near Ouarzazate, the Noor Solar Complex is one of the world's most extensive solar power facilities. It consists of multiple phases combining photovoltaic and concentrated solar power (CSP) technologies, with a total capacity of 580 MW (Forrester, 2024). In 2015, Morocco established one of the largest solar power plants in the world, the Noor-Ouarzazate plant, with an ultimate capacity of 580 MW, adjoined with large-scale Concentrating Solar Power (CSP) plants, a unique solution between photovoltaic and solar technologies. The cluster's development should be State-led due to a lack of local entrepreneurial and financial resources, policy capacity, and awareness of local technologies and selection mechanisms (Ainou et al., 2022).

National Energy Transition Consortium: Recently launched, this consortium aims to drive Morocco's transition to sustainable energy. It brings together various stakeholders, including public and private entities, to coordinate efforts to advance renewable energy projects and policies (Simpara, 2024).

These efforts are part of Morocco's broader strategy to increase its renewable energy capacity and reduce carbon emissions, aligning with its National Energy Strategy targets for 2030. The country aims to have 52% of its installed power capacity from renewable sources by this year.

3.7. Experience and influencing factors of renewable energy clusters

The reasons for Jiangsu Solar PV cluster's success are the supportive government policies, the largest capacity in the world, an extensive supply chain of supplier companies and raw materials inputs, the considerable increase in global demand for solar PV after the mid-2000s, much lower labour costs relative to developed countries; subsidies for land, installation of factories, electricity, and finance; an extensive domestic supply chain. However, this cluster also experienced difficulties: the glut in solar PV manufacturing in 2011 led to financial challenges and imposed anti-dumping tariffs by the United States and the European Union.

In the case of wind industry clustering in Jiangsu, local governments have acted as a strong enabling factor, either by initiating the construction of wind farms or by planning large wind power-related industrial parks. In the Jiangsu case, top-down planning undertaken by the local governments is believed to be a solid enabling factor in the development and evolution of clusters (Huang & Liu, 2017).

In the case of the solar industry in Shandong, pioneering enterprises such as Himin have played an important role during the early stage of cluster emergence since "successful imitation is most likely to take place in close geographical proximity to the pioneering firms". In the Shandong case, a bottom-up formation process can be observed, in which the role of pioneering enterprises is imperative.

California's more than 40-year-old solar PV cluster was driven by state government policies supporting solar energy, input from the California Research Centers, and Silicon Valley's venture capital investment. In the early 2000s, its market share was lost to other countries and U.S. states. California state did not incentivize manufacturers to maintain its solar PV manufacturing base.

The Great Lakes region has substantial wind energy capacity, with a 4% global share of cumulative installed capacity. Key technology demand-side policies, feed-in tariff programs, the U.S. government's investment tax credits and various tax incentives have supported this wind cluster. The Great Lakes region's pre-eminence in other manufacturing industries—automotive, fabricated metal parts, and machinery manufacturing—played a key role in developing the wind industry through the transfer of technology, use of skilled labour from these industries, and use or conversion of plants in these industries.

The German wind innovation cluster emerged as the number of wind turbine installations increased rapidly, starting in the 1980s. Turbine manufacturers, wind farm operators, and research institutions agglomerated in a strong cluster in northwest Germany. Now, it is a leading wind turbine innovation cluster that benefited from supportive government policies. Most of these government policies have been on the demand side (such as feed-in tariffs), with coordination by federal and state governments and cooperation and input from labour and industry. Technology transfer and use of skilled labour, equipment, and plants from Germany's turbine and machine-building manufacturing industries played a key role in the success of this cluster.

Conclusions

The supportive Government policy, the feed-in tariff program, the Government's Investment tax credit and different tax incentives are essential for the success of renewable energy clusters; this factor was emphasized in all examined cases.

Increased or decreased demand, which is challenging to regulate, can still affect the survival or viability of the existing cluster. It positively impacted the Jiangsu Solar PV, The Great Lakes region, and Germany clusters, while it negatively impacted the California PV cluster. However, fluctuations in demand must be supported by state policy.

Pre-eminence in other manufacturing industries /industrial foundations should also be an important factor, as in the case of the Shangdon Solar Cluster or the Great Lakes Cluster, or lower labour costs in the case of the Jiangsu Solar PV Cluster.

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CIRCULAR ECONOMY AND SMART SPECIALISATION BUSINESS STRATEGIES: THE DNIPROPETROVSK REGION CASE

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Abstract. This article explores the integration of the circular economy in Ukraine's smart specialisation strategies, focusing on a case study of the Dnipro Region. Investigating the symbiotic relationship between these concepts delves into legal aspects and presents an overview of Dnipro's unique economic characteristics. The case study illustrates the city's potential to use the smart specialisation approach to enhance economic growth. Utilising correlation regression analysis, it assesses the region's readiness for circular economy principles. Global case studies offer insights for Dnipro, and a SWOT analysis guides policymakers. In conclusion, the article provides a roadmap for harmoniously integrating circular economy principles and smart specialisation to future-proof Ukraine's regional development trajectories.

Keywords: circular economy; smart specialization; circular business models; sustainable development; regional development; Ukraine

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JEL Classifications: O20, O10, R10

1. Introduction

Ukraine is currently fighting against the aggressor. The paper is devoted to the analysis of the transition towards a circular economy and smart specialisation before the war.

The urgent task of accelerating the Ukrainian economy has consistently been a key priority. Ukraine has worked towards closing the gap with leading European nations regarding GDP per capita for many years. The goal has been to create employment opportunities, offer fair wages, and foster growth across light and heavy industries and the agricultural sector (OECD, 2022). Moreover, the country envisions creating a healthier society where people enjoy clean air and the purest drinking water. But can these goals be achieved simultaneously, ensuring both economic growth and environmental sustainability? The answer is yes, through implementing a circular economy model, which focuses on fundamental principles such as energy efficiency, eco-friendly consumption and production, and regenerative methods (see Ellen MacArthur Foundation, 2013). A circular economy aims to minimise waste and optimise resource utilisation by redefining conventional production and consumption approaches (Ellen MacArthur Foundation, 2013). This concept has gained increasing importance as the world faces challenges related to carbon emission reductions, pollution control, and the shift away from fossil fuel dependency (Khalifa et al., 2022). Unlike traditional development models, the circular economy promotes the

conservation of resources and materials, creating pathways for long-term sustainable growth (Ellen MacArthur Foundation, 2013, Bressanelli et al., 2022; Ruginè & Žilienė, 2024; Bazienė et al., 2024; Daniek et al., 2024; Webster, 2024; Sondhi et al., 2025).

While the European Union has integrated circular economy principles into its economic development policy for several years, Ukraine has only recently adopted these practices (OECD, 2022). The shift toward a more circular economy in Ukraine is expected to deliver various advantages, such as the emergence of new market niches in areas like recycling, services, and industrial design, alongside the introduction of innovative business models. Additionally, the success of this transition will rely heavily on creating a state incentive program, strong regional governance frameworks, technological innovation, and attracting investments (OECD, 2022). Implementing a circular economy could offer numerous benefits to Ukraine, including economic renewal, energy and resource savings, job creation that helps reduce unemployment, lower carbon emissions, and an overall improvement in the environmental situation. The focus of this paper on Ukraine's transition toward circularity highlights the importance of this shift at both the national and regional levels (OECD, 2022). This also emphasises the need for active collaboration between academics and policymakers to deepen research and evaluations in this field.

Developing smart specialisation in the context of the circular economy in Ukraine is an urgent and strategically important task (Koval et al., 2025). Ukraine has abundant natural resources and can benefit significantly from the balanced use and rational management of these resources through the circular economy. Smart specialisation and the circular economy would allow regions to develop specific areas with unique capabilities or advantages. In Ukraine, where many regions have distinctive economic and industrial characteristics, smart specialisation in a circular context can catalyse innovative and sustainable solutions in renewable energy, secondary processing of raw materials and the more efficient use of resources. At the same time, developing these strategies can contribute to reducing the negative impact on the environment, which is one of the main problems in Ukraine. Using circular production and resource management models can help reduce waste and pollution, contributing to a country's sustainable development. Smart specialisation, therefore, in the context of the circular economy in Ukraine, is a relevant strategy that can contribute to innovative, sustainable and effective development of regions, ensuring competitiveness and the balanced use of resources. The paper, therefore, critically evaluates existing government policies and initiatives pertinent to the adoption of circular economy principles in Ukraine, focusing on assessing their efficacy. The analysis identifies opportunities for optimising collaboration between various stakeholders to promote circular economy practices in the Dnipro region and potential strategies to improve coordination and communication among government, industry and academia. Subsequently, evidence-based recommendations for integrating circular economy principles, addressing challenges, and leveraging opportunities in the Dnipropetrovsk region are discussed.

2. Literature review

2.1. Circular economy

The circular economy helps to change the traditional "wasteful" consumption and production paradigm, moving to more efficient use of resources and waste processing. The application of circular economy principles allows products, components, and materials to pass through successive life cycle stages, which are stored, recycled, and reused instead of being thrown away after use. Ghisellini et al. (2016) emphasise balancing economic and ecological systems. The European Commission's "Circular Economy Package" defines strategies and policies to support the development of the circular economy. In a similar vein, initiatives such as "Towards the Circular Economy" and "Circular Economy in Cities: Evolving the Model for a Sustainable Urban Future" from the Ellen MacArthur Foundation (2013) provide strategies for sustainable development at various levels from the global to the regional and local level. The authors argue that the transition to a circular model contributes to creating sustainable and resilient urban systems, directly affecting regions' standard of living and economic dynamics. Interestingly, Tashtamirov (2023) analyse practical cases of implementing circular strategies at the regional level

and their impact on sustainability, employment, and innovation. Rezk et al. (2023) examine numerous challenges to establishing a circular economy, such as limited understanding, insufficient government backing, and inadequate infrastructure; there are also opportunities, such as increasing demand for eco-friendly goods and services and a receptive business environment.

A key point, therefore, from the literature is that the circular economy can and does have a significant impact on the development of regions, creating new opportunities for sustainable economic growth, increasing competitiveness and improving the quality of life of the population (e.g., Dielini et al., 2024). We use this as the premise for analysing the development and implementation of the circular economy at the regional level within Ukraine. Hitherto, it is relevant to discuss research on the links between the circular economy and sustainable development that have been carried out by Ukrainian researchers including (see Churikanova & Denysenko, 2022); the analysis of the conditions for the introduction of the circular economy in Ukraine (see Trushkina, 2021); the study of the development of the circular economy in the context of industrial enterprises (see Gurochkina, & Budzynska, 2020); and the development of circular economy in the Ukraine context (see Timoshenko & Dronova, 2018).

It is essential to highlight that the circular economy extends far beyond waste management. This concept entails profound transformations in the mechanisms underlying economic processes. These changes involve selecting more sustainable and recyclable raw materials, adjusting production techniques, and adopting innovative service models where waste from one process serves as valuable input for another. Economically, the circular economy's principle of converting waste into resources tackles environmental concerns and addresses pressing economic challenges, such as the ongoing depletion of natural resources, rising costs of raw materials, and reduced reliance on imported resources. These issues became particularly evident during the recent pandemic, as border closures forced many domestic industries to halt operations. Additionally, the full-scale military invasion of Ukraine has introduced new challenges for the national economy and reshaped the specialisation of its regions, making the need for regional economic development strategies even more urgent.

The relevance of the circular economy has only grown in this context, as it often relies on domestic supply chains and distribution networks, minimising external dependencies. In this model, regions are central hubs for supply, sales, and processing. Therefore, adopting circular economy principles at both national and regional levels becomes imperative. This approach is vital for economic growth and offers a strategic path forward for Ukraine's recovery and long-term development.

2.2. Smart specialisation and the circular economy

The concept of "smart specialisation" was first used in the European Commission's (EC's) "Green Paper on Territorial Cohesion", published in 2008 (Green Paper on Territorial Cohesion, 2008). Subsequently, the approach was further elaborated in the "Europe 2020" strategy - the development strategy of the European Union for the ten years from 2010 to 2020. In this context, "smart" stands for the abbreviation: "S" - acceleration (Smart), "M" - modernisation (Modern), "A" - activation (Accessible), "R" - resources (Resource-efficient), "T" - creativity (Transparent). Since then, it has become a core policy embedded within the EC's Regional Policy funding to support the efficient use of resources to drive regional innovation, competitiveness and economic development across Europe (see Foray, 2014). In summary, smart specialisation means selecting and developing priority development areas in a particular region or country, focusing on respective competitive advantages, expertise and innovative potential. This strategy envisages the concentration of efforts, resources, and investments in highly innovative industries that will contribute to economic growth and increase the region's competitiveness in the international market. Arguably, it has become essential for stimulating economic development and creating jobs in areas, using their specific potentials and unique competitive advantages. The main idea is to focus on areas where a country or region already has expertise, which can be developed further, creating competitiveness in the

global market. This helps regions avoid direct competition with other areas and focus on unique opportunities to achieve more sustainable and innovative development.

In this paper, we argue that smart specialisation can contribute to the development of the circular economy, in particular regions, by encouraging interventions to develop innovation (see Figure 1). For example, suppose a country has the technological potential to produce electric vehicles. In that case, focusing efforts on the development of this industry can help reduce dependence on traditional cars with fuel engines and facilitate the transition to a more sustainable transport system with electric vehicles that can use secondary materials. Thus, the two approaches can complement and support each other. When implementing a circular economy, regions can focus their efforts on developing industries that allow efficient use of resources and materials already in the economy. These can be industries focused on recycling, secondary processing or repair of goods. Thus, regions can become specialised in the sustainable use of resources and environmentally friendly technologies.



Figure 1. Synergy of Circular Economy and Sustainable Development
Source: developed by authors

Thus, the combination of a circular economy and smart specialisation can help to contribute to economic growth and sustainable development through the allocation of resources to those areas where a country or region has an advantage and opportunities to achieve competitiveness in the global economy combined with the creation of innovative solutions to ensure sustainable development. In turn, this can contribute to reducing the environmental impact, reducing waste and exploiting natural resources, and creating new opportunities for business and the labor market. Combining these two approaches can help countries and regions become more sustainable, competitive and capable of ensuring the quality of life for their communities. For example, industries focused on recycling secondary materials or repairing and restoring products are becoming essential elements of the circular economy, accelerating the development of green industries and reducing the negative environmental impact. Moreover, applying the circular economy can increase the responsible use of resources, reduce the adverse environmental effects and ensure a more sustainable future for our planet. The focus on smart specialisation makes this process more efficient and more focused on achieving specific development goals. This combination can lead to a more prosperous, environmentally sound and economically sustainable future.

2.3. The legislative dimensions

This section explores the legislative dimensions of smart specialisation strategies and the circular economy. First, in 2013, EU Regulation 1303/2013 laid down the following definition: “a smart specialisation strategy is a national or regional strategy that sets priorities to build competitive advantages by innovatively developing own strengths for business needs, in a coordinated manner, without duplication and fragmentation of efforts using new opportunities and market trends”. Subsequently, the smart specialisation concept has developed from an avant-garde idea to Europe's most popular approach to regional development. Indeed, the need to build and implement smart specialisation strategies became mandatory for all EU regions in order to receive research support funding from the Horizon 2020 and Horizon Europe 2021-2027 funds respectively. Significantly, in this paper context,

with the entry into force of the Association Agreement between Ukraine and the EU in 2017, the approach to regional development through smart specialisation became embedded into domestic legislation. The Ukrainian Cabinet of Ministers made appropriate changes to the procedures for developing the State Strategy for Regional Development and Regional Development Strategies (Resolution No. 959 dated November 14, 2018). Moreover, current legislation contains the following definition: “smart specialisation is an approach that involves the reasoned determination by regional development entities within the framework of the regional strategy of individual strategic goals and objectives for the development of types of economic activity that have innovative potential taking into account the competitive advantages of the region and contribute to the transformation of sectors to make the economy more effective.”

In Ukraine, the main circular economy programme documents include the following:

- 1) State Strategy for Regional Development for 2021-2027;
- 2) Action Plan for 2021-2023 for the implementation of the State Strategy for Regional Development for 2021-2027;
- 3) National waste management strategy until 2030;
- 4) Strategy of the state environmental policy of Ukraine for the period until 2030;
- 5) Concept of implementation of state policy in the field of climate change for the period up to 2030 and its implementation plan;
- 6) Low-carbon development strategy of Ukraine until 2050, etc.;
- 7) The strategy for the development of the economy in Ukraine until 2030 is a strategic document that defines the main directions of the development of the circular economy in Ukraine and includes specific goals and measures.

Enacted in 2017, the National Waste Management Strategy, which runs until 2030, outlines the adoption of the finest European practices for managing different types of waste in Ukraine. This includes industrial waste, solid household waste, agribusiness waste, construction waste, hazardous waste, and other waste categories. The primary objectives of this strategy are to address and resolve key waste management issues in Ukraine, identify priority areas for establishing an innovative waste management model, enhance the existing waste management infrastructure through improved methods and approaches, promote sustainable development in Ukraine, enhance the quality of services provided and reduce administrative burdens.

The National Waste Management Plan, which also runs until 2030, approved by the Cabinet of Ministers in February 2019, serves as a guiding document for realising the National Waste Management Strategy. It sets out precise objectives and actions to enable Ukraine to transition towards a new waste management model, embracing a closed-loop economy similar to those adopted by leading Western European countries by 2030. Implementing these measures aims to align national waste management legislation with EU standards.

The fundamental principles (strategy) of Ukraine's state environmental policy until 2030, approved in 2019, aim to address the consequences of environmental issues and tackle their root causes. This strategy, which has been successfully implemented in EU countries, includes measures to reduce water and air pollution and necessary adjustments in public administration through adopting environmental norms and standards. The strategy aligns fully with EU ecological norms and standards and the government's medium-term priority actions.

The formulation of draft laws and other regulatory acts in the field of climate change is guided by the concept and implementation plan of the Ukrainian domestic policy on climate change for the period up to 2030. These documents also establish the key areas of focus for implementing the concept. The purpose of the concept is to enhance the state's policy on climate change and create conditions for Ukraine's transition to a low-carbon development path while ensuring the well-being of its population and economic, environmental, and energy security.

The Ukraine Low-Carbon Development Strategy until 2050 (SNVR), adopted on July 18, 2018, by the Ukraine Central Committee, outlines the transformation of the Ukrainian economy into a low-carbon development model. This involves a shift towards renewable energy sources and primarily focuses on reducing greenhouse gas emissions into the environment. The strategy was devised to fulfil Ukraine's commitments under the Paris Agreement, decisions made by the Conference of the Parties to the UN Framework Convention, and the directives of the Cabinet of Ministers of Ukraine. The strategy's goals encompass establishing a new energy system, increasing carbon absorption and retention, reducing greenhouse gas emissions, and implementing eco-friendly production concepts in Ukraine through adopting "green" (environmentally friendly) technologies.

