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MASTER'S THESIS

Policy Pathways for Sustainable Cooling Markets: Enabling Business Model Innovation in the Global South

submitted by

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Abstract

Cooling demand is rising rapidly in the Global South, driven by urbanisation, economic growth, and climate change. Without targeted policies, this expansion risks increasing energy use and emissions, while leaving vulnerable populations without adequate access. Business model innovations such as Cooling-as-a-Service or Energy Service Companies offer pathways to expand access, improve efficiency, and align private incentives with public sustainability goals. Their adoption, however, depends on supportive policy and institutional conditions.

This thesis investigates which policy instruments support business model innovation for sustainable cooling and how enabling conditions vary across Article 5 countries under the Montreal Protocol. First, a literature review maps instruments across governance, finance, and digitalisation. Second, indicators linked to these instruments are drawn from global datasets to approximate enabling conditions. Using clustering analysis, 98 countries are grouped into nine profiles.

The results show wide variation across countries. Some combine moderate efficiency frameworks with digital readiness, while others face systemic institutional or financial barriers. The typology offers policymakers and international organisations a tool to identify policy gaps and tailor support strategies.

1. Introduction

Cooling plays an essential role in daily life, from the safe delivery of food and vaccines to comfort and productivity in workplaces and homes (UNEP, 2023). However, rapid urbanisation processes and rising global temperatures are increasing cooling demand worldwide (IEA, 2023; UNEP, 2023), with the sharpest impacts expected in the Global South (IFC & UNEP, 2024). It is estimated that 3.5 billion people, mostly in developing countries, reside in hot climates, but only 15% have access to air conditioning (IFC & UNEP, 2024).

Furthermore, the cooling industry is a major source of emissions not only due to its energy use, but also as a result of refrigerant leakage with high global warming potential (Amath et al., 2021; UNEP, 2023). In 2022, the greenhouse gas (GHG) emissions from global cooling equipment were estimated at 4.1 billion tons of carbon dioxide equivalent (CO_2eq), out of which 64% were energy-related and 36% came from refrigerants (UNEP, 2023).

In this context, meeting the rising demand for cooling becomes a climate adaptation and mitigation challenge, and it is essential to align it with sustainable approaches. Sustainable cooling refers to the provision of cooling that is environmentally responsible, affordable, and accessible, supporting health, productivity, and resource efficiency while limiting emissions and refrigerant impacts (Peters, 2019). To achieve this, clean and efficient technologies are essential (Della Maggiora et al., 2022). These technologies are characterised by facilitating the efficient use of energy, while also adopting refrigerants with low or no global warming potential, in alignment with the Kigali Amendment to the Montreal Protocol (Della Maggiora et al., 2022). Thus, they play a crucial role in decoupling cooling from climate harm, which in turn is essential for long-term sustainability.

Building on this foundation, the literature identifies technology as a critical enabler of sustainable cooling, offering concrete pathways to reduce emissions, improve efficiency, and expand access, through smart controls, district cooling networks, and digitally enabled maintenance (Shen et al., 2024). However, as these technologies begin to scale, they also expose the limitations of the traditional cooling industry, which remains organised around equipment sales and misaligned stakeholder incentives (Della Maggiora et al., 2022).

In response to these systemic limitations, servitisation models such as Cooling-as-a-Service (CaaS) have emerged as a business model innovation that aims to realign incentives and enable the scalable delivery of sustainable cooling. Rather than selling equipment, providers retain ownership and offer cooling as a pay-per-use service, bundling financing, installation, and maintenance into a single offering. Servitisation models encourage long-term operational efficiency and shift financial and performance risk away from end-users, addressing many of the barriers identified in the traditional industry (Della Maggiora et al., 2022).

However, specific cooling business models such as CaaS have only recently entered academic discourse with the first peer-reviewed publication on the topic appearing in 2024 (Palafox-Alcantar et al., 2024). While servitisation has been explored in energy systems, particularly in heating in developed markets, its application within the cooling sector specifically remains underexplored. This is especially relevant for developing countries, where models like CaaS are emerging in response to specific contextual conditions, including the absence of legacy infrastructure, affordability constraints, and entrepreneurial experimentation (Palafox-Alcantar et al., 2024).

Realising the potential of business model innovations depends not only on technological readiness but also on supportive institutional environments (IFC & UNEP, 2024), yet policy frameworks that enable such conditions remain poorly mapped, especially in the Global South. This thesis addresses that gap by identifying and analysing policy instruments that shape and support sustainable cooling initiatives. It then identifies measurable indicators that approximate the enabling conditions linked to these instruments. Using these indicators, machine learning techniques are used to generate a typology of country profiles, highlighting structural differences that either facilitate or constrain innovation. The resulting framework aims to support policymakers and international organisations in identifying gaps, tailoring interventions, and guiding engagement.

This thesis is guided by the research question: What policy instruments enable business model innovation for sustainable cooling in the Global South? Sub-questions include: What distinct country profiles exist for sustainable cooling business model innovation in the Global South? Which policy instruments are most suitable for each profile to foster sustainable cooling business model innovation?