Notably, despite numerous programme documents, Ukraine has not yet established a cohesive system of support for advancing the circular economy. The development level of sectors operating within the framework of the "closed-cycle" economy remains relatively low. Furthermore, these strategic documents lack sufficient coordination and collaboration among relevant departments. Consequently, as this paper explores, integrating smart specialisation and the circular economy in the Ukrainian context remains challenging, and much more work is required. Several significant opportunities and strengths can be developed with the right policy interventions. This is precisely the aim of the Dnipro case study that we explore in more detail in this paper.

3. Research questions

The aim is to illustrate how and in what ways smart specialisation interventions can be implemented to encourage more circularity in the Ukrainian sub-national context. In so doing, the case study addresses the following key research questions:

- How can the principles of the circular economy be effectively integrated into the smart specialisation strategies of Ukraine's regions, specifically in the Dnipro region?
- How can the circular economy contribute to sustainable economic development and environmental protection in the Dnipro region?
- What are the specific industry sectors in the Dnipro region have the highest potential for circular economy practices, and what strategies can be employed to leverage these opportunities?
- What are the key challenges and opportunities associated with the transition to a circular economy in the context of Ukraine's economic and environmental landscape?
- What role can government policies and initiatives play in facilitating the adoption of circular economy practices in Ukraine?
- How can collaboration between various stakeholders (government, industry, academia) be optimised to promote the circular economy in the region?

The following section discusses the methodological approach used to collect and analyse the data for the Dnipro case study.

4. Research methodology

The methodology adopted involves a comprehensive approach to examining the transition to circular economy and smart specialisation in the Dnipropetrovsk region. It begins with a thorough literature review and legal analysis, followed by data collection from various sources. A SWOT analysis identifies key development aspects, while case studies and economic modelling explore sector-specific dynamics. Environmental assessment and policy analysis inform recommendations for enhancing stakeholder collaboration and integrating circular economy principles into regional strategies.

This study will comprehensively analyse European and Ukrainian research on the circular economy and smart specialisation. The primary objective is to lay the theoretical groundwork for the research while identifying

existing gaps that require further exploration. Additionally, examining Ukraine's contemporary legal framework will focus on the normative legal base relevant to the circular economy.

As part of the research methodology, the study will offer a detailed overview of Dnipro, Ukraine, emphasising its economic and industrial characteristics. Special attention will be given to the application of Smart Specialization within the Dnipropetrovsk region to understand its potential for circular economy development.

The study aims to gather relevant data through rigorous scientific methods. Primary data sources include analytical reports on the Dnipropetrovsk region, particularly the *Strategy for the Development of the Dnipropetrovsk Region*. Additional datasets will be collected from reports published by the State Statistics Committee of Ukraine, focusing on the region's economic, social, and environmental aspects. Practical applications of circular economy principles currently in the region will also be identified and organised to provide real-world insights.

A Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis specific to the region's transition toward a circular economy will be performed. This analysis will highlight innovative development opportunities through smart specialisation and circular economy initiatives.

Select industrial sectors within the Dnipropetrovsk region will be chosen for detailed case studies. These case studies will explore ongoing circular economy initiatives, focusing on successful strategies, best practices, and challenges encountered.

The core analytical tool will be a correlation-regression analysis widely used in social and economic research. This model will examine relationships between various factors, assessing how social, industrial, and innovation climates interact. The primary goal is to determine how these factors act as prerequisites for effectively introducing circular economy principles within the region.

The research will evaluate potential environmental trade-offs and synergies associated with adopting circular economy practices. Key circular economy tools will also be examined, identifying challenges and prospects at the regional level and for end consumers.

A critical review of current government policies and initiatives related to the circular economy will be conducted. The research will assess the effectiveness of these policies, providing policy recommendations based on best practices observed in similar regions and countries.

Opportunities for optimising collaboration between stakeholders will be identified to promote circular economy practices within the Dnipro region. Strategies for improving communication and coordination among government bodies, industry, and academic institutions will be developed. The study will explore integrating circular economy principles into the Dnipropetrovsk region's smart specialisation strategies. It will also assess how circular economy practices can align with and support regional development objectives.

The findings from each section will be synthesised to address the research questions. Evidence-based recommendations will be provided to guide the integration of circular economy principles in the region, address challenges, and leverage existing opportunities for sustainable development.

5. Results

This section discusses the Dnipropetrovsk regional case study.

5.1. An overview of Dnipropetrovsk region, Ukraine, highlighting its economic and industrial characteristics

Dnipropetrovsk region is one of the most economically developed regions of Ukraine. It is located in southeastern Ukraine (see Figure 2). It is characterised by a favourable geographical location, rich natural resources, powerful industrial and scientific potential, developed agricultural production, and high transport and communication development.

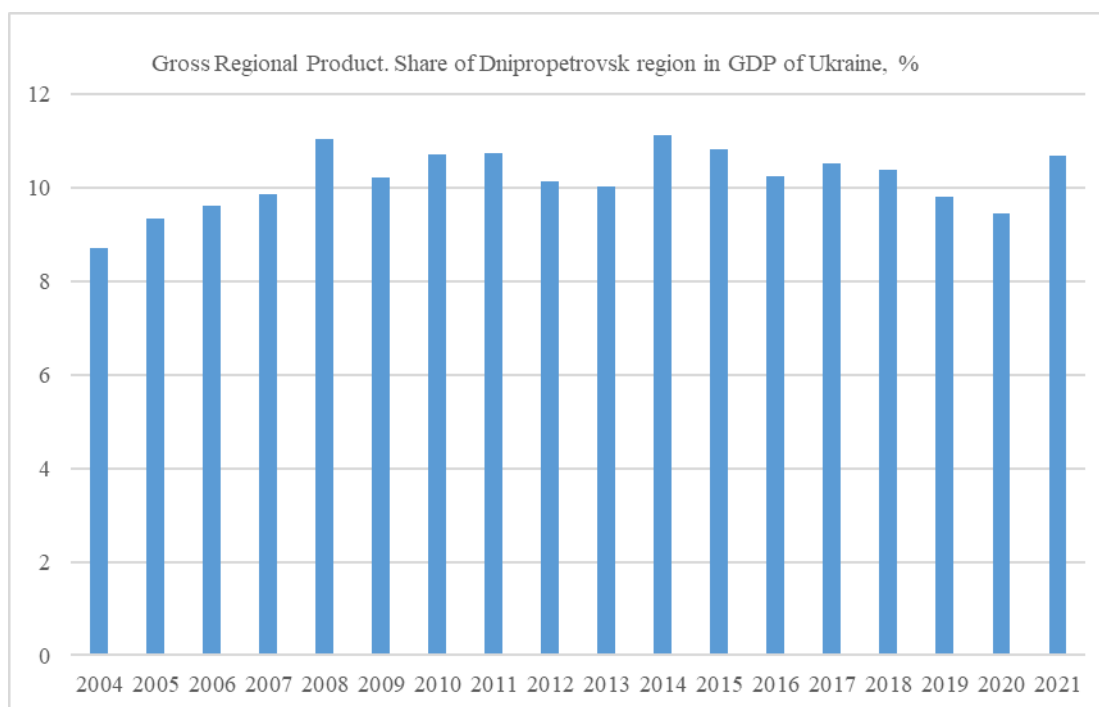


Figure 2. Map of the Dnipropetrovsk region

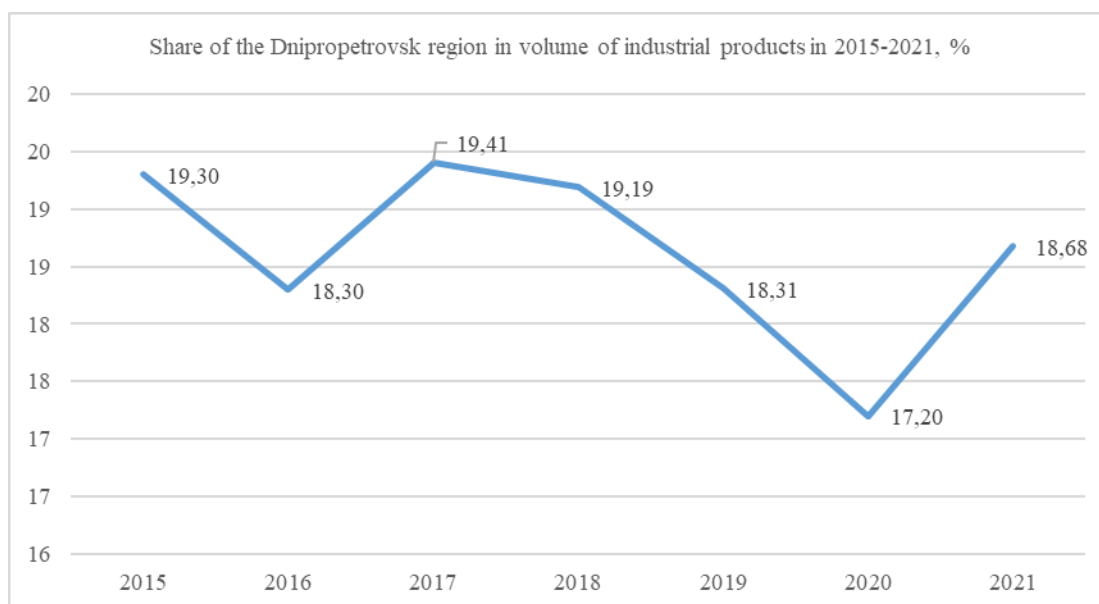
Source: developed by authors

The Dnipropetrovsk region is unique in its diversity and reserves of minerals. The richness of the region's subsoil is known in the country, Europe, and the world because unique mineral deposits are concentrated here. The region owns about 50% of the national mineral reserves. The supply of mineral resources is more than three times higher than the national level; 100% of manganese ore, iron ore, coal, uranium, rare earth metals, kaolin and granites, oil and gas are also mined in the region. The Kryvyi Rih iron ore basin ranks first in Ukraine in terms of the number of discovered reserves and the annual production volume. Nikopol basin of manganese ores is one of the largest in the world. Forty types of mineral raw materials are mined in the region. The primary foundation of the region's soil cover consists of ordinary chernozems of different depths of the humus layer and mechanical composition, which, together with the favourable natural and climatic conditions of the region, allow intensive agriculture, promote the cultivation of all grain crops and allow obtaining high-quality food grain.

Occupying 5.3% of the territory with a population share of 7.6%, the Dnipropetrovsk region is one of the leading regions of Ukraine. Its contribution to the Gross Regional Product of Ukraine is more than 10% (see Figure 3), and the region also has a share of more than 18,5% (in volume) of industrial products sold in Ukraine (Figure 4).

**Figure 3.** Gross Regional Product. Share of Dnipropetrovsk region in GDP of Ukraine, %

Source: developed by authors on statistical data

**Figure 4.** Share of the Dnipropetrovsk region in volume of industrial products in 2015-2021, %

Source: developed by authors on statistical data

Dnipropetrovsk region (or oblast) is a significant industrial region. The largest industrial centres of the region are the cities of Dnipro, Kryvyi Rih, and Kamianske. Powerful industrial enterprises are also located in Nikopol, Pavlograd, Marhanka and Novomoskovsk. More than 4,000 industrial enterprises of almost all main types of economic activity, with a total employment level of about 267,000 people, are engaged in economic activity in the region. The region's most significant share of industrial production is realised by enterprises in mining and

metallurgical processing (almost 65%), which provides nearly a third (or UAH 139.6 billion) of the total volume of industrial products sold in the region. More than 67,000 people are employed at metallurgical enterprises. The leading enterprises include PJSC "ArcelorMittal Kryvyi Rih", PJSC "Dniprovsky Metkombinat", LLC "Metallurgical Plant "Dniprostal". The volume of sold products in the production of chemicals and chemical products is 3.7% (or UAH 15.7 billion) of the region's industrial production volume.

Dnipropetrovsk region is also one of the most energy-rich regions in Ukraine. Electric power is a highly developed branch of the region's economy, which includes power-generating enterprises. The main businesses include VP "DTEK Kryvorizka TPP", JSC "DTEK Dniproenergo" and VP "DTEK Pridniprovska TPP", JSC "DTEK Dniproenergo", branch "Serednyoprovsk HPP" PJSC "Ukrhydroenergo" and JSC "Dniprovska Tets".

5.2. Smart Specialisation in the Dnipropetrovsk region

The Dnipropetrovsk region uses the concept of smart specialisation to try to drive innovation, competitiveness and sustainable growth within the region. Aligned with the State Strategy for Regional Development (2021-2027), the key regional priorities are listed below:

The priorities of smart specialisation are:

- Production of complex agrochemical products;
- "smart" paints and varnishes, flame retardants, household chemicals, cosmetics products, reagents for water purification, materials for modern diagnostic methods;
- production of the latest materials for technological solutions in the machine building industry, in particular high-tech, transportation, energy, defence industry, agricultural production (precision agriculture);
- development of knowledge-intensive and high-tech industries, including aerospace, precision instrumentation, etc.

The main objectives of the strategy include:

- The creation of chemical and machine-building clusters to expand chemical and pharmaceutical production, including existing value chains and the manufacturing of differentiated products for consumer markets (including complex agrochemical products, "smart" paints and varnishes, flame retardants, household chemicals, cosmetics, reagents for water purification, materials for modern diagnostic methods diagnostics). In addition, the objective production of the latest materials for the latest;
- developing technological solutions in the machine building industry, in particular high-tech, transportation, energy, and defence industries, agricultural production (precision farming);
- the development of knowledge-intensive and high-tech sectors, including aerospace, precision and precision instrumentation, etc.

In conclusion, the Smart Specialization strategy outlined for the Dnipropetrovsk region presents a promising path towards economic prosperity and technological advancement. By prioritising key sectors and fostering innovation, Dnipropetrovsk region aims to unlock new opportunities, enhance competitiveness, and secure sustainable growth for the future.

5.3 Correlation-regression analysis of the social, industrial and innovation climate of the Dnipropetrovsk region as a prerequisite for the introduction of circular economy principles

Correlation-regression analysis is a powerful tool in social and economic research that allows you to study the relationships between various factors and determine how one affects another. We aim to conduct such an analysis to assess the social, industrial and innovation climate in the Dnipropetrovsk region and find out how these factors can be prerequisites for introducing circular economy principles. Let's look at the details of this idea.

Analysis of the social climate: First, it is important to study the social climate in the region, which includes factors such as education, cultural development, access to information and awareness of citizens. By analysing these data, it is possible to determine how open society is to new economic models, particularly circular economy.

Analysis of the industrial climate: The circular economy's success largely depends on the region's industrial base. Analysing the level of innovation and the degree of readiness of enterprises to switch to a circular production method, it is possible to determine which industries have the potential to develop a circular economy and where obstacles may arise.

Analysis of the innovation climate: The circular economy requires new innovative solutions in production and consumption. Analysis of the innovation climate in the Dnipropetrovsk region will allow us to determine the presence and development of innovative companies, research centres and state support for creative projects. To build the mathematical model, the following statistical data for the region from 2007 to 2021 were taken (Table 1).

Table 1. Statistical data of the Dnipropetrovsk region from 2007 to 2021

Years	GRP	VIP	VInnP	N _{Inn}	EP	N _{SE}	N _{R&D}	Ex	InnP	VI	N	E	UnE	In
2007	71173,0	109585,2	1622730,8	9,3	31,5	68	93	192569,00	1,80	654,46	99642,2	1582,4	39,9	39015
2008	104687,0	142612,4	1678887,5	7	47,4	72	88	182926,00	0,90	975,4	14656,0	1580,0	33,9	52352
2009	93331,0	111487,0	532400,7	6,3	167,9	69	84	39580,80	1,90	675,95	13066,0	1537,1	52,1	56014
2010	116136,0	166497,8	179667,2	7,1	85,4	71	78	64527,00	2,10	720,77	16259,0	1541,9	117,7	69394
2011	140020,0	200555,8	471514,5	7,1	56,8	76	73	18481,30	3,60	1238,5	19602,0	1531,3	112,3	80888
2012	147970,0	220458,2	302268,8	7,7	60,2	80	69	13324,50	3,60	1215,49	20715,0	1528,5	108,5	95349
2013	152905,0	107033,5	668532,8	7,8	69,2	79	62	13767,10	0,80	1021,92	106987	1531,0	106,8	98806
2014	176540,0	123578,0	108028,4	8	66,3	82	57	13233,30	0,50	1327,68	149755	1437,3	128,9	105223
2015	215206,0	150644,2	203067,0	8,9	72,1	80	58	6867,80	0,60	1703,39	158783	756,3	115,3	127830
2016	244478,0	171134,6	53785,2	9,8	73,4	79	55	11525,50	1,40	3606,42	151432	1391,3	121,7	143861
2017	313830,0	219681,0	69042,6	9,9	73,1	86	54	12708,10	2,30	3867,69	142146	1347,9	129,2	185230
2018	369468,0	258627,6	81283,0	9,8	75,1	91	55	10082,40	4,40	3162,45	140377	1402,3	121,5	240620
2019	390325	273227,5	85871,5	9,8	78	93	52	10842,36	0,40	39033,5	148502	1380,5	124,1	189903,6
2020	398732	279112,4	87721,0	9,9	78,2	94	50	11075,88	0,20	39870,2	153234	1375,1	125,35	212925
2021	582363	407654,1	128119,9	10,1	85	98	51	16176,75	1,8	59236,3	167567	1402,3	121,5	240620

Source: Developed by the authors based on data from the State Statistics Committee of Ukraine

Where: VIP – Volume of industrial products sold (million UAH); VInnP – Volume of innovative products (thousand UAH); N_{Inn} – Number of enterprises that implemented innovations, %; EP – Economic potential of industrial enterprises (profit dynamics), %; N_{SE} – Number of small enterprises per 10,000 of the existing population, units; N_{R&D} – Number of organisations, which perform scientific research and development; Ex – Expenses of organisations for the implementation of research and development by their forces, thousand UAH; InnP – Share of implemented innovative products in the volume of industrial production, %; VI – Volume of investments in industry, million UAH; N – Number of enterprises; E – Employment of the population (thousands of people); UnE – Population unemployment (thousands of people); In – Disposable income of the population (million UAH).