To address these questions, Section 2 starts by reviewing the literature on sustainable cooling and business model innovation. Subsequently, Section 3 outlines the methodological decisions that guide this study, while Section 4 is focused on presenting the policy instruments identified and clustering analysis. Section 5 depicts the typology of country profiles and discusses their policy implications. Finally, Section 6 concludes by summarising the main findings and providing a future outlook of the research.

2.Literature Review

2.1. The Current State of the Cooling Business

According to IFC and UNEP (2024), the cooling market can be divided into three distinct segments: 1) space cooling, which includes residential and non-residential uses, 2) refrigeration, also including residential and non-residential uses, and 3) mobile cooling, which encompasses passenger vehicles and refrigerated transport vehicles. Each segment involves different stakeholders with varying technical, financial, and regulatory characteristics.

On the supply side, firms evolve from startup to maturity, moving through stages of research and development (R&D), pilot testing, market adoption, and growth (IFC & UNEP, 2024). Early phases centre on prototyping and real-world testing of technologies or business models, while later phases focus on scaling and stimulating demand once the solution becomes established (IFC & UNEP, 2024). Furthermore, each stage is associated with different financing needs, with early innovators often relying on grants, subsidies, or risk capital, and mature firms requiring traditional debt and capital markets (IFC & UNEP, 2024). Particularly, IFC and UNEP (2024) highlight the specific complexity of cold chains, which involve multiple independent actors responsible for storage, transportation, and distribution, which may result in a combination of companies at different stages and with diverse financing needs.

On the demand side, stakeholders are highly heterogeneous, ranging from those who lack access to cooling altogether, to those who can afford cooling but need incentives to adopt sustainable alternatives (IFC & UNEP, 2024). The first group includes low-income households, smallholder farmers, and micro or small enterprises with limited access to finance (IFC & UNEP, 2024). The second group, comprising high-income households, well-capitalised small and medium-sized enterprises (SMEs), and large firms, primarily requires affordable debt-based financing solutions that justify upgrading to sustainable cooling technologies (IFC & UNEP, 2024).

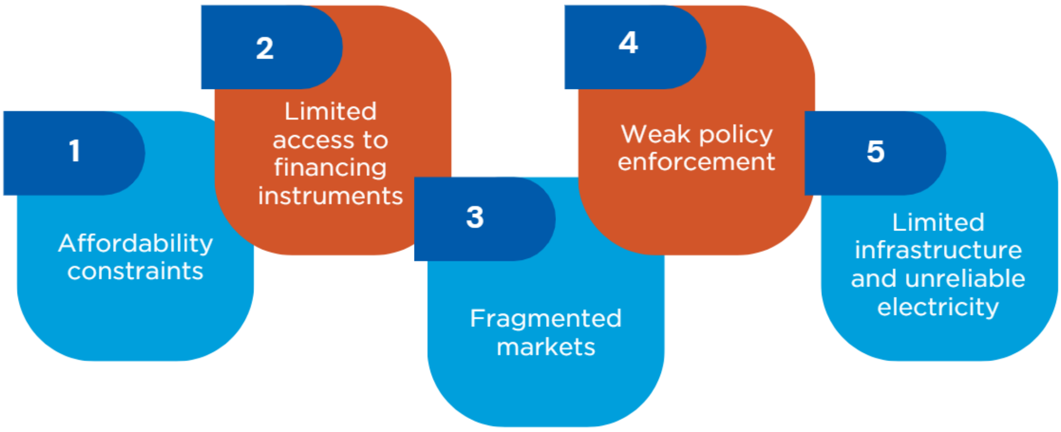
Della Maggiora et al. (2022) point out important differences between supply and demand, by outlining that the predominant cooling business model forces suppliers to prioritise short-term sales and production volume, while end users are mostly focused on reducing the electricity cost associated with the use of cooling equipment. Moreover, in some cases, the user responsible for paying electricity and maintenance costs is not the same as the one making capital investment decisions, which further generates a misalignment between stakeholders (Della Maggiora et al., 2022; IFC & UNEP, 2024). As a result, traditional models offer little incentive for manufacturers and capital owners to invest in energy-efficient and low-emission technologies since operational and maintenance costs fall on the end user, and no single actor brings together the responsibility and incentives to optimise long-term performance (Della Maggiora et al., 2022; IFC & UNEP, 2024).

These misalignments are critical in the context of sustainable cooling. While new and efficient technologies are central to the transition, their adoption is constrained by the dynamics of existing business models. For instance, customers are deterred from investing in energy-efficient systems because the financial benefits from lower energy consumption materialise over time, and firms often have competing investment priorities, which is why spending in energy-efficient cooling technologies is deprioritised since it is seen as an expenditure outside of core operations (Della Maggiora et al., 2022; IFC & UNEP, 2024).