The statistical data analysed in this study is limited to the period from 2007 to 2021 due to significant disruptions caused by the full-scale war in Ukraine, which began in 2022. The war has drastically impacted the region's economy, altering industrial output, innovation activities, employment levels, and investment flows. Many

enterprises have ceased operations or shifted priorities toward essential wartime needs, leading to a reorientation of economic and social strategies. As a result, the pre-war data provides a more stable foundation for assessing long-term trends and prerequisites for introducing circular economy principles. However, given the evolving economic challenges, future analyses must reassess whether priorities remain unchanged and how post-war recovery efforts may redefine the region's approach to circular economy development.

Gross regional product (GRP), one of the key indicators used to assess the effectiveness of the region's activities, was adopted as the resulting indicator in the economic-mathematical model. GRP determines the total economic productivity and value of all goods and services produced in a given region over a given period. It reflects the region's economic growth, social development, the degree of efficiency in the use of resources, the introduction of innovations, etc. The results of the correlation analysis are presented in Table 2 (see below):

Table 2. The results of the correlation analysis

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14
X1	1,0													
X2	0,9	1,0												
X3	-0,6	-0,5	1,0											
X4	0,8	0,6	-0,4	1,0										
X5	0,1	0,0	-0,4	-0,3	1,0									
X6	1,0	0,9	-0,6	0,7	0,0	1,0								
X7	-0,8	-0,6	0,8	-0,7	0,0	-0,9	1,0							
X8	-0,5	-0,4	0,9	-0,3	-0,4	-0,6	0,8	1,0						
X9	-0,1	0,2	-0,1	-0,1	0,0	-0,1	0,2	-0,1	1,0					
X10	0,9	0,8	-0,3	0,6	0,1	0,8	-0,5	-0,3	-0,3	1,0				
X11	0,7	0,4	-0,5	0,9	-0,1	0,7	-0,8	-0,4	-0,4	0,5	1,0			
X12	-0,3	-0,1	0,4	-0,4	0,0	-0,3	0,5	0,4	0,3	-0,1	-0,6	1,0		
X13	0,6	0,5	-0,9	0,5	0,0	0,7	-0,9	-0,9	0,0	0,3	0,6	-0,4	1,0	
X14	1,0	0,8	-0,7	0,8	0,1	1,0	-0,9	-0,6	0,0	0,7	0,7	-0,4	0,7	1,0

Source: Developed by the authors

Where: X1 – GRP; X2 - Volume of industrial products sold (million UAH); X3 - Volume of innovative products (thousand UAH); X4 - % of enterprises that implemented innovations; X5 - Economic potential of industrial enterprises (profit dynamics), %; X6 - The number of small enterprises per 10,000 of the existing population, units; X7 - The number of organisations, which performs scientific research and development; X8 - Expenses of organisations for the implementation of research and development by their own forces, UAH; X9 - The share of implemented innovative products in the volume of industrial production, %; X10 - The volume of investments in industry, million UAHs; X11 - Number of enterprises; X12 - Employment of the population (thousands of people); X13 - Population unemployment (thousands of people); X14 - Disposable income of the population (million UAH).

The results of the analysis of the influence of regional development indicators are presented in Figure 5.

As the results of the correlation analysis illustrate, the level of industrial enterprise significantly influences the region's development (correlation coefficient is 0,9), which once again confirms the status of the Dnipropetrovsk region as an industrial one.

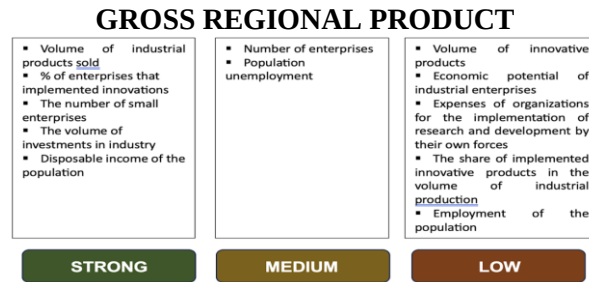


Figure 5. The results of the analysis of the influence of indicators of the Dnipropetrovsk region on the Gross Regional Product

Also, the indicator recorded a significant degree of influence reflecting the number of enterprises introducing innovations (correlation coefficient is 0,9). Indeed, regional policy is aimed at developing innovations in the region. The number of enterprises that introduce innovations can significantly influence the development of the circular economy in the region.

Businesses that actively engage in innovation are usually looking for more efficient and sustainable ways of producing and consuming. Innovations can help companies reduce waste, improve resource efficiency, and move towards a circular business. Enterprises that invest in innovation can develop new business models to save resources and recycle products. Regions with active, innovative enterprises usually attract more investments. Investors value companies that implement new technologies and creative approaches, as this increases their competitiveness and stability. This can contribute to the development of infrastructure for a circular economy.

Therefore, the number of enterprises that invest in innovation can be a key factor in forming a favourable ecosystem for developing a circular economy in the region. Innovations contribute to changes in consumer behaviour and efficient use of resources, creating opportunities for increased sustainability and reduced negative environmental impact.

The next indicator found to be very influential is the number of small enterprises in the region (correlation coefficient is 0,9). Small businesses often have greater flexibility and speed in decision-making, which makes them more prone to implement innovative approaches. In the context of the circular economy, this can mean creating new products, services, and business models to reduce waste and use more resources. Small businesses can more easily cooperate with local suppliers and buyers. This creates opportunities for the development of local circular supply chains, where waste from one enterprise can become resources for another.

Small businesses often have closer relationships with consumers and the local community. They may be more inclined to consider the wishes of consumers and create more sustainable products and services that meet the demand for quality and responsibility. Small businesses can act as circular economy ambassadors in local communities. They can actively contribute to spreading awareness about the importance of resource conservation and responsible consumption among the region's residents.

Small businesses, particularly those specialising in circular solutions, can create additional regional jobs. This can improve the quality of life of the local population and support economic development.

Summarising, the number of small enterprises in the region can be a key factor in implementing and developing the circular economy. They can be more flexible and innovative in implementing circular practices and contribute to creating a sustainable and responsible economy in the region.

Let's move on to the next powerful indicator - the volume of investments in the industry (the correlation coefficient is 0,9 for GRP and 0,8 for the volume of investment).

The volume of investments in the region can significantly impact the development of the circular economy. Investments can create an enabling environment for developing circular practices and promote implementation. Investments can be used to make the necessary infrastructure for a circular economy, such as sorting lines, recycling plants, processing centres, and the development of waste collection and processing systems. Investments can finance research and development of new technologies and innovative resource and waste management approaches. This can contribute to the improvement of circular processes and the creation of new circular solutions. Investments can provide financial support to startups and small businesses specialising in circular solutions. This can contribute to developing circular business models and increase their competitiveness. Investments can attract investors interested in circular practices and sustainable production. This can create additional capital for circular projects and stimulate the development of this direction. Therefore, investments in the region can strengthen and develop the circular economy, making the necessary conditions and resources for the implementation of circular practices and promoting the transition to more sustainable and responsible consumption and production.

The next indicator that has a significant impact on the region's development is the population's disposable income (the correlation coefficient is equal to 0,7-1). A higher income can positively influence the population's willingness to implement circular practices. People with higher incomes may be more inclined to buy goods and services that are built on circular economy principles, such as refurbished or recycled goods. Higher household income can stimulate investment in circular enterprises and startups. People with higher incomes may be able to invest in circular projects, which contributes to their development.

Changed demands for products: Higher income can lead to changes in demands for products and services. Consumers with higher incomes may look for higher quality and durability of goods, which can stimulate the development of circular business models, as they aim to extend the life of goods and recycle them. Usually, a higher level of income is accompanied by a higher level of education and consciousness. People with higher incomes may be more educated about waste and the environmental impact of consumption. This can contribute to the promotion of circular practices and more responsible consumption.

As for other factors, the impact of which is of a medium or low level, we see that the level of use of innovative products, the implementation of scientific developments by enterprises and the introduction of innovations, in general, is still low.

The circular economy is based on innovative technologies and methods for saving resources, waste and production. If the region does not invest in research and development of new technologies, achieving significant improvements in circular processes is difficult. Analysing the statistics of the region's innovative activity, we can conclude that investments in innovative development are available but insufficient to impact the region's growth significantly.

Thus, summing up the availability of a favourable climate in the region, Correlation analysis showed that the number of industrial enterprises and innovatively developing enterprises are key factors. The industrial foundation of the area creates a basis for the implementation of circular practices, and innovations contribute to more efficient use of resources and waste reduction. Along with that, the region should pay more attention to innovative research and the introduction of innovations. This is possible thanks to attracting investments in this direction.

In addition, the growth of small businesses supports sustainable consumption and reduced environmental impact. Investments also play an essential role in creating an enabling environment for the circular economy. In summary, the region has the potential to develop a circular economy thanks to a favourable climate and infrastructure.

5.4. Case studies or examples of the enterprises from the Dnipropetrovsk region that have successfully integrated smart specialisation and the circular economy

Building on the previous analysis, there is considerable potential for the Dnipropetrovsk region to use smart specialisation to develop a circular economy. This takes time to implement; it is a gradual process and requires an incremental approach to investment and policy coordination; The government needs to work closely with small and large companies to move the agenda forward.

There are already positive developments worth noting here. For example, Polygreen, a recycling plant part of the Biosphere Corporation, is one of the largest in Ukraine. Thanks to modern equipment, they carry out a complete cycle of processing and purification of polymers, turning plastic into polyethylene granules. Any manufacturer can use these pellets, including McDonald's, which cooperates with the Biosphere Corporation. This is just one example of the implementation of the circular economy in the Dnipropetrovsk region of Ukraine. New recycling plants, waste processing enterprises, and other initiatives are gradually appearing, contributing to a closed cycle of resource use and reducing the negative environmental impact.

Another example is PAPACKS, a company that works in the field of circular economy in Ukraine. They specialise in the production of environmentally friendly paper and cardboard packaging. The company's primary goal is to reduce the use of single-use plastic packaging and promote the reuse and recycling of materials. PAPACKS is an example of a company that implements the principles of the circular economy in its activities, ensuring the sustainable use of resources, reducing the use of plastic materials and improving the impact on the environment. Their efforts contribute to the development of a more sustainable and environmentally responsible approach to packaging and consumption.

"Nova Poshta" is one of the largest and most successful logistics companies in Ukraine, which can also be recognised as an example of the circular economy. They implement various practices and initiatives to reduce environmental impact and create a more sustainable logistics system. Some aspects that reveal their circular activity are the following: energy efficiency and emission reduction, use of secondary resources, restoration and repair, electric mobility, and electronic solutions.

Dvipa LLC, based in the Magdalynivka district of Dnipropetrovsk region, has been growing organic wheat, raspberries, strawberries, currants, corn, rye, spelt, red currants, and amaranth seeds for more than 15 years, and now annually exports 100 tons of grain and up to 60 tons of berries to the EU. This company's products, sold under Ahimsa, are entirely organic and have the Organic Standard certificate. The company is located in the National Nature Park on the banks of the Orla River and has 150 hectares of certified organic fields. Recently, the company started offering a new 'trendy' product - freeze-dried berries, freeze-dried yoghurt, berry and vegetable powders, seeds and shirts oil. With this assortment, Dvipa LLC took part in the international exhibition BIOFACH 2020 and aroused interest from international buyers.

A striking example of using the benefits that have opened up for Ukrainian agricultural producers after the signing of the Association Agreement and the introduction of European approaches to food safety and quality is the Zdravlyk farm in the village of Hreve, Hrechane. By setting up snail-like production based on HACCP principles, the farmers could sell their products to the EU. The planned production volume of Zdravlyk is 20 tons of snails per year, and 95% of them are exported to the Baltic States. From there, intermediaries distribute the snails across the European Union. The farm produces processed products, such as salted snail caviar, which also meets the ISO22000 quality standards. Half of the company's profits are used to help internally displaced people, promote the development of personal snail agribusiness and support the local community.

Sady Dnepra LLC is one of the largest apple producers in Ukraine. The company grows, stores and sells apples under the UApple brand. Founded in 2016, the company is dynamically developing and rapidly gaining

momentum, with the territory of the orchards expanding by 100 hectares every year. Today, the company sells its products to local supermarket chains and exports them to the European Union, Asia, and the Middle East. UApple's team gains knowledge and experience in growing, caring for, storing, and processing Apple products from experts from the European Union (the Netherlands). At the same time, regional companies in other industries do not lose their positions in global rankings and annually produce specialised products for domestic consumption and export and provide services.

Interpipe is a prominent Ukrainian industrial company specialising in producing and exporting seamless pipes and railway wheels. With a broad global reach, the company supplies products to more than 80 countries through an extensive network of sales offices, focusing on key markets in the CIS, the Middle East, North America, and Europe. In 2020, Interpipe achieved sales of 662 thousand tons of finished goods, including 192 thousand tons of railway products under its K LW brand. The company has demonstrated its ability to cater to diverse market needs by developing a customised wheel design for Indian Railways tailored to meet India's specific operational requirements. Additionally, Interpipe supplies railway wheels to Deutsche Bahn, Germany's national railway operator, further solidifying its position as a reliable partner in the global rail industry.

5.5. SWOT analysis of the Dnipropetrovsk region in terms of circular economy development

The development of the Dnipropetrovsk region strategy follows European and national legislation. The set of defined strategic and operational goals and tasks meets the requirements of smart specialisation of the city of Dnipro within the framework of the socio-economic development strategy for Ukraine. An important aspect is that the European definition of smart specialisation is based on the same terminology ("strengths", "opportunities") as the SWOT analysis methodology. Conducting a SWOT analysis of a region is essential to make evidence-based decisions and guide sustainable development efforts in line with the principles of circular economy and smart specialisation. Such analyses allow stakeholders to build on strengths, address weaknesses, capitalise on opportunities and mitigate threats, ultimately contributing to sustainable and prosperous communities (see Table 3). Subsequently, the tools, expected results and challenges to implementing circular economy principles in the Dnipropetrovsk region are presented in Table 4.

Table 3. SWOT analysis of the Dnipropetrovsk region regarding following the strategy of smart specialisation and circular economy

Strengths	Weaknesses
– A strong base of educational and scientific institutions; – Availability of creative specialists to create innovations; – Availability of vocational and technical educational institutions, specialists-graduates (potential labour resources); – Availability of strong business and manufacturing industries to support and develop the educational sector; – Presence of large industrial developed business clusters (metallurgy, aerospace industry, IT, construction, chemical, financial, food processing sectors); – A million-population city as a primary sales market, an environment for multiplier effects from innovations (availability of a "critical mass" for the implementation of viable innovations) and a source of a large number of educated workers; – The city's brand is perceived as an industrial and scientific centre; – Proximity to natural resources (iron, manganese, nickel, aluminium, uranium, titanium, rare metals, water, black earth) and powerful sources of electricity; – Experience of commercialisation by industries; – Availability of primary small municipal support for technological innovations (INNODNIPRO startup project competition);	– Loose interaction of local businesses with scientists and developers, unfair distribution of profits; – Wear and tear of the material and technical base of education, lack of modern laboratories; – Lack of popular cases of commercialisation of technical innovations, which forms the brand of the city; – The small amount of commercialisation of innovations by industries does not give the effect of overflowing knowledge and practice - "copy and do"; – Low level of operation of the municipal support infrastructure, etc.; – Inertness of the existing industry to changes and obsolescence of technological systems; – Closedness of local businesses to innovations: they do not develop themselves and distrust both innovations and partners and competitors on the market; – The weak material base of the innovation support ecosystem – Lack of understanding that innovation is the economy and GDP (the city management has an interest in supporting the innovation vector only as a brand); – Unsystematic approach, lack of a city strategy and vision for

– The physical presence of large anchor enterprises that can be both consumers of innovations and generators of their innovations and a source of innovation; – City management is interested in supporting the innovation vector as a brand.	industrial development; – Limited connection with world centres of economic activity.
Opportunities	Threats
– The general global trend towards the formation of cities as subjects of the ecosystem, etc.; – The possibility of attracting major market players to cooperate and partial financing of scientific and educational centres; – A large number of support programs from foreign funds for the creation and financing of innovative ecosystems; – Deepening of the decentralisation reform (partial budget decentralisation, creation of regional and local authorities equal to cities, territorial and administrative reform with redistribution of powers, but without expansion of economic rights of communities). Cities will be able to independently make decisions regarding the development strategy and financing of innovative sectors; – The possibility of creating local financing tools: funds from local budgets; own funds of specialised state and communal innovative financial and credit institutions; funds (investments) of any individuals and legal entities; donor business support programs and grant programs; – A new stage in the development of the world's aerospace industry involving the private sector; – Decreasing the cost of energy sources (due to the transition to alternative energy sources: hydrogen, sun, wind, etc.); – The possibility of developing industries through educational and entertainment infrastructure (scientific, economic, industrial, ecological, entertainment theme parks); – Increasing the mobility of scientists; – Establishment of scientific partnerships with leading innovation centres.	– Lack of a strategic plan for the development of innovations at the country level; – The imperfection of patent law for ensuring insecurity of innovators and investments; – Lack of interest in vocational and technical schools in the city and other stakeholders (absence of a quality system of ordering state, municipal, and private sectors for vocational technical specialists); – Imperfect system of tax, financial and other instruments, which increases the threat of creation of legal entities in different jurisdictions; – Front-line city, war: due to the high mobility of the creative class, threats of this kind influence the acceleration of the outflow of the creative class from the city; – Depopulation of the city. The greatest threat is the departure of the creative class as the most mobile segment of the community. – Lack of a legislative framework regarding the possibility of having institutions and development tools at the regional level and implementing policies and standards.

Table 4. The systematisation of tools, expected results and challenges for following circular economy principles in the Dnipropetrovsk region

Tool	Expected result	Challenges of implementation
Design. This approach aligns with the core principle of the circular economy, which emphasises production processes that rely on recycled materials. By reintroducing waste into the value chain, recycling minimises the extraction of new resources, reduces environmental impact, and fosters sustainable production. This principle ensures that materials retain their value within the economy for as long as possible, supporting the transition to a more resource-efficient and eco-friendly economic model.	The goal is to reduce production waste and optimise the use of raw materials.	Currently, the Dnipropetrovsk region is only at the beginning of introducing the concept of circular economy at the regional level. Therefore, there is a problem of finding chains of transformation of waste into raw materials.
Sharing and virtualisation. The development of platforms for effective interaction between users and products or services aims to maximise their utilisation. This approach is particularly valuable for manufacturers facing low product usage rates or underutilised production capacities. Additionally, it fosters opportunities for competitors to collaborate by sharing fixed	Ensure product or service efficiency improvement, cost reduction, profit increase, and rapid product penetration into new markets.	The Dnipropetrovsk region has a sufficiently highly competitive environment both within the region and outside. Along with this, major market players lack the intention to share their resources with competitors. Programs of state stimulation and encouragement in this direction are needed.

costs, thereby improving operational efficiency. Such platforms promote resource-sharing, extend product lifecycles, and enhance productivity, aligning with the principles of both the circular economy and cooperative business models.		
Goods as a service. This approach serves as an alternative to the conventional model of selling goods or services. It moves beyond traditional direct sales, leasing, or renting by offering clients the option to enter into a subscription agreement. Customers gain continuous access to the product or service through a fixed monthly or annual payment without needing ownership. This model ensures more efficient utilisation of resources and fosters longer-term relationships between providers and users, promoting sustainable consumption patterns in line with circular economy principles.	Applying this approach reduces the costs for users who purchase the product. The product can be used for several cycles (which helps reduce raw materials costs and additional costs during production).	The trust of the end consumer in the quality of products on the one hand, and the responsibility of the manufacturer regarding the control of ensuring this quality on the other. The general problem is not only for the Dnipropetrovsk region but also for the country. Despite a quality control system, some industries may have no or insufficient control, especially in agriculture and small enterprises. In addition, in Ukraine, there is a lack of modern infrastructure and equipment to ensure adequate quality control. And finally, insufficiently strict laws on quality control and product standards can lead to a drop in the quality of products on the market.
Reuse in production. This approach emphasises the secondary use of certain parts and individual components of products that can no longer function as a whole. Many products globally are discarded despite containing components that remain in good condition. By salvaging and reusing these parts, manufacturers can reduce waste and extend the lifecycle of valuable materials. This practice minimises the need for new raw materials, decreases environmental impact, and aligns with circular economy principles by promoting repair, refurbishment, and remanufacturing over disposal.	This approach significantly reduces production costs, minimises the use of raw materials, and substantially contributes to improving the environment around the world by reducing the use of natural resources.	A significant challenge lies in the insufficient investment in innovation, research, and development. This issue was already substantial before the war, but it has intensified during the conflict, further exacerbated by the migration of skilled professionals from the country. An urgent priority is the improvement of systems for collecting used parts and components for reintegration into production processes. The successful adoption of a circular economy also depends on advances in processing technologies and the secondary use of raw materials. Achieving this requires substantial investment in innovative research and development and upgrading production facilities to accommodate new technologies and processing methods. Without these investments, the transition to a circular economy remains challenging to realise effectively.
Reuse in consumption. This approach focuses on reusing previously used products and can be applied at multiple levels. At the <i>client-to-client</i> level, individuals resell used goods through online marketplaces, social initiatives, or trading platforms, promoting product longevity and reducing waste. At the <i>business-to-client</i> level, enterprises complete the restoration or refurbishment of used products, returning them to the market at a lower price point. This strategy makes goods more affordable and decreases the environmental footprint by minimising the need for new production, aligning with the principles of sustainable consumption and the circular economy.	Applying this approach allows you to extend the product's life cycle, increasing the company's profits not through producing new products but by recovering and recycling existing ones. It also enables the population to satisfy their needs for specific products at a much lower price. This approach contributes to the reduction of raw material costs and the efficient use of natural resources, which improves the environmental situation in general. The recovery and recycling of existing products help reduce the amount of waste and pollution, which positively affects the natural environment.	Substandard products and customer-to-customer fraud can affect trust in the circular economy approach. This requires the development of verification mechanisms and quality standards for reused products. The lack of a developed business client interaction algorithm can delay the spread of the circular economy at the company level. It is necessary to promote the exchange of knowledge and experience between companies and stimulate a conscious change in management. The small volume of manufacturing companies implementing the product recovery procedure may limit the range of products available on the market. Here, it is necessary to promote the support of innovative enterprises and create a favourable

		environment for implementing circular solutions. The solution to these problems may include legislative support, the development of standards and certifications, increasing public and business awareness of the benefits of the circular economy, and active promotion of innovative enterprises.
Industrial symbiosis and processing of industrial waste. Implementing circular economy principles plays a crucial role in enhancing business efficiency. It enables companies to reduce production costs, lowering prices for manufactured goods. These savings are achieved by optimising resource use, incorporating recycled and reused materials, and streamlining production processes. Additionally, the circular economy supports the reduction of CO ₂ emissions and minimises environmental harm. Using recycled inputs and energy-efficient technologies, businesses can lower their greenhouse gas emissions, contributing to resource conservation and improved air quality. This approach fosters economic sustainability and aligns with global environmental goals.	The implementation of the circular economy significantly increases business efficiency in all directions. This includes minimising economic costs for production, which decreases the cost of manufactured products. Recovery and use of secondary resources allow for the reduction of the costs of purchasing new raw materials and production costs. Circular economy approaches also help reduce CO ₂ emissions. Less need for new raw materials, less energy consumption for processing, and less waste going to landfills and incineration leads to a reduced volume of greenhouse gases released into the atmosphere.	There are almost no industrial symbioses in the Dnipropetrovsk region. In general, the number of enterprises that exchange resources and interact in a circular format is still limited in Ukraine. The need for investment at the initial stage: the initiation and development of circular practices requires some investment, especially at the first stage. However, the long-term benefits of resource efficiency may outweigh the costs. Modernisation and innovation: the successful implementation of the circular economy requires modernising technologies and the introduction of innovative developments. This may require additional efforts and funding from businesses and the state.
Recycling. Recycling is a well-established practice, serving as a key component in the circular economy and traditional economic models. It focuses on repurposing waste materials into new products, enabling the reintegration of discarded resources into production cycles. This approach reduces the need for virgin raw materials, promoting resource efficiency and sustainability across conventional and circular economic systems.	Encouraging the processing industry will help create new jobs, promote the development of innovative technologies, and attract investments. Introducing a system of extended responsibility, where they take responsibility for the final stage of the life cycle of their products, will increase the motivation to use more sustainable materials and reduce waste producers. This approach will help reduce the negative impact on the environment, reduce pollution and increase the level of renewable resources.	Currently, most large state-owned companies in Ukraine and the Dnipropetrovsk region are transitioning toward using recycled materials in their production processes. However, the adoption of recycling practices among small businesses remains limited. As a result, processing raw materials is primarily the domain of larger enterprises. The significant financial investment required to modernise production processes and implement innovative technologies is a key barrier preventing smaller companies from engaging in these practices. Such upgrades are necessary to efficiently integrate secondary raw materials into production, making it challenging for small businesses to participate in the shift toward sustainable manufacturing.

Conclusions

This research underscores the benefits of seamlessly integrating circular economy principles into the Dnipropetrovsk region's smart specialisation strategy. This study's key findings and insights emphasise the substantial economic, environmental, and social advantages that can be derived from such integration. These are discussed below.

Circular Economy Benefits

The research unequivocally establishes that adopting circular economy practices in the Dnipropetrovsk region can lead to enhanced resource efficiency, diminished waste generation, and considerable cost savings across various industries. These practices, particularly in manufacturing, agriculture, and energy production, offer a promising avenue for sustainable economic growth.

Environmental Impact

A transition to a circular economy can significantly reduce the environmental footprint of the Dnipropetrovsk region. This includes a notable decrease in emissions and pollution and a more responsible use of natural resources. These ecological benefits align with global imperatives for climate change mitigation and improving air and water quality.

Economic Growth

Circular economy initiatives emerge as catalysts for stimulating economic growth in the Dnipropetrovsk region, fostering innovation, creating job opportunities, and attracting investments. By prioritising sustainable economic development, the area can bolster its competitiveness on a global scale.

Challenges and Barriers

Identified challenges such as limited awareness, inadequate infrastructure, and regulatory hurdles highlight the need for concerted efforts to overcome these barriers. Enhanced stakeholder collaboration and improved coordination mechanisms are crucial to addressing these challenges effectively.

Policy and Governance

The research underscores the pivotal role of effective government policies and incentives in promoting circular economy practices. Clear regulations and supportive initiatives can motivate businesses and industries to embrace circular models, drawing valuable lessons from international experiences.

Collaboration Optimisation

Optimising stakeholder collaboration through improved communication and information-sharing mechanisms is imperative. Establishing platforms for knowledge exchange and best practice sharing can contribute to the successful implementation of circular economy principles.

Recommendations for Further Research and Action Steps

The outlined actions and recommendations provide a roadmap for future endeavours, encompassing awareness campaigns, infrastructure development, policy refinement, and robust monitoring and evaluation frameworks. Pilot projects in key sectors and international cooperation could offer tangible pathways to showcase the feasibility and benefits of circular practices. In conclusion, integrating the circular economy within the Dnipropetrovsk region's smart specialisation approach presents a potentially transformative opportunity for sustainable economic development, environmental protection and improved resource management. By implementing the recommended actions, the region can expedite progress towards a more circular and prosperous future while adeptly navigating and addressing the challenges that may arise along this transformative journey.

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HUMAN RESOURCE STRATEGY AND INNOVATION CAPABILITY OF SERVICE COMPANIES

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Abstract. It is widely acknowledged that human resource management can build a dedicated and engaged workforce, which contributes to a strong corporate performance; However, researchers are only beginning to explore the role of Human Resource (HR) strategy in fostering organisational innovation, while its impacts on service companies' effectiveness and efficiency still hold untapped potential for sustainable and socially responsible development of innovative services and call for a holistic approach to the HR strategy. The research question: how could human resource strategies orient stakeholders' performance to sustainable competitive advantages of service companies? The pursuit of new business opportunities is essential for sustainable growth: innovative HR strategies might provide the basis for an economy to reach a new level of technological excellence, productivity, and prosperity, while human resource management has a significant impact on employees' behaviour, attitudes, and the overall corporate performance. This study aims to explore and deepen the theoretical, methodological, and empirical knowledge on the interaction between organisational culture and human resource practices to foster innovation and contributes with the enhanced organisational innovation capability. The semi-structured interviews with human resource experts of service companies led to pertinent implications for human resource strategy enhancement.

Keywords: human resource strategies; innovation system; sustainability; service companies; effectiveness; efficiency

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1. Introduction

Innovation is discussed in various disciplines, such as social science, economics, management, arts, etc. For instance, Chaudhry et al. (2021) and Inegbedion et al. (2020) scrutinise aspects such as engaging employees and other stakeholders in decision-making, innovation, and resource-sharing initiatives. Over the last two decades, many scientists have provided elaborate definitions of innovation. For instance, Kochetkov (2023) described innovation as a trigger and driver for change in the context of social actions, along with economic, business, entrepreneurship, behavioural, and institutional dimensions, where diverse types of innovation (such as product, process, service; radical vs. incremental, social and shared-value, technological, managerial, etc.) are combined within diverse business models. Thus, innovation is about new products and new ways of solving challenges, coexisting in open innovation and entrepreneurship ecosystems via cutting-edge technologies, strategic collaborations, and unique forms of working, servicing and managing human resources. Given that many companies are driven by the business model, focused on the value generated per employee, the human resource department (HRD) emerges as a key catalyst within innovation processes (Saini, 2022). The human resource strategy refers to the policies, practices, and systems that influence employees' behaviour, attitudes, and

contributions (such as work autonomy, job demand and security, training and talent development, job and task rotation, and the liaisons with the overall business strategy) that provide a competitive advantage in the industry in the long run (Tran et al., 2020). Effective human resource practices can create a working environment which encourages the development of an effective organisational culture as well as influences innovative capabilities (Botelho, 2020; Lauzikas et al., 2023); thus, an organisation should focus on employees' and other stakeholders' ability to innovate and contribute to the overall organisational performance via creativity and learning. According to Mujtaba et al. (2020), Human resource management supports the company's operations by fostering employees' innovative behaviour, contributing to employee and customer satisfaction. Human resource policies and strategies are a significant booster for innovation, including knowledge management, talent development, creativity enhancement, learning, modern technologies, key strategic partnerships, and communication (Toke, 2024).

The recent papers are covering the phenomenon of digitalisation (Kim, 2021; Deloitte, 2024; Arefief et al., 2023), collaboration (Vuong & Nguyen, 2022; Sewpersadh, 2023), cutting-edge technologies (Tohidi et al., 2020), social value-added (Agudelo et al., 2019), diversity and inclusivity leadership (Noor et al., 2024; Bersin, 2024), data management (Caloisi et al., 2023), micro-cultures, etc. Such evolution elucidates the necessity, scope, and scale of innovation in the context of the combination of economic and social value-added, talent development (Agustian et al., 2023), as well as the dynamics and flexibility-driven approach towards more sustainable and unique business models (Gilsing et al., 2022). Moreover, scholars and business intelligence experts introduce more sophisticated metrics for measuring the innovation strategy effectiveness (Yeboah et al., 2023), while drawing attention to learning, cross-departmental synergy, open and shared-value economy-based innovation systems, and new forms of collaboration with universities, R&D transfer institutions, diverse types business entities, public organisations, investors, and social agents.

Diverse uncertainty periods, such as the pandemic or geopolitical vulnerabilities, dramatically impacted all types of businesses worldwide (Holman & See, 2020). While underscoring the firms' need to develop and offer a continuous stream of innovation (Qun & Sousa, 2019), companies must implement successful innovation processes, integrate knowledge from various sources, implement innovation, and raise stakeholder confidence. Furthermore, according to Malec and Stanczak (2020), to forecast the efficiency of innovation processes, it is necessary to take the following actions: to conduct the risk analysis before and during its implementation period to determine all the tasks of the project management process, defining the scope of duties and responsibilities; to assess the feasibility of a project. The need for creativity and innovation is essential for a company's successful development to maintain a clear and critical understanding of the social and economic value creation paradigm (Ingram & Fenton, 2020), companies need to develop a sustainable and effective innovation commercialisation model to meet the customer needs and mitigate the potential uncertainties. Within the recent studies, the scholars also add inclusive employee performance in the process of product development, market expansion, and innovation commercialisation (Toke, 2024), while Rodríguez-Vilá et al. (2024) introduce a three-dimensional model of defining, serving, and operating in the market (Komm et al., 2021). They rely on the HR strategy and new preconditions, liaising with new work forms (Wong, 2024), well-being, and learning (Kelly et al., 2021), which might lead to more organic and sustainable financial results. The service industry occupies a dominant position in advanced economies regarding value-added and employment: companies require service innovation to strengthen competitive advantages (Raeisi et al., 2020). No single 'best way' describes how service innovation is created (Raeisi et al., 2020). However, all these viewpoints contribute to the development of a broad field of service innovation research.

2. Innovative Human Resource Strategies

Although the scientific literature on the role of human resources in business is well established, it is crucial to analyse the human resource strategy impacts on the overall organisational performance while the human resource department is an intermediary between management, workforce, and other stakeholders (Maurer-Klein, 2019; Rodjam, et al., 2020). Employee engagement in the context of a business strategy and managers' proactive participation could encourage innovation while reducing bias perception across organisational departments and making employees feel satisfied, valued and safe (Delapenha et al., 2020). The strategic approach to human resource management (HRM) should combine several practices within more complex systems. At the same time, competitive and sustainable HR strategies should incorporate global business and entrepreneurship trends, such as flexibility, accountability, use of modern technologies, business intelligence, data management, inclusive leadership, and strategic collaborations (Barcan, 2020). The leadership challenges and risks might be mitigated by applying cutting-edge technologies (for instance, data-driven analytics and AI; Bérubé et al., 2024).

It is crucial to notice the role of talented employees who use their skills and knowledge in practice, which calls for efficient talent recruitment, development, and retention tactics (Maurer-Klein, 2019). Many factors must be considered, such as the target group's expectations, a differentiated employer's value proposition (EVP), brand consistency and communication, and assessing/monitoring the employer's branding efforts (Eger et al., 2019). Moreover, businesses must be ready for the change management (Jones, 2020). Stahl et al. (2020) recommend focusing on sustainability practices in HRM while increasing engagement and commitment. Employees should play a critical role in strategy planning, depending on the management style. Furthermore, a transdisciplinary approach to combining tactical and strategic objectives, implementation plans, and monitoring models is necessary (Kaaria, 2024).

Given that innovation can help a company unleash and achieve its competitive advantage via human capital (Pahuja et al., 2024), human resource management and talent management have a strong influence on workforce competencies, knowledge, and results (Stachová et al., 2019; Guo & Lu, 2023). Sewpersadh (2023) scrutinises the interdependencies between networks and cutting-edge technologies while liaising the HR strategies with a company's digital business models and potential outcomes. Thus, innovative solutions within the field of HR Management should be supported by 'top management' and maintained by line managers (Hamilton & Sodeman, 2020). Dyson (2024) adds that applying cutting-edge technologies is critical for inclusive leadership (covering aspects such as creativity, learning, talent development, collaboration, and communication).

The technological function provides the opportunity to save time and cost. From the organisational perspective, HR big data analytics should focus on employees' development to drive a company's profitability. Such an implication was also supported by Columbus (2020): many HR information systems (HRISs) are usually used for administrative tasks, and therefore, they do not fully serve their potential to collect more data regarding workforce productivity. The analysis of HR's big data could help identify what training or motivational benefits programs are the most beneficial in terms of innovativeness, quality improvement, management efficiency, and talent pool advancement: the more efficient the usage of IT tools in the HR department is, the higher contribution this department could generate to the business strategy, while the innovation department could provide solutions to other departments and, in this way, help a company build stronger image, reputation, and trust (Meister, 2020).

Organisational innovation can be in the form of implementing new methods in the organisational process, such as methods to work in groups, workplaces, or operations. Sheeba & Christopher (2020) add the role of training and development that enhance innovative work behaviour, affective commitment, work proficiency, and managing conflicts, which ultimately leads to improved employee performance and productivity. HR practices can create a working environment (context) that encourages an effective organisational culture and influences innovative capabilities (Botelho, 2020).

3. Research on the Role of Human Resource Strategies in Service Companies: Methodology

The analysis of studies on service innovation shows the diversity in terms of HR strategies, along with the strategic context of various sub-industries and cultures. Thus, to gain an in-depth understanding of innovative HR strategies, semi-structured expert interviews were conducted, focused on the performance of the HR department in service companies. This research aims to assess the role of the HR department and its strategies in the context of efficiency, innovativeness, and alignment with the business strategy. The key objectives are oriented to skills needed for HR leaders, innovative HR practices, the collaboration between the HR and other managerial departments, the role of the HR function within the innovation process, and experts' perception regarding the HR strategies in light of technological changes and innovation.

Many scientific studies have emphasised the importance of the human resource strategy in creating a sustainable environment for innovation. The methodological pillar of this study is anchored on the theoretical approaches proposed by other researchers. The list of the studies used as the theoretical background of this research is presented in Table 1.

Table 1. The theoretical foundations of the research

No	Author	Year	Research method	Aim of the research	Value added of the research
1.	Arefief et al.	2023	A systematic approach (quantitative data analysis)	To highlight the principles of managing companies' global competitiveness in the e-commerce field in the context of digitalisation.	The effects of networks on performance efficiency and competitiveness are presented.
3.	Aldieri et al.	2019	Quantitative research	To examine the potential effects of the workforce quality, observed as intangible assets, on the firms' efforts to generate product and process innovation.	To measure what role HRM plays in innovation processes.
4.	Kohnová & Papula	2019	Quantitative research	To analyse the characteristics of employees from the point of view of employers' assessment in the context of an innovation activity.	To examine the most valuable competencies of HR specialists and key elements of effective leadership. Moreover, to analyse the role of Employee Branding strategy.
5.	Pillai & Sivathanu	2020	Quantitative research	To investigate the adoption of AI technology for talent acquisition.	To assess the implementation of IT tools for HR effectiveness enhancement.
8.	Botelho	2020	Quantitative research	To analyse mechanisms via which the methods of personnel management have an additional impact on an organisation's organisational culture and innovative potential.	To examine the Talent Management strategy implementation as a methodically organised strategic process.
9.	Waheed et al.	2019	Quantitative research	To analyse the impact of HRM practices on innovation efficiency, the role of organisational innovation and the constraining role of the innovation climate.	To explore the HR strategies, unleashing people's creativity throughout an organisation.
12.	Guo & Lu	2023	A case study of Chinese international construction companies (CICCs)	To measure the firm competitiveness via data-driven principal component analysis (PCA), A "3Ps" (performance, potential, and process).	Other scholars could use the applied methodology to examine competitiveness across different industries.

Source: prepared by the paper authors, based on Aldieri et al., 2019; Kohnová & Papula, 2019; Pillai & Sivathanu, 2020; Botelho, 2020; Waheed et al., 2019; Guo & Lu, 2023; Arefief et al., 2023.

Nearly all the compared research methodologies incorporated quantitative research methods while diminishing the potential of an in-depth, perception-based insights analysis, not ingeniously presenting the experience and

strategic information held among HR experts. The semi-structured interviews with the experienced HR managers of service firms are more in line with the research question of the present study (addressing many perception and experience-based aspects). Moreover, the selected type of research method gives more flexibility and depth, and it is more appropriate for a small sample size, seeking a deeper insight into the subject, along with the possibilities for examining the research problem more contextually and strategically.

The purposive research sampling method was chosen: the interviewees needed to meet specific criteria: an interviewee must be a graduate from university (preferably in HRM, international business, or psychology fields); they must be working in a managerial position (to be either eligible to make decisions regarding business and corporate strategies or influence HR management). Relying on the knowledge-based approach in the thematic category of HR strategies (since managers are often involved in strategy development processes), some interviewees were department managers within a service-based company. In contrast, the others had a strong educational knowledge of HR or were able to consult a firm regarding its HR strategy. The sample size reads 10 interviewees.

The qualitative data analysis process within the present study involves coding and categorising, which helps understand a vast amount of data by reducing the amount of non-relevant information, identifying significant patterns, and finally, building a logical chain of evidence. Moreover, a step-by-step process was introduced for data analysis and interpretation: transcribing the collected data, coding the answers, identifying the liaisons between the different perspectives of respondents, and revealing the main theoretical assumptions to draw broader conclusions and recommendations (see Table 2).

Table 2. Assumptions of the research

Knowledge Block	Experts with more transdisciplinary experience (working in diverse fields, particularly with a degree in business-related studies) consider the HR department strategic, cross-departmental, and horizontal. The experts with more transdisciplinary experience might have better knowledge of talent management.
Sustainability programs	To improve competitive advantage, it is crucial to run sustainability campaigns, which should be executed by leaders with extensive experience in HR strategy development and implementation.
Management and leadership models	The HR department's high autonomy might influence innovation and culture enhancement. However, technological evolution calls for incremental and radical process improvement and innovation that leaders influence. Therefore, it is vital to propagate transformational leadership that fosters creativity, diversity, and inclusivity.
Employer branding	Employer branding should be a key success factor in HR strategies: it will contribute to a social image via motivated employees and attract more talented candidates.
Business intelligence	HR strategies should be tightly aligned with the innovation culture, where HRD plays a crucial role in fostering innovation by empowering and motivating employees.
Management of change	The HR department was a front-line communicator and a leader in crisis management. In the best-case scenario, the HR department could implement both innovative and crisis management strategies during the time of change and, in this way, strengthen its role by collaborating with other departments.
Data management	To enhance the innovation culture in a company, HRM should apply innovative strategies (For instance, GenAI). Data management can be a helpful tool in talent and performance management.
Finance	Expenditures/ inputs in innovative HR functions are critical to achieving the competitive advantage; However, the investments might generate the desired return/ value-added in the long-term only if creative leadership, technology-based communication, and employee empowerment are well-implemented. Continuous monitoring (with priority weights, outputs, and feasibility scores should be tracked in diverse time frameworks compared to peers).

Source: Prepared by the paper authors, based on the literature review

Linking the responses of various categories of experts with the theoretical research pillars helped create and test the conceptual assumptions (that could be further used in the research of the same series). It contributed with pertinent recommendations for service companies.

4. Research Results: Preconditions for Effective HR Strategies in Service Companies

The results, related to the first assumption (Knowledge block), revealed that only a few experts (2 out of 10) had sufficient knowledge of HR. However, nearly all the experts emphasised the role of the HR Department as an essential strategic organisational construct or an epicentre of knowledge sharing. The educational background in business or economics does not fully ensure the proper knowledge for the SHRM approach --- a more holistic and transdisciplinary approach is necessary to unlock the potential contributions of this department to the overall company's performance. It was accentuated that the HR department is responsible for providing an essential labour supply, talent development, and productivity. However, various motivation programs should be implemented (covering well-being, creativity, learning, and innovation). This is the main contribution towards business strategy since happy employees stimulate business growth. Five experts (four of them represented the generation 'Y') have not yet implemented a talent management strategy in their organisations. One of the experts, belonging to the association of HRM professionals, explained that only 15% of Lithuanian companies had an effective talent management program, according to their study. The talent management function to attract high-qualification level employees was not supported, although all the interviewees indicated talent management as a key strategic driver for high-performing employees. Moreover, talent management, as well as the motivational role of HRM, was evaluated by a relatively high 3.9/5 score. Despite a positive perception of talent management, most of the HR experts were failing to perform successfully, which might be related to the lack of involvement of the HR department in business strategy development.

While examining the role of sustainability programs, it is essential to point out that they are perceived as the least effective and relevant compared to other strategies. Notwithstanding the lack of attention to sustainability program implementation, some companies have transferred all paper documents to the digital form. This practice was accelerated due to the Covid-19 restrictions. Moreover, one of the respondents underlined the inclusivity strategy, centred on 'elderly adults' employment' as the most successful HR strategy, diminishing the social gap between different generations and reaching synergy effects via shared value economy principles. Sustainability is the weakest area of the examined companies, and it is crucial to excel in the engagement and commitment of employees (and other stakeholders) at the strategy development and implementation stage.

While tackling the role of management and leadership models, 5 out of 10 experts revealed that responsibility in terms of innovation is usually disseminated throughout an organisation. This role is generally performed by the R&D, Marketing, or other departments, leading to the validated "Management and leadership models" assumption. Most experts agree that the HR department is not directly related to implementing innovation. Nevertheless, they confirm that the HR department is partly facilitating or fostering this process by creating an appropriate environment and organisational culture, which might motivate employees to innovate. Moreover, three interviewees alluded to implementing and maintaining innovation as an organisational value: this produces a long-lasting competitive advantage and creates dramatic shifts towards the competitive attitude.

Many interviewees acknowledge the importance of creativity enhancement in promoting innovative culture inside the organisation. One interviewee specified the significant role of HRM in the innovation commercialisation process's effectiveness/efficiency. 6 of 10 respondents admit that knowledge sharing is essential for a company to create an innovative culture and motivate employees to generate new ideas. At the same time, 6 of the interviewed experts define creative leadership as the most valuable HR competence. Creative leadership helps develop and implement innovative ideas by gaining a shared sense of empowerment, development, and entrepreneurship. Moreover, three key dimensions for effective leadership are identified: empathy, ownership mindset, and transparent communication.

The experts interpreted the employer's branding (EB) strategy as an area where at least two departments must collaborate and seek the same goal: the EB strategy is where marketing, communication, and human resource

departments are united to market activities, create a social image of a company, as well as reach potential employees and customers. The successful EB strategy relies on each employee, while the HR role in this strategy is to draw a “perfect candidate profile”. According to the experts, the Marketing and Communication departments are to set the rules of EB and select the most suitable channels for advertisement. One of the interviewees, who works in a highly secure and confidential company, defined the EB as an opportunity and responsibility of a recruitment team. Even though the interviewees emphasised the importance of EB, this is one of the areas for improvement since the perception of efficiency is not positive. All the interviewees accentuated the EB as part of the recruitment process and, contrary to the literature analysis, affirmed that this strategy should concern other departments. It proves the necessity to establish a horizontal HR department, which should work hand in hand with different departments while reaching cross-departmental synergies and higher value-added to the overall company's performance. HRM covers a vast spectrum of functions, while successful implementation of HR strategies is impossible without open and smooth technology-based communication, efficient resource management and value sharing.

While emphasising the role of business intelligence, only 2 of 10 respondents indicated that HR department does not contribute to innovation-fostering processes via BI techniques. In contrast, other respondents see HR professionals as specialists who should strive to create an innovation climate of thinking outside the box, along with creativity enhancement and motivation programs: all these prerogatives should be implemented via business intelligence technologies. According to the experts, innovation-fostering processes include hiring talents and actively motivating employees to engage in a company while promoting an innovative and relaxed work environment (giving time, space, and power to speak freely). Moreover, one interviewee specifies the importance of work-life balance in promoting innovation because it affects the company's bottom line, making it more innovative and productive. Half of the interviewees see teamwork as essential in building a creative environment based on innovation and Business Intelligence techniques. Teamwork combines diverse knowledge, personalities, generations, and cultures that bring different thoughts and ideas together. Two respondents acknowledge the benefit of gamification, as it can create value for leaders, teams, and employees. As a result, the appropriate introduction of gamification to the workplace motivates and inspires employees, which is a key factor for a company's ability to innovate. Thus, innovation drives growth, but to remain competitive, creativity should be enhanced by effective and innovative HR practices aligned with modern technology and new creative approaches.

Managing change is another critical dimension of the effective HR strategy: nine out of ten interviewees stated that unexpected changes affect almost all aspects of the organisational development, including the HR department. The role of the HR department becomes more critical since 'care must be taken to ensure the safety of employees, while organising work remotely, without diminishing other important HR functions' (stated one interviewee). It has become essential to monitor stress levels to enable employees to perform their activities in a comfortable atmosphere. It is also crucial for the HR Department to track the employees' engagement and motivation. As was found in the literature review, HRM has become a front-line communicator responsible for safety and remote work policy. In parallel, innovation can be seen as a tactic for recruitment, while new IT tools should accelerate this process.

Given the growing role of data management in modern organisations, most of the HR department's IT tools are oriented to the recruitment process (candidates' pipeline systems, talent pools, standardised tests, etc.). At the same time, some of the techniques help measure performance and improve skills. Therefore, since the recruitment might be fulfilled remotely, one of the experts indicated a newly acquired video platform used for interviews. This investment can be considered an innovative solution; However, it does not impact the already-hired employees. New technological tools are applied to enhance efficiency and foster innovation: the innovation culture requires additional efforts and initiatives. The interviewees noted creative leadership and analytical and communication skills as the most valuable factors for HR specialists. Nevertheless, to unlock data potential, it is necessary to have

a technological and scientific educational background. None of the respondents had experience in the technology or science fields, leading to a lack of knowledge of data management and an inability to use advanced IT tools.

The HR experts also emphasised the financial dimension: implementing new HR tools leads to larger expenditures. 6 out of 10 respondents confirm the rise in HR costs. At the same time, one expert gives a precise example (the video platform for performing the remote interviews is marked by a significant OPEX expenditure and might diminish the bottom line). The substantial increase in HR costs and implementation of new IT tools in the HR department show that companies struggle to raise funds to recruit, retain, engage, and develop their talents. Given the complexity of HR technology implementation, organisations need to respond to market pressures in the short term and prepare their employees for new work realities in the long term. Thus, technology implementation can help HRM underline key work metrics and help maximise efficiency by enabling a company to achieve its goals. The theoretical pillars, deriving from the literature review, were tested, and the conceptual model summarising the research results was developed (see Figure 1).

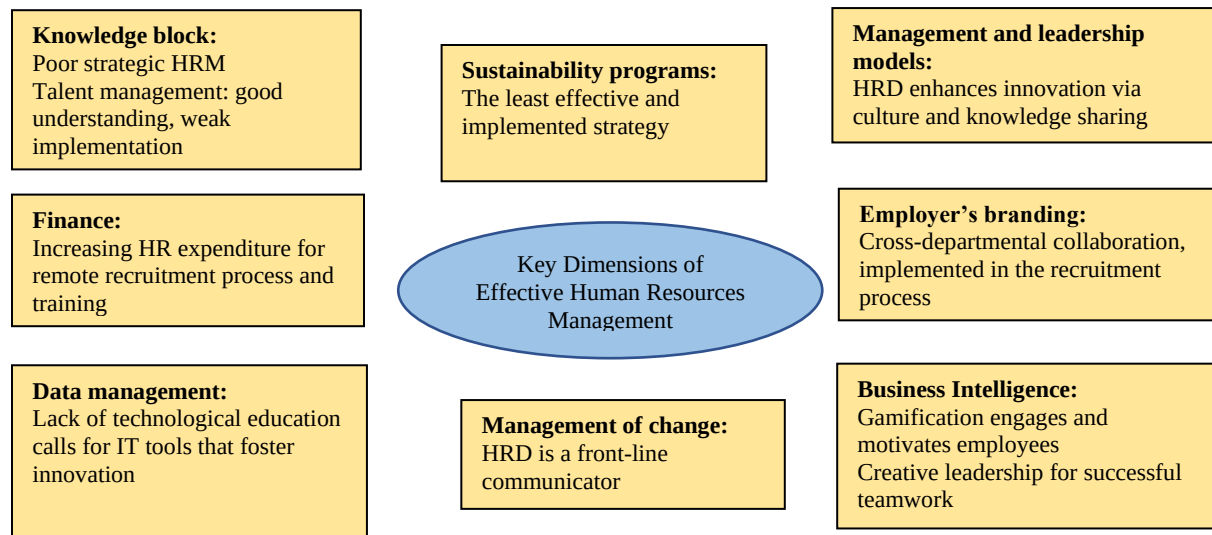


Figure 1. The key dimensions of effective Human Resource Management
Source: prepared by the authors, based on the literature review and the Experts' Responses

The conceptual model reveals the lack of technological and business intelligence knowledge to implement various innovative HR solutions jeopardises the whole HR strategy. At the same time, orientation to short-term objectives (versus long-term sustainability programs) calls for more knowledgeable, inclusive, intelligent leadership, effective risk management, and stronger financial analysis. The analysis implied that the cross-departmental synergy might be diminished if effective knowledge-sharing and talent development (including learning programs) are missing. The limited organisational openness towards stakeholders could also explain the insufficient use of modern technology within the HR department via the shared value economy.

Given that the qualitative research method is based more on perception and experience rather than on statistical or mathematical interpretation, the implications of the present study might serve as fundamentals for quantitative research to find patterns and means, test causal relationships, and summarise results for a wider population. This study mainly focused on certain HRM practices and strategies that influence employee behaviour and attitudes while improving corporate performance. Thus, the researchers may further explore some additional HR functions and practices (such as empowerment, job design, participation in the decision-making process, etc.).

Conclusions

The HR department can foster innovation through knowledge management, employee development, and collaboration. In contrast, organisational innovation could be encouraged via motivational and talent development functions, creativity systems, modern technologies, and an adequate environment. Based on the research results, innovative solutions are mainly executed in the recruitment process by standardised tests for screening candidates, using talent pool and candidate pipeline software, chatbots in social media profiles, etc. Apart from that, the HR department is responsible for practices that aim to identify the strengths of least-performing employees, motivate high-performing individuals, cut gaps in terms of their performance, and recognise hidden talents. Most interviewees do not have a fully implemented talent development and management strategy. In addition, any talent management platform which could be powered by AI or big-data analysis is not identified as an IT tool within HRM. Poor understanding of IT tools' potential is related to the lack of technological/scientific education that could help unleash the opportunities deriving from big data management.

Some creativity-boosting initiatives and employee empowerment techniques should impact reshaping employees' innovative behaviour. Workshops with managers and leaders, knowledge-sharing sessions, "ideas pitch", and reward programs might be the right choice. However, these initiatives should result from collaboration among several managerial departments. Although some companies have a separate department responsible for innovation commercialisation, the HR department is crucial to promoting an organisational culture where people feel empowered and engaged. Employee engagement is a key component of workforce efficiency and productivity, key strategic relationships, health, and safety. New forms of work-life balance should emerge as a core axis of efficiency, creativity, and innovation. Managing change and crisis management might be a weakness of the HR department, calling for more attention to long-term targets and sustainability programs.

Employers' branding and sustainability initiatives should be correlated to attract talent and engage employees. However, both strategies require marketing, communication, and HR departments' involvement: it would be challenging to reach strategic goals without a cross-departmental synergy and efficient communication; the HR department should be a horizontal managerial unit, while performance improvement of each involved factor should be continuously monitored at different time perspectives (short-, medium-, long-).

Companies have continuously invested more in modern technology while orienting the HR function towards engaging employees virtually: HR leaders become data scientists or IT experts. Using AI for talent management and recruitment is a compelling long-term strategy. It is crucial to start paying attention to training HR leaders to enhance their technological knowledge and skills.

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INVESTIGATING GENDER INEQUALITY IN THE WORKPLACE: A SOUTH AFRICAN PERSPECTIVE*

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Abstract. This review provides a comparative analysis of gender equality practices in the workplace, with a particular emphasis on Kwa-Zulu Natal, South Africa. The research employed a qualitative review of existing literature to gain an in-depth understanding of gender inequality in KwaZulu-Natal and to inform potential policy interventions to promote gender equity in the workplace. Gender equality is essential for promoting inclusive workplaces, economic development, and societal advancement. Wage disparities, unequal promotion opportunities, and under-representation in leadership roles are common consequences of gender inequality in the workplace, which is a persistent issue. Cultural norms, organisational biases, misogyny, patriarchal influences, intersectional marginalisation, and gendered organisational structures are contributing factors. Legal reforms, diversity initiatives, personal empowerment strategies, and solutions such as bridging the gender pay disparity, promoting work-life balance, and challenging gender biases are necessary to address this issue. The study contributes to the existing body of knowledge by providing an overview of research on gender inequality in Kwa-Zulu-Natal and identifying gaps that warrant further investigation. Through feminist theory as its framework, the paper explores gender inequalities in South Africa, advocating for the equal and fair treatment of men and women. Furthermore, it is an essential resource for government sectors, emphasising the necessity of effective policies and interventions to resolve workplace inequalities, thereby assisting policymakers in implementing targeted initiatives. The research paper employed a systematic review approach to collect information from qualitative studies, thereby ensuring a context-sensitive analysis and improving the rigour and precision of the search process.

Keywords: gender; discrimination; inequality; bias; workplace

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JEL Classification: J70, J71

1. Introduction

In South Africa, gender inequality is influenced by a range of interconnected factors, including the enduring legacies of apartheid and colonialism, which have undermined family structures and worsened economic disparities (Kirkwood, 2018). Patriarchal traditions and cultural norms further contribute to gender-based violence and the marginalisation of women (Helman & Ratele, 2016; Snodgrass, 2018). Although regulatory frameworks promoting gender equality, such as policies encouraging women's participation in managerial roles, have been established, significant challenges persist. These include the gender wage gap and limited resource access (Janse van Rensburg et al., 2020; Vyas-Doorgapersad, 2023). Sexism remains a central factor in the unequal treatment of women in the workplace, reinforcing barriers to employment and hindering career advancement while sustaining male-dominated advantages (Zhu, 2021). Gender disparities in the labour market are complex, encompassing labour force participation, employment opportunities, pay, job quality, and access to benefits, rights, and career

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progression. A 2020 analysis of the World Bank's Women, Business, and the Law (WBL) study examined the effectiveness of legal frameworks in promoting gender equality in the workplace across various countries (Malinga, 2024).

In response to these challenges, South Africa enacted the Promotion of Equality and Prevention of Unfair Discrimination Act 52 of 2002, which aims to accelerate gender equality in the workplace. This Act addresses issues of gender-based discrimination and harassment, promotes equality, and safeguards human rights. Its additional objectives include advancing gender equality, fostering unity in diversity, and supporting the country's transition to a democratic society. Kok et al. (2016) contend that the Act addresses the injustices and oppression resulting from apartheid by prohibiting unfair discrimination and promoting equity. However, despite the presence of such legal frameworks, gender inequality persists, particularly in industries like construction, where women remain vastly underrepresented. According to Statistics South Africa, women comprised only 9% of the construction workforce as of the second quarter of 2018 (Stats SA, 2018). In response, the South African government has introduced initiatives such as appointing women to construction committees and developing targeted recruitment programs. However, these efforts have yet to improve female representation in the industry significantly.

This research aims to examine the impact and manifestations of gender inequality within the KwaZulu-Natal construction industry, focusing on the factors contributing to disparities in career advancement, pay, and employment opportunities. Despite advancements in female education and skills development, women in KwaZulu-Natal's construction sector continue to experience discrimination in recruitment, promotion, and remuneration (Mkhize & Ngwenya, 2021). Women have proven their competence in various traditionally male-dominated trades. Yet, they persistently face discrimination, even when performing supervisory roles under challenging conditions or operating heavy machinery. This study is motivated by the absence of localised research addressing the specific dynamics of KwaZulu-Natal, which are frequently overlooked in broader discussions of gender inequality. Understanding these regional dynamics is essential for developing targeted interventions sensitive to the area's unique cultural, social, and economic context, a gap that this study intends to fill.

2. Problem statement

Despite the implementation of legislative measures aimed at eradicating discrimination and promoting equality, gender disparity in the workplace remains a significant issue in South Africa (Musetsho et al., 2021; Ndzabela & Lukman, 2023). Research across various sectors, including academia (Shober, 2014), mining, and the automotive industry (Lloyd & Mey, 2007), reveals persistent gaps in hiring opportunities, career advancement, and leadership roles. Women continue to face challenges such as bias, stereotypes, and sexual harassment (Zhu, 2022), along with discrimination often linked to their roles as mothers (Shober, 2014). Sinden (2017) highlights that women remain disproportionately underrepresented in senior management roles predominantly held by men across all industries (Khuzwayo, 2016). Proposed solutions to address these disparities include empowering women, offering flexible work arrangements, raising awareness about gender discrimination (Lloyd & Mey, 2007), and using education to promote equality (Zhu, 2022). Despite some advancements, the slow pace of progress underscores the ongoing need for sustained efforts to eliminate gender inequality in South African workplaces (Musetsho et al., 2021; Sinden, 2017).

Gender inequality in the workplace continues to be a global issue, driven by pay disparities, limited opportunities for career advancement, and a lack of female representation in leadership positions (Du, 2024). Contributing factors include deeply ingrained gender stereotypes, intersectional marginalisation, and gendered organisational structures (Du, 2024). Occupational segregation remains a significant determinant of the gender pay gap, particularly in specific industries, despite improvements in educational access for women (Zhu, 2024). Other challenges women face include the "motherhood penalty", perceptions of diminished competence, and balancing

work with family responsibilities (Ozer, 2023). Addressing these inequalities requires a comprehensive approach, including policies that promote work-life balance, diversity initiatives, and campaigns to combat gender bias. Achieving gender equality in the workplace necessitates empowering women, increasing awareness, and leveraging legal and educational reforms (Zhu, 2024). Numerous initiatives, many focused explicitly on women, have emerged in response to the ongoing underrepresentation of women in various fields (Lambert et al., 2023).

While prescriptive advice such as "lean in" (Sandberg, 2015), "push back" (Rezvani, 2024), "dare to lead" (Brown, 2018), and "be a girl boss" (Amoruso, 2015) is intended to empower women and boost their self-esteem, it risks implying that women themselves are to blame for the challenges they face (Kim et al., 2018). Women remain underrepresented in many areas, including fields such as surgery, where they make up less than 20% of the workforce; research and development, where they account for less than 30% (UIS, 2019); military personnel, at just 7% (NATO, 2019); and senior roles in financial services, where they represent fewer than 20% of leaders (Ryan & Morgenroth, 2024). Women are also underrepresented in influential and powerful positions, such as in political leadership (UN Women, 2022), senior corporate roles, and on corporate boards (Ryan & Morgenroth, 2024). This ongoing underrepresentation not only hinders the career advancement of individual women and impedes progress toward gender equality but also negatively impacts society. The lack of female leaders skews the prioritisation, handling, and resolution of key societal issues (Perez, 2019; Little et al., 2001).

3. Methodology

This review utilised a qualitative source investigating gender inequality in the workplace in Kwa-Zulu Natal Province. This review paper followed a rigorous system that involved peer review of journals and reports from the past 4 years. Several databases, such as Google Scholar, Spring Link, Science Direct and Academic Edu, were utilised to find relevant qualitative studies using a Document matrix to find appropriate keywords, such as "gender", "inequality", and "workplace". The authors found thousands of articles and studies, which were narrowed down by language, subject area, study area, year of publication, and open access. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses framework guided the study selection process. The inclusion criteria were qualitative studies that investigated gender inequality in the workplace. However, studies examining similar experiences were also included. A total of 55 articles were utilised after careful consideration and screening. The screening procedure recorded by the PRISMA 2020 flow diagram below (see Table 1 and Figure 1) was used as a guide in this study. The screening process narrowed the data down to three themes, which you will discuss below.

Table 1. Document Matrix

Block 1	Block 2	Block 3
Gender	Inequality	Workplace
Male/ Female	Imbalance	Organisation
Sexuality	Bias	Enterprise
	Discrimination	
	Unfairness	

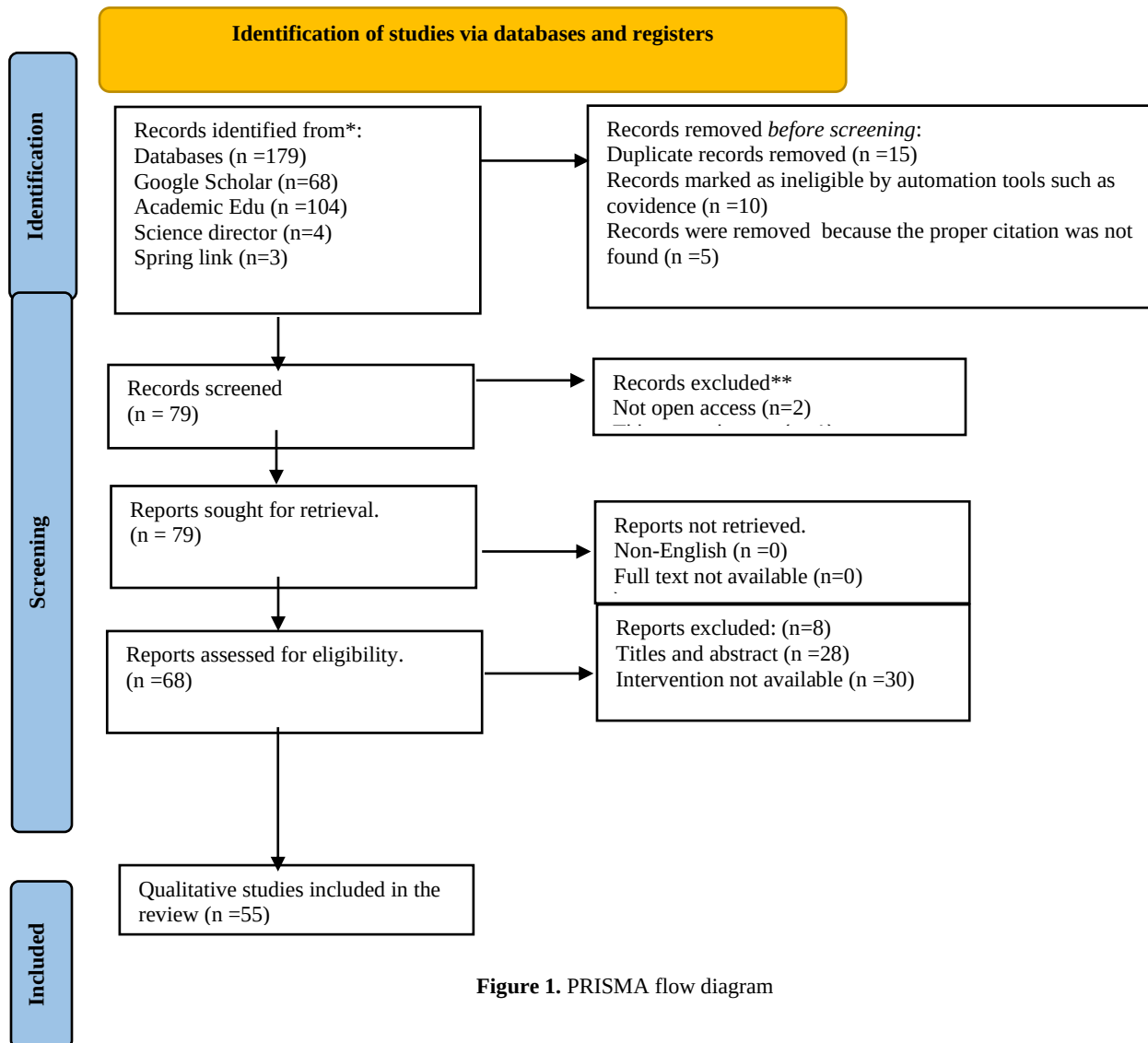


Figure 1. PRISMA flow diagram

Theoretical framework. This research paper employs feminist theory as its theoretical framework to examine gender inequalities in South Africa, advocating for the equal and fair treatment of both men and women. Feminist theory centers on women's experiences as key to understanding gender inequality while promoting their interests and rights (Min, 2016). It highlights how societal values often overlook gender disparities, underscoring the enduring nature of this issue (Ji et al., 2017). The theory also emphasises the importance of gender politics and power dynamics in perpetuating imbalances and discrimination (Wu & Dong, 2017). By focusing on the detrimental effects of gender discrimination, feminist theory aims to address systemic inequalities that undermine women's rights and opportunities (Zurndorfer, 2018).

Given these considerations, feminist theory is regarded as the most suitable lens for this research, particularly in examining the treatment of employees in workplace contexts (Liu, MacPhail & Dong, 2018). Investigating workplace gender inequality through a feminist perspective reveals the systemic barriers women face and stresses the need for broader societal change. By considering the historical context and contemporary dimensions of these inequalities, feminist theory provides a comprehensive framework for understanding and addressing women's challenges in professional settings. Furthermore, feminist theory contributes valuable insights for developing

practical solutions to workplace gender inequality. By focusing on systemic issues and advocating for meaningful change, this research aims to significantly contribute to advancing gender equity in professional environments.

4. Literature review

Women's work-life balance as gender discrimination factor in the workplace

Work-life balance (WLB) refers to achieving an appropriate equilibrium between professional responsibilities and personal life, enabling individuals to perform optimally in their careers while enjoying quality time with family and friends (Wood et al., 2020). It is a crucial aspect of contemporary life that aids individuals in managing both their professional and personal commitments (Hill & Carroll, 2014; Verma & Gautam, 2022). A balanced life contributes to employees' overall wellbeing and satisfaction (Kelliher et al., 2019), and organisations increasingly acknowledge the value of fostering work-life balance, recognising its positive impact on employee engagement (Yadav et al., 2022). However, women, in particular, encounter unique challenges in balancing their work and personal lives, often due to societal expectations that place additional roles on them, such as those of wife, mother, and homemaker (Atteh et al., 2020; Sarker et al., 2021). Responsibilities such as marriage, childcare, and household duties often hinder women's career progression, leading to greater dissatisfaction with their work-life balance than their male counterparts (Saks et al., 2022). While the traditional view of work-life balance emphasises maintaining a clear separation between work and personal life, work-life integration offers a more flexible approach, seeking harmony between both spheres (Afif, 2019).

The demand for work-life balance has grown more urgent, particularly in light of global shifts such as the COVID-19 pandemic, which reshaped workplace dynamics (Kniffin et al., 2021). In many countries, including the United States and across OECD nations, dual-earner households have become the norm, with women representing nearly half of the workforce (OECD, 2023; Schaeffer, 2024). A 2023 survey identified work-life balance as one of the top three factors influencing job satisfaction, highlighting its increasing importance to employees (Eren & Toy, 2024). Despite the rising participation of women in the workforce, they are often relegated to non-decision-making roles, particularly in male-dominated industries like manufacturing, construction, and mining, where their representation in senior positions remains disproportionately low (Gaston & Simon, 2021). Gender-based discrimination and societal norms frequently restrict women's access to higher positions, contributing to their underrepresentation in leadership roles (Enaifoghe & Idowu, 2021; Abalkhail, 2020). In South Africa, for example, women are still predominantly employed in lower-level positions, despite having equivalent qualifications, especially in sectors such as mining, where they are often assigned non-specialised roles instead of positions of authority (Kaggwa, 2020; Sinden et al., 2017).

The challenges of achieving work-life balance are not confined to South Africa but extend globally, where women face similar struggles. In Ahmedabad, India, for instance, women in the IT sector experience difficulty balancing professional responsibilities with domestic duties despite progressive workplace policies intended to improve their work-life balance (Vijayaraghavan & Martin, 2020; Rajesh & Rajini, 2022). Job satisfaction, working hours, and working conditions are key factors influencing women's ability to achieve work-life balance. Job satisfaction is vital in fostering employee loyalty and contentment (Jalaja, 2020). In public sector banks in Ahmedabad, perceptions of work-life balance initiatives significantly affect women's ability to maintain a healthy balance between work and personal life (Balamurugan & Sreeleka, 2020). These examples highlight the widespread work-life balance challenge, with women across diverse cultural contexts navigating the complexities of balancing professional and personal obligations in the face of societal expectations and workplace dynamics.

Remuneration discrepancies among genders in the workplace

Earnings disparities can arise from various factors, including education, experience, gender, race, occupation, and geographic location (Casale & Posel, 2020; Hill, 2020; Mosomi, 2019). Wage inequality has long been a persistent issue in South Africa, deeply rooted in the historical context of apartheid, which created significant

socio-economic divisions between the affluent and the impoverished. While there has been notable progress in reducing income inequality since the end of apartheid, wage inequality remains a significant challenge nationally, at regional, and local levels (Bassier & Gautham, 2024; Moyo et al., 2024). One of the main contributors to wage inequality in South Africa is the disparity in education and skills. Research by Burger and Fourie (2019) highlights the critical role of education in determining wage levels, with individuals with higher education levels earning higher wages.

Gender discrimination is another significant factor contributing to wage inequality in South Africa. Studies by Olawuyi et al. (2024) reveal that women, on average, earn less than men and are more likely to work in lower-paying sectors. This gender wage gap is partly driven by occupational segregation, where women tend to be employed in traditionally female-dominated industries, such as caregiving and domestic work, which typically offer lower wages compared to male-dominated sectors like manufacturing and mining (Statistics South Africa, 2018). Furthermore, the structure of South Africa's labour market exacerbates wage disparities, particularly within the informal sector, where women, especially Black African women, are disproportionately represented. This reinforces gender and race-based wage disparities in the formal sector (Statistics South Africa, 2018). For example, in the healthcare sector, the gender pay gap is evident among registered nurses, with male nurses generally earning more than their female counterparts (Wilson et al., 2018). The studies reviewed indicate that men typically have access to more benefits, including higher salaries and better job opportunities (Ovadia, 2022).

The gender pay gap in industries like oil, gas, and mining is further exacerbated by gender segregation, where male-dominated fields tend to offer higher-paying positions and greater opportunities for career advancement (Perks & Schulz, 2020). Addressing gender inequality in these sectors could yield broader developmental outcomes, as women could gain more influence and power, potentially narrowing the wage gap (Ovadia, 2022). However, societal norms often place women in more passive roles, while men are generally more assertive in negotiating better compensation and career progression (Maotoana et al., 2024). Additionally, women are more likely than men to leave the workforce due to family obligations, which negatively impacts their career trajectories and earnings. In contrast, men are more likely to remain in the workforce, receiving merit-based promotions and wage increases (Maotoana et al., 2024). This pattern of inequality is also reflected in international studies of nursing staff. In six studies examined, including research from the United States, the United Kingdom, and Germany, male nurses consistently earned more than their female counterparts. For instance, Jones and Gates (2004) found that male nurses in the U.S. earned 7.8% more than female nurses. Similarly, Wilson et al. (2018) reported a 10% gender pay disparity between male and female registered nurses in the U.S., while Muench et al. (2019) identified significant pay gaps across different healthcare settings. The gender pay gap is also evident in speciality areas, with surgical specialities showing the largest pay disparity, reaching up to \$24,285 (Punshon et al., 2019). These findings suggest that the gender pay gap is a national issue and a global challenge, requiring systemic changes to address its underlying causes.

Interventions that address gender inequality

Reducing the gender wage gap is particularly critical for female-headed households, which account for 42.1% of households in South Africa (Stats SA, 2022). As long as gender-based income disparities persist, individuals in female-headed households are more likely to experience poverty compared to those in male-headed households (Mosomi, 2019). This, in turn, adversely affects the wellbeing of future generations. By addressing the gender wage gap, the welfare and empowerment of women—and, by extension, their families can be significantly improved (Danquah et al., 2021). This underscores the importance of tackling gender pay disparities not only as a matter of fairness but also as a critical factor influencing broader societal wellbeing.

Organisations have a unique opportunity to lead cultural transformation efforts that challenge stereotypes and promote more inclusive norms. By cultivating workplace cultures prioritising diversity, companies can create environments where all employees, regardless of gender, feel supported and valued (Thomson et al., 2022).

Additionally, engaging in community initiatives that promote gender equality can further this transformation. Collaboration between organisations and local communities can raise awareness about the benefits of gender equality and foster a shared understanding of the need for diverse and inclusive workplaces (Thomson et al., 2022). Socioeconomic factors, such as access to education, affordable healthcare, and work-life balance policies, are pivotal in advancing gender equality (Thomson et al., 2022). Disparities in these areas disproportionately affect women, limiting their full participation in the workforce. Addressing these gaps through comprehensive legislation and workplace policies that support women—such as maternity leave, affordable childcare, and flexible work arrangements—can create a more equitable work environment (Rees et al., 2023).

Beyond structural and policy changes, organisations must focus on inclusive leadership to promote gender equality. This involves implementing mentorship programs, leadership development initiatives, and transparent promotion processes (Simmons & Yawson, 2022). Encouraging diverse representation at decision-making levels is crucial, and organisations can provide mentorship, sponsorship, and networking opportunities to support women's professional growth within their respective organisational cultures. To combat bias and discrimination, companies should implement diversity and inclusion training, foster a culture of openness and accountability, and regularly review their hiring and promotion practices (Davenport et al., 2022). Addressing gender bias requires a multifaceted approach, which includes educational campaigns, sensitisation programs, and the enforcement of anti-discrimination policies. Furthermore, organisations must continue advocating for gender equality legislation, such as paid family leave, equal pay laws, and anti-discrimination measures, to establish a legal framework that promotes equality (Hervías Parejo & Radulović, 2023).

In South Africa, despite some progress, the pace of change in addressing gender inequality remains slow, highlighting the need for continued efforts (Musetsho et al., 2021; Sinden, 2017). Effective solutions require a comprehensive strategy that combines legal reforms, diversity initiatives, and empowerment strategies (Hu, 2024). Global studies have shown that organisational culture barriers and leadership commitment to gender equality are key factors in overcoming these challenges (Andrade, 2023). Therefore, fostering cross-cultural dialogue, empowering women, and enacting supportive policies are essential to closing the gender gap (Zhu, 2022).

5. Findings and discussions

Theme 1. Women in low management level

The representation of women in leadership positions remains low in industries traditionally dominated by men, such as manufacturing, construction, mining, and quarrying. South Africa must implement a more comprehensive and targeted action plan to address this disparity and increase the number of women in managerial roles (Simon & Gaston, 2021). Research indicates that countries with higher female labour force participation tend to have more women involved in politics, highlighting the broader societal importance of gender equality (Sinden et al., 2017). In the mining sector, Kaggwa (2020) found that most women were employed in lower-level, non-specialised roles, such as "general workers," rather than in positions of authority or expertise. Even when women possess the same qualifications as their male counterparts, men are more likely to be promoted (Maotoana et al., 2024).

Women in lower management positions continue to face substantial barriers to career advancement, including limited access to mentorship, unequal promotional opportunities, and gender biases that undermine their leadership potential. These challenges are further exacerbated by the tendency to overlook women for high-profile assignments, which are critical for career progression (KPMG, 2020). Additionally, women often receive less organisational support than men, which hampers their ability to build the networks and skills required for advancing to higher management roles (McKinsey & Company, 2021). The intersection of gender and race amplifies these challenges, as women of colour face even more significant disadvantages. Despite some progress

toward gender equality, the "glass ceiling" remains a significant barrier for women in lower management, restricting their access to leadership roles. These findings emphasise the need for organisations to implement more inclusive policies, including mentorship programs, transparent promotion criteria, and leadership development initiatives, particularly for women at lower management levels.

Theme 2. Harassment

The reviewed studies indicate that men are more likely to have access to benefits such as higher-paying jobs and salaries (Ovadia et al., 2021), a disparity that is particularly evident in sectors like oil, gas, and mining, where gender segregation exacerbates gender pay inequality (Perks & Schulz, 2020). Despite some progress toward gender equality, recent research shows that women continue to earn less than their male counterparts across nearly all industries, even when controlling for factors such as experience, education, and job role (McKinsey & Company, 2021; OECD, 2020). This persistent pay gap is compounded by systemic biases, with women—especially women of colour—facing greater wage disparities due to historical underrepresentation in higher-paying fields.

Furthermore, women are more likely than men to exit and re-enter the labour force due to family obligations, often for extended periods, while men are more likely to receive continuous merit-based promotions and salary increases (Maotoana et al., 2024). Women are also less likely to negotiate their salaries, and when they do, they often face negative perceptions or penalties, exacerbating the issue. Some studies report that a few female employees do not receive overtime compensation, while many women earn wages insufficient to meet their basic needs (Kaggwa, 2020). Research also suggests that if gender inequality were reduced and the proportion of women in sectors like oil, gas, and mining increased, women could gain greater economic power through higher incomes, potentially challenging patriarchal structures and contributing to broader developmental outcomes (Ovadia et al., 2021).

While some organisations have introduced pay transparency initiatives, the gender pay gap remains significantly broad, underscoring the need for more comprehensive policies, such as equal pay audits and more vigorous enforcement of anti-discrimination laws (KPMG, 2020). Closing the gender pay gap is not only essential for advancing gender equality but also for improving organisational performance, as studies show that companies with more equitable pay structures tend to experience higher employee satisfaction and retention rates (McKinsey & Company, 2021).

Theme 3. Inequality in Remuneration Compared to Men

The studies reviewed indicate that men are more likely to have access to benefits such as higher-paying jobs and salaries (Ovadia et al., 2021). This trend is particularly prevalent in industries like oil, gas, and mining, which are characterised by gender segregation and contribute to the widening gender pay gap (Perks & Schulz, 2020). Despite some progress in achieving gender equality, recent research shows that women continue to earn less than their male counterparts across most sectors, even when factors such as experience, education, and job roles are considered (McKinsey & Company, 2021; OECD, 2020). This persistent wage disparity is further exacerbated by systemic biases, with women—particularly women of colour—experiencing even greater pay gaps due to their historical underrepresentation in higher-paying fields.

Additionally, women are more likely than men to temporarily leave and re-enter the workforce due to family obligations, often for extended periods. In contrast, men in similar roles are more likely to receive continuous merit-based promotions and salary increases (Maotoana et al., 2024). Women are also less likely to negotiate their salaries, and when they do, they are often penalised or viewed negatively, which only exacerbates the issue. Some studies also report that a small proportion of female employees do not receive overtime pay, and many women earn insufficient wages to cover their basic needs (Kaggwa, 2020).

Moreover, research suggests that reducing gender inequality and increasing women's participation in industries like oil, gas, and mining could increase women's economic empowerment through higher wages. This, in turn, could challenge patriarchal structures and contribute to broader socio-economic development (Ovadia et al., 2021). Although some organisations have implemented pay transparency initiatives, the gender pay gap remains stubbornly wide, highlighting the need for more comprehensive policies, such as equal pay audits and stricter enforcement of anti-discrimination laws (KPMG, 2020). Closing the gender pay gap is crucial not only for advancing gender equality but also for improving organisational performance, as studies show that companies with more equitable pay structures tend to experience higher employee satisfaction and retention rates (McKinsey & Company, 2021).

Conclusions

The studies highlight the ongoing challenges women face in industries dominated by men, especially in leadership roles, pay, and workplace harassment. Although progress has been made in gender equality, women are still underrepresented in senior management and face obstacles like limited access to mentorship, unequal promotion opportunities, and gender bias that hold back their career growth. Women also continue to earn less than men, partly due to factors like family responsibilities, less confident salary negotiations, and discrimination. These issues are even worse for women of colour, who face additional barriers in both pay and career advancement. To address these problems, a comprehensive approach is needed, including stronger equal pay policies, mentorship programs, clear promotion criteria, and stricter enforcement of anti-discrimination laws. Also, increasing women's presence in industries like mining, oil, and gas could help empower them economically, challenge gender-based power structures, and contribute to broader societal progress. Ultimately, closing the gender pay gap is vital not just for achieving gender equality but also for improving company performance, as businesses with fairer pay practices tend to have higher employee satisfaction and retention.

Recommendations

To guarantee a secure work environment, the researchers will suggest that policymakers should reinforce laws and policies that penalise employees who sexually harass their colleagues. Furthermore, the researchers recommend that the state reinforce laws that safeguard women in the workplace, as it is clear that gender discrimination persists in these environments. Lastly, the researchers suggest that female employees, particularly those who are married, be afforded equal opportunities to occupy managerial roles without discrimination.

Limitations of the study

This investigation was restricted to a specific Kwa Zulu Natal, South Africa province. A number of constraints has impacted the research. The availability of outmoded or incomplete data was a significant issue that distorted the comprehension of current gender dynamics. The researchers could not capture the nuanced experiences of individuals affected by workplace inequalities due to the absence of primary data collection, resulting in an oversimplified perspective. Furthermore, the analysis' restricted scope also impeded the examination of intersectional factors, such as race and class. Finally, the temporal constraints of the data limited the incorporation of recent advancements in workplace policies, underscoring the necessity of additional primary research to gain a more thorough comprehension of gender inequality in the region.

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ALLEVIATION OF POVERTY THROUGH ENTREPRENEURSHIP IN SAVINGS AND CREDIT ASSOCIATIONS – STOKVELS – A CASE STUDY FROM SOUTH AFRICA

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Abstract. Women, especially widows, have always faced different forms of discrimination and financial exclusion. During the COVID-19 pandemic, most economic activities came to a standstill, resulting in a struggle for survival for widows involved in stokvel-preneurship. This study is set against the background that although studies on stokvels exist and, whilst negative impacts of the COVID-19 pandemic have been felt across the country, little is known about how widows involved in stokvel-preneurship in the Eastern Cape province went on with their stokvel activities during the COVID-19 pandemic to alleviate poverty, a gap that this study aims to address. We used a quantitative process by employing a positivist paradigm from a unique axiology, ontology, epistemology, technique, and rhetorical stance. Data were collected using questionnaires and analysed a T-independent test was employed as a data analysis tool to test the significance difference between the mean groups. Descriptive statistics were used to describe the features and summaries of the study's data set. The study found that widows could continue their stokvel businesses during the COVID-19 pandemic. The study concluded that the COVID-19 pandemic was a huge disruptor, but widows involved in this study moved on with their stokvel activities because they needed to survive.

Keywords: stokvel-preneurship; widows; poverty; inequality; discrimination

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JEL Classification: L26, L29

1. Introduction

After the Coronavirus was first reported in Wuhan, China, the WHO declared a pandemic, making staying at home mandatory to maintain social distancing (Panneer et al., 2022). As a result of the world being unprepared, the cost of responding to COVID-19 includes the closure of businesses, among others (Fairlie, 2023). The theoretical concept of necessity entrepreneurship is conceptually underdeveloped due to a lack of research (Reid et al., 2015). In no small measure, this gap can be traced to the field's disproportionate research emphasis on the high-growth and job-creating ventures of opportunity entrepreneurs, who engage in venturing by choice. We are thus connecting traditional practices on entrepreneurial processes among individuals who have become entrepreneurs out of necessity (Gaddefors & Anderson, 2019; Dencker et al., 2021; Dodd et al., 2021).

Universities have not engaged systematically to deliver theoretical knowledge about stokvels (Akonkwa et al., 2022). Thus, this research responds to the dearth of academic attention among widows who are in extreme poverty in the Global South (Anderson & Lent, 2019; Eijdenberg et al., 2019) by showcasing how stokvel-

preneurship, created out of necessity, can bring about new economic, social, institutional and cultural environments through the actions of a group of individuals such as widows.

After the coronavirus was detected and businesses came to a standstill in 2020, the challenges of coping with COVID-19 and adapting to a new lifestyle were brought about. Since little is known about the situation of widows involved in stokvel-preneurship in the Eastern Cape province, the overall purpose of this study is to analyse how widows involved in stokvel-preneurship coped with their savings club during the COVID-19 pandemic. We highlight how the COVID-19 pandemic and subsequent responses involving lockdowns and limited movement have exacerbated existing structural inequalities and vulnerabilities widows in South Africa face. Studies on stokvels exist and, whilst negative impacts of the COVID-19 pandemic have been felt across the country, little is known about how widows involved in stokvel-preneurship in the Eastern Cape province went on with their stokvel activities during the COVID-19 pandemic and how stokvels solve the issues of poverty and inequality.

2. Theoretical framework

This study is grounded on the Ujamaa theory which is based on African philosophy (Ikechukwu, 2023). The study uses the Ujamaa framework to examine how stokvels align with indigenous African philosophies and affect women socio-economically. Julius Nyerere, Tanzania's first president, popularised the Swahili term Ujamaa, meaning “familyhood” or “extended family,” according to Bangura (2018). Traditional African values like communalism and familyhood underpin Ujamaa (Sithole et al., 2021). Thus, Ujamaa embodies Nyerere's call for collective responsibility (Bangura, 2018).

The Ujamaa theory is essential to understanding women entrepreneurs' complex stokvel participation. It promotes collective responsibility, community improvement, shared resources, socioeconomic equity, and community development (Ikechukwu, 2023). Understanding how these principles apply to women's entrepreneurial activities in stokvels, which involve collective financial initiatives, is crucial. Since Ujamaa promotes resource aggregation and cooperative efforts for the benefit of all, analysing how widows involved in stokvel-preneurship coped with their savings club during the COVID-19 pandemic is compelling.

3. Review of selected literature

3.1. Conceptualising Stokvels

Stokvels, initially conceptualised as rotating savings and credit associations (ROSCAs), were explored in the conceptual works of Ardener and Geertz in the 1960s (Geertz, 1962; Ardener, 1964). With its long and often turbulent history (Redford & Verhoef, 2022), *stokvels* have long been a part of Africa's development. Some authors state that *stokvels* have been used to support economic and social activity (Biehe & Wolf, 2022). Regional and linguistic factors have a major influence on the terminology of *stokvels* (Bagire & Namagembe, 2022). *Stokvels* in multilingual South Africa are referred to as *chita* or *chitu* in Tamil or Hindi in Natal (Ardener, 1964). Other names for *stokvels* are *gooigoois*, which means 'throw' (money), *kuholisana* ('draw wages'), *mahodisana* ('pay back to each other'), *umgalelo*, and *umshayelwano* (Swanepoel, 2012).

Stokvels are a global phenomenon, existing in various forms across different cultures and economies (Lappeman et al., 2020). Calvin and Coetzee (2010) mention that the contention in defining *Stokvels* is due to a wide variety of stokvels that exist. Some are savings (Hlatshwayo, 2023), burial (Maziriri, 2024), festive, grocery, housing, and entertainment stokvels (Bophela & Khumalo, 2019).

Stokvels can be categorised into different types based on their operational frameworks. In savings *stokvels*, contributions are collected and paid out to members in a rotating manner. This model not only provides

immediate financial relief to members but also encourages disciplined saving habits (Hlatshwayo, 2023). Another model involves accumulating contributions over time, which are then paid out as a lump sum, often with accrued interest, at a specified maturity date. This approach allows members to plan for larger expenses, such as education or home purchases, thereby enhancing their financial stability (Hlatshwayo, 2023).

The flexibility and adaptability of these models make *stokvels* an attractive option for individuals who may not have access to traditional banking services. The impact of *stokvels* on financial inclusion is profound, particularly in the context of micro, small, and medium-sized enterprises (MSMEs). *Stokvels* serve as a vital source of capital for entrepreneurs who struggle to secure funding from formal financial institutions. By pooling resources, members can access larger sums of money that can be used for business ventures, thereby contributing to local economic development and job creation (Fomum & Opperman, 2023). Moreover, the informal nature of *stokvels* allows for a more personalised approach to lending and borrowing, which can be particularly beneficial for individuals with limited credit histories (Ngcobo, 2023).

This informal financial ecosystem not only supports individual members but also strengthens community ties and fosters economic resilience. The business model employed by *stokvels*, which are informal savings and credit groups predominantly found in South Africa, reflects a unique approach to financial inclusion and community support. *Stokvels* operate on principles of mutual aid and collective responsibility, allowing members to pool resources for various purposes, including savings, loans, and social events. This model is particularly significant in the context of marginalised communities, where access to formal financial services is often limited. The structure of *stokvels* can vary, but they typically involve regular contributions from members, which are then distributed according to predetermined rules, thereby fostering a sense of solidarity and community engagement (Hlatshwayo, 2023).

Depending on the reason for the formation of a *stokvel*, any member of society may participate in the *stokvel* business if they agree with the terms of reference of the *stokvel* that they want to join. Since participants in *stokvels* contribute to the survival of *stokvels*, they become shareholders of the *stokvels*, and, in a way, co-owners of the *stokvels*.

Lack of access to credit is often cited as one of the main causes of poverty in the world in general and in developing countries in particular. For the poor, money is a matter of absolute survival. Credit is often used to develop income-generating activities (IGAs), to feed, to care for themselves, to finance their children's schooling, etc. When they need to, they do not hesitate to go to pawn shops to relinquish their prized possessions for a meagre amount that contributes to keeping the poor in their precarious conditions (Ali & Siembou, 2022).

Several factors can influence savings behaviour at the individual, household, or national levels (Peprah & Redford, 2022). *Ipso facto*, extensive primary research by several authors (Adeola et al., 2022; Bagire & Namagembe, 2022; Gudeta et al., 2022; Mathuva, 2022; Onomo & Nkakleu, 2022; Verhoef & Hidden, 2022) in broad geographical regions across several African countries testifies to the sustained reliance on *stokvels* as an alternative for formal financial services. The research finds that it is incorrect to consider *stokvels* to be the exclusive preserve of 'the poor', and our research shows instead that they have emerged as a preferred vehicle for savings and wealth-building strategies also for people of more stable means, the rapidly growing African middle class as well as the higher-income strata of society.

In this context, there is evidence of persistent and extensive involvement in the efficacy of collective action through *stokvels* (Brito, 2022). *Stokvels* are fundamental to self-driven capacity-building, using informal social capital, as a path to self-empowerment and, eventually, formal financial inclusion, in line with the World Bank's Universal Financial Access 2020 goals (World Bank, 2020). *Stokvels* in Africa are typically agents of economic

growth, self-driven to address the existential phenomenon of poverty through informal community action (Redford & Verhoef, 2022).

From the outset, SG4Africa formulated the scope of the research to be '*stokvels* plus'. In other words, the consortium sought to understand *stokvels* as an integral part of a wider ecosystem of financial behaviour, financial inclusion for empowerment, wealth creation, and sustainable development. One of the main trends identified by SG4Africa as relevant to *stokvels* in the modern context is the rise of new forms of integration with formal financial services, especially micro-finance institutions (Redford & Verhoef, 2022).

The COVID-19 pandemic has significantly impacted women's economic security and livelihood, particularly in the informal sector. Women earn less, save less, and hold less secure jobs, with limited access to social protections. The pandemic has worsened pre-existing gender inequalities, particularly in the informal sector (Nkansah-Dwamena & Fevrier, 2022). The pandemic has resulted in the loss of lives, shrinking economies, overburdened healthcare sectors, unemployment and loss of benefits, unpaid work, increased domestic burdens, weaker social protections, and decreased earnings, to name a few. The pandemic has significantly reduced the livelihood and economic security of women (UN Women, 2020). Due to the stringent lockdown being declared as a public health response, the economic impact of this COVID-19 crisis has been dire, especially for the poor and the informal sector (Ajam, 2021).

3.2. *Stokvels* and the issues of poverty, unemployment, and widows

3.2.1. Poverty

Poverty refers to a lack of sufficient resources to provide the necessities of life (World Bank, 2020). Although it is a concept typically measured by income, poverty involves more than the income needed to provide a sustainable livelihood as it manifests in such things as lack of access to education and other basic services, social exclusion, discrimination, and lack of participation in decision making (United Nations (UN) 2005). Poverty reduction has increasingly become a core subject for researchers across the social sciences from economics and finance to management and entrepreneurship (Chen et al., 2017; Dollar et al., 2016; Sutter et al., 2019). This is in response to the severity of the problem of extreme poverty and the decidedly mixed results of poverty alleviation measures (Easterly, 2006). These measures include foreign aid programmes, microfinance and property rights promotion, and bottom-of-the-pyramid initiatives (Alvarez et al., 2015). These initiatives have not had much impact on extreme poverty and may have created some additional problems (Easterly, 2006).

In South Africa, poverty and inequality are often mentioned in the same breath. This ignores the over-important conceptual differences between poverty (measured by incomes at a particular threshold) and inequality (measured by gaps between groups or individuals). Poverty is analysed as an individualised metric, a person's income level, or a multidimensional index relative to an income or multidimensional poverty line (Leibbrandt & Pabon, 2021). As such, the analysis of poverty cannot necessarily explain the forces reproducing intergenerational inequality or poverty.

3.2.2. Inequality

Achieving gender equality and the empowerment of women and girls is essential. This is because women deserve to be treated equally and because empowered women can reinforce economic gains by contributing to the overall development of their families and societies (Yadav et al., 2020). The importance of women's empowerment is underscored by the Sustainable Development Goals (SDGs), particularly Goal 5, which aims to achieve gender equality and empower all women and girls (Keith et al., 2022). Societies must use all human capital optimally. Women, young and old, are part of society's human capital (Rickard, 2022). Providing women and girls with equal access to education, health care, decent work, and representation in political and economic decision-making processes will fuel sustainable economies and benefit societies and humanity at large (Demirgug-Kunt, 2018).

Despite the economic arguments for gender equality, women are among the most financially excluded segments of society. Out of the 1.7 billion unbanked adults globally (unbanked persons have no account with a financial institution or through a mobile money provider), the majority (56%) are women (Demirgüç-Kunt, 2018). The 2018 Global Gender Gap Report, which benchmarks countries on progress towards gender parity, reveals persistent gaps in the control of financial assets and in the time spent on unpaid tasks which continue to preserve economic disparities between men and women. In only 60% of countries, women have the same access to financial services as men, and women spend, on average, twice as much time on housework and other unpaid activities than men (World Economic Forum, 2018).

As revealed by Goetz and Sen Gupta (1994), on average, women make up 80% of savings group members globally. *Stokvels* appeal to women because of the low level of documentation they require for access and can be set up at a more convenient distance than most formal financial services (Johnson, 2004). As reported by Karla et al. (2017), women in *stokvels* report familiarity with handling money and independence in financial decision-making, solidarity, improved social networks and respect from the household and other community members and enhanced financial decision-making capabilities. Since enhanced economic independence often leads to the assumption that *stokvels* consistently contribute to women's empowerment, we believe that *stokvels* can provide access to basic financial services to financially excluded women through savings in small amounts, credit on flexible terms, and micro-insurance.

Stokvels have evolved from a pure methodological form of promoting financial management in the 1990s to complex multidimensional programmes accounting for health, gender, and education components. This confirms that *stokvels* offer an effective tool to reach the most excluded with an integrated package of support and services (Rickard, 2022). With various agents seeking to tap into the potential of women-led businesses for economic growth and job creation (Nguyen, 2012), *stokvels* often present an additional potential platform to support women's entrepreneurship and market engagement (Rickard, 2022).

3.2.3. Widows and their involvement in *stokvel*-preneurship

Widowhood does more than just make people sad; it changes their lives in fundamental ways. Although both widowed women and men experience lower levels of physical and psychological well-being (Bennett & Soulsby, 2012), women seem to be more vulnerable to the physical health challenges associated with widowhood (Das, 2013), as the psychological effects are further exacerbated among women related to particular social and cultural norms (Trivedi et al., 2009). Widows are vulnerable to social stigmatisation, economic vulnerability, and humanitarian injustices, especially in developing countries (Loomba Foundation, 2015).

We focus on women, and widows in particular, because they represent an extreme case of entrepreneurship out of necessity. Men, too, engage in entrepreneurship out of necessity. However, being a widow exacerbates the problems of being poor – whereby social isolation and ostracisation have resulted in various forms of isolation – geographic, economic (being far from markets), and from mainstream institutional support. Being cut off from family support and being stripped of any marital assets left these women destitute in terms of access to both social and livelihood resources. Facing the necessity of providing for themselves and their children, they had virtually no resources. Arguably, if progress is to be made in achieving the United Nations' number one Sustainable Development Goal (SDG) - 'End poverty in all its forms everywhere', learning more about entrepreneurship in contexts of necessity has a great deal of practical importance as a foundation for impactful policy and programmes.

The literature on all the case studies in Africa substantiates the observation that women constitute the core of voluntary informal *stokvels* (Verhoef & Hidden, 2022). The role of women in the rollout of *stokvels* across South Africa should not be underestimated, nor should the widely acknowledged empowerment function be performed

for its members (James, 2018; Van Wyk, 2017). In developing countries, most women are engaged in entrepreneurial activity driven by pure survival. This is out of necessity rather than opportunity due to a lack of jobs and a need for additional income (Vossenbergh, 2013). During the earlier stages of urbanisation, the start-up businesses in which many Black women invested their *stokvel* funds in micro-enterprises, included shebeens (taverns), laundry and sewing services, small grocery shops, also known as spaza shops, and dairy shops. In rural areas women operate most of the micro-enterprises, using collective savings funds for operations, such as the purchase of stock or transport of goods (Neves & Du Toit, 2013).

A recent report conducted by the Finmark Trust (2018) suggests that relationships within households improved thanks to the funding from *stokvels* members were able to support each other financially and plan together. *Stokvels* have a profound impact on the social cohesion and trust within a community.

4. Hypotheses

Our research hypotheses are:

- H_0 : COVID-19 did not influence widows' involvement in *stokvel-preneurship*.
- H_1 : COVID-19 influenced widows' involvement in *stokvel-preneurship*.
- H_0 : *Stokvels* do not solve the issues of poverty, inequality, and women's discrimination.
- H_1 : *Stokvels* solve the issues of poverty, inequality, and women's discrimination.

5. Methodology

5.1. Research paradigm

This was a non-experimental, descriptive, and correlational design, assessing reliability and validity through statistical analysis to establish a relationship between variables (Karambakuwa, 2024). The study utilised a positivist research paradigm, focusing on quantitative methods and universal laws governing human behaviour (Acharya, 2024). The rigidity and quantitative method of positivism were reflected in the use of numbers and statistics in this study (Omodan, 2024). It utilised logic, mathematical equations, statistical analysis, and a systematic approach to interpret knowledge based on empirical facts (Nyabuto & Wabwoba, 2024).

5.2. Sampling

We targeted widows who engage in project-based *stokvel-preneurship*. We selected individuals who conformed to specific criteria and possessed the characteristics of the study. We identified 10 *stokvels* from various research sites through a census sampling technique to acquire data from every member of the targeted population (Chandra, 2020; Johnson & Christensen, 2020; Quinlan et al., 2019). As a result, 50 widows were sampled for this study. The sample, aged between 40 and 55 years, had varied levels of education with little income, if any. They were all widows who had lost their husbands in the last two years, regardless of the cause of death and had contributed to their respective *stokvels* for two years.

5.3. Instrumentation

A self-administered questionnaire was used to gather data on the effects of COVID-19 on widows in *stokvel-preneurship* and the importance of *stokvels* in solving poverty, inequality, and women's discrimination. The questionnaires were actionable (Masha & Eze, 2022) and cost-effective (Batchelor et al., 2022).

5.4. Data Analysis

Data were analysed using the eight stages of data analysis proposed by Wild and Diggines (2020) whereby a T-independent test was employed as a data analysis tool to test the significance difference between the mean groups. Descriptive statistics were used to describe the features and summaries of the study's data set (e.g., variables mean, standard deviation, and frequency (Struwig & Stead, 2022)).

5.5. Ethical Considerations

Since this study was conducted by researchers in institutions of higher learning, we had to be sanctioned by the research ethics committee before the issuance of an ethical clearance certificate (Sefotho, 2024). We secured informed consent from respondents (Bartley & Hashemi, 2024) and we assured them of their confidentiality and anonymity (Fouché & Chubb, 2024).

6. Study findings

The hypotheses in this paper are empirically tested to form a basis for accepting or rejecting the *Ho*. In particular, the t-test was utilised to test the significant difference between the two means of COVID-19 disruptions and women's involvement in *stokvel-preneurship*. With the verity that the study sampled human participants, a 5% level of confidence interval was utilised indicating that only 5% of the data is expected to occur by error.

6.1. Research hypothesis one

The first research hypothesis that COVID-19 disruptions did not influence widows' involvement in *stokvel-preneurship* was empirically tested with the t-independent test via the IBM SPSS version 21. The t-test coefficient detailed in Table 1 exhibits the strength and means between the different scores.

Table 1. T- independent test

Items	Est.	T Stat.	Decision	Remarks
COVID-19 was a disruptor	0.769	2.022	Significant	Accept
We were able to do business during the COVID-19 pandemic	0.466	1.554	Significant	Accept
We were able to make a profit during the COVID-19 pandemic	0.080	0.213	Significant	Accept
We were able to maintain our partnership during the COVID-19 pandemic	0.700	2.143	Significant	Accept
We were able to sustain ourselves during the COVID-19 pandemic	0.165	0.479	Significant	Accept

Source: Prepared by the researchers

Table 1 shows the significant coefficient of the different constructs that form the hypothetical statement of the influence of COVID-19 disruptions on widows' involvement in *stokvel-preneurship*. The results indicate that all constructs are above the limit of the threshold of ($t=2.022$; $t=1.554$; $t=0.213$; $t=2.143$; and $t=0.479$, $p<0.05$). Clearly, the results explain that the COVID-19 disruptions can be used to explain widows' involvement in *Stokvel-preneurship*. Similarly, it is important to stress that the results do not only indicate that COVID-19 disruptions explain widows' involvement in *stokvel-preneurship*, but also show a highly significant influence of the COVID-19 disruptions on widows' involvement in *Stokvel-preneurship*.

6.2. Research hypothesis two

The second hypothesis that *stokvels* do not solve the issues of poverty, inequality, and women discrimination was tested with the t-independent test via the IBM SPSS version 21. The t-test coefficient detailed in Table 2 exhibits the strength and means between the different scores.

Table 2. T- independent test

Items	Est.	T Stat.	Decision	Remarks
<i>Stokvels</i> solve the issue of poverty	0.685	6.244	Significant	Accept
<i>Stokvels</i> solve the issue of inequality	0.867	13.482	Significant	Accept
<i>Stokvels</i> solve the issue of unemployment	0.494	4.044	Significant	Accept
<i>Stokvels</i> solve the issue of discrimination against women	0.774	6.028	Significant	Accept
<i>Stokvels</i> are a source of income for widows	0.884	13.871	Significant	Accept

Source: Prepared the researchers

Table 2 shows the significant coefficient of the different constructs that form the hypothetical statement of the influence of *stokvels* in solving issues of poverty, inequality, and women's discrimination. The results indicate that all constructs are above the limit of the threshold of ($t=6.244$; $t=13.482$; $t=4.044$; $t=6.028$; and $t=13.871$, $p<0.05$). Clearly, the results explain that *stokvels* influence the issues of poverty, inequality, and discrimination among window women. In addition, it is important to stress that the results do not only indicate that *stokvels* influence poverty, inequality, and discrimination, but also show a highly significant influence of *stokvels* in issues of poverty, inequality, and discrimination among window women.

7. Interpretation of findings

The primary aim of the study was to test two hypotheses: One was to test if COVID-19 influenced widows' involvement in *stokvel-preneurship*, and the other was to test if *stokvels* solve the issues of poverty, inequality, and women discrimination.

Due to COVID-19's rapid global spread, most organisations found it difficult to continue operating during these COVID-19 times since there was a decline in economic indicators (Boateng et al., 2021). The vulnerability of women who work in informal employment was greatly increased when the COVID-19 epidemic broke out in early 2020 (Webb et al., 2020). Families throughout the world were greatly impacted by the COVID-19 problem (Yanti & Fauziah, 2021). COVID-19 finally became a pandemic that influenced many facets of society, including social interactions, human health, and the economy (Boateng et al., 2021).

Poverty reduction has become a central focus for social science researchers in a variety of fields, including economics, finance, management, and entrepreneurship (Sutter et al., 2019). Poverty not only hurts mental health but also lowers social status, trauma, violence, crime risk, and poor physical health (Baranyi et al., 2021; Hyde et al., 2020; Machado et al., 2022). To understand how *stokvels* affect women's empowerment, one must examine the various empowerment domains and how programmes with different designs and components can produce different empowerment results (Rickard, 2022). The UNDP (2019) stresses gender equality and women and girl empowerment. Because empowered women improve family and society's well-being and women should be treated equally, economic gains can be reinforced. Women and girls' equal economic participation will fuel sustainable economies, societies, and humanity (Demirgug-Kunt, 2018).

Women are among the groups in society that are most financially excluded, even despite the economic justifications for gender equality. Women make up the majority (56%) of the 1.7 billion unbanked adults worldwide (those without an account with a financial institution or through a mobile money provider) (Demirgug-

Kunt, 2018). Women spend twice as much time as men do on housework and other unpaid activities, and only 60% of countries provide women.

Women are drawn to *stokvels* because they can be established more conveniently than most formal financial services and require less paperwork to access (Johnson, 2004). Therefore, through small-scale savings, flexible-term credit, and microinsurance, *stokvels* can give financially excluded women access to basic financial services. Women in *stokvels* report feeling more at ease with money and independent when making financial decisions. They also report feeling more united, having better social networks, receiving respect from family and neighbours, and having better financial decision-making skills (Karlan et al., 2017). Increased economic independence frequently results in the belief that *stokvels* permanently aid in the empowerment of women.

In the 1990s, *stokvels* were a strictly methodical way to promote financial management; today, they are intricate, multifaceted programmes that take gender, health, and education into account. This demonstrates that *stokvels* provide a useful instrument for reaching the most marginalised people with a comprehensive set of services and support (Rickard, 2022). *Stokvels* frequently offer an additional potential platform to support women's entrepreneurship and market engagement, as various agents look to capitalise on the potential of women-led businesses as a means of achieving economic growth and job creation (Nguyen, 2012).

Gender inequality happens in many places and for many groups of people in the general population. This is especially true when it comes to how it hurts women (Padavic et al., 2020), which in turn makes economic inequality worse (Bapuji, 2015). This means that the young women who are discriminated against don't reach their full potential, which in turn means that society does not reach its full potential. Since widows have less bargaining power in sub-Saharan African cultures, they are more likely to be mistreated. Widows comprise a large portion of the female population in all societies, but research on their plight and status in developing countries is scarce.

Widows are accused of bewitchment or sorcery for the deaths of their partners in Africa and communities (Udoh, 2023). In many countries, widowhood practices are condoned, some of which are life-threatening and psychologically harmful and drive widows and their children into extreme poverty and marginalisation (Dube, 2023). An array of harmful widowhood rites in some communities in Africa, making widows' mistreatment a clear sign of gender inequality (Owusu, 2023). Not all African societies abandon widows. Widowers and children of deceased parents observe *ukuzila*, but widowers are exempt from more difficult bereavement customs (Carton, 2003). Thus, *stokvel-preneurship* by women reduces poverty and inequality.

Conclusions

This study examines the impact of the COVID-19 pandemic on widows in *stokvel-preneurship* in the Eastern Cape province. It found that despite the pandemic being a disruptor, widows were able to continue their *stokvel* activities, make a profit, maintain their partnership, and sustain themselves. The study also found that *stokvels* can effectively address poverty, inequality, and discrimination against widows. Despite the challenges, widows continued their *stokvel* activities to survive. The study highlights the negative impacts of lockdowns and limited movement on widows in South Africa, and the need to understand how they coped with their savings club during the pandemic. The results indicate that despite the pandemic, widows in project-based *stokvel-preneurship* were able to do business, make a profit, maintain their partnership, and sustain themselves.

Recommendations

This study focused on widows in project-based *stokvel-preneurship*, revealing widespread engagement in communal action through *stokvels*. *Stokvels* are essential for self-driven capacity-building and financial inclusion, aligning with the World Bank's Universal Financial Access 2020 goals. Future research could include any type of *stokvel*. The study highlights the COVID-19 pandemic's effects on widows, *stokvel-preneurship*'s potential to address poverty, inequality, and discrimination, and the organisation of widows during the pandemic.

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