Furthermore, emerging technologies are perceived as risky, and when the expected energy savings do not clearly outweigh that risk, the investment is seen as unjustified (Della Maggiora et al., 2022). This perception slows adoption among users and firms, who tend to favour safer, more familiar options over potentially more efficient but less proven alternatives (Della Maggiora et al., 2022).

In addition to the above, cooling markets in the Global South face deeper systemic barriers that prevent them from transitioning to more sustainable approaches. These include weak regulatory enforcement, poor infrastructure and unreliable electricity access, and a lack of standardised market data (IFC & UNEP, 2024). Such constraints undermine investor confidence and hinder capital mobilisation (IFC & UNEP, 2024). Therefore, the barriers to scaling sustainable cooling are not merely technological or financial but also relate to structural and institutional aspects.

Figure 1. Summary of Barriers for Sustainable Cooling Adoption



Source: Own elaboration based on reviewed literature.

2.2. BMI4Cool: Business Model Innovation for Sustainable Cooling

As described in the previous section, the implementation of sustainable cooling technologies in developing countries is hindered by entrenched financial, technical, and institutional barriers. In response, innovative business and financing models have emerged, with UNEP and IFC (2024) highlighting the need for adaptive mechanisms tailored to the heterogeneous needs of consumers and providers across diverse markets.

In management literature, business models are understood as the configuration through which a firm articulates its value proposition, value creation and delivery system, and value capture mechanism (Bocken et al., 2014; Foss & Saebi, 2017). They define how a company creates value for customers, how it organizes the necessary partnerships and internal operations to deliver this value, and how it generates revenue (Bocken et al., 2014; Foss & Saebi, 2017). However, business model innovation (BMI) refers to changes in how the firm traditionally operates and captures value, thus extending beyond products and processes since it involves changing “the way you do business”, rather than “what you do” (Bocken et al., 2014; Foss & Saebi, 2017).

BMI is increasingly recognised as a necessary response to dynamic settings and technological disruption, especially when existing business models no longer align with their context, requiring deliberate and nontrivial changes to key elements or their interrelations (Foss & Saebi, 2017). Moreover, Bocken et al. (2014) analyse BMI in the context of sustainability and argue that the challenges associated with it demand a deeper reconfiguration of business logics. They argue that while eco-efficiency and corporate social responsibility have shaped much of the current industrial sustainability agenda, “they are insufficient in themselves to deliver the holistic changes necessary to achieve long-term social and environmental sustainability” (p. 42). This view positions BMI as a strategic tool to address sustainability issues that conventional approaches cannot resolve. Palafox-Alcantar et al. (2024) make this link explicit in the context of sustainable cooling, noting that delivering sustainable cooling through BMI remains an underutilised yet essential opportunity.

One prominent example of BMI is servitisation, which offers a unique opportunity to transform traditional business operations within the cooling industry. By shifting from a product-centric business logic to a service-centric approach, servitisation enables suppliers and manufacturers to offer value through the use of their services, rather than through the purchase of their product or service-hours, assuming greater responsibility for the overall value-creating process (Kowalkowski et al., 2017). As such, the revenue mechanism of a service-centric model relies on the outputs of customer value-creating processes, such as achieving expected performance levels (Kowalkowski et al., 2017).

The rise of servitisation is increasingly evident across global economies, particularly among developed countries (Jankiewicz & Szulc, 2024). In this regard, Jankiewicz and Szulc (2024) acknowledge that this model has gained traction due to technological development, which has enabled firms to offer advanced service solutions that contribute to improved energy efficiency. Similarly, Singh et al. (2022) and Filosa et al. (2025) note that in recent years servitisation has been closely linked to digitalisation, as it relies on digital tools such as Internet of Things (IoT), sensors, low-code platforms, cloud computing, Artificial Intelligence (AI) and digital twins, among others, to enable the monetisation of data, automated billing, real-time monitoring, and data analytics. Particularly, Singh et al. (2022) highlight the emergence of different models within the energy sector, such as Heating-as-a-Service (HaaS), Flexibility-as-a-Service (FaaS), Microgrid-as-a-Service (MaaS), among others, which can be grouped in an archetypal category named X-as-a-Service (XaaS).

In the specific case of sustainable cooling, UNEP & IFC (2024) introduce a range of innovative business models aimed at overcoming affordability and financing barriers for its adoption. These models are organised around two main challenges: affordability for consumers and financial viability for providers. On the demand side, proposed mechanisms include Pay-As-You-Go (PAYGo), which allows users to make small incremental payments; On-Bill Financing and On-Wage Financing, which integrate repayment into utility bills or salaries; and dealer financing or leasing arrangements, which spread costs over time. On the provider side, the literature mentions CaaS, a servitisation model where users pay for delivered cooling rather than equipment ownership, and Energy Service Companies (ESCOs), which offer performance-based contracts that recover investment from energy savings. These approaches are meant to improve access to efficient cooling while mitigating capital expenditure and performance risk (IFC & UNEP, 2024).

In contrast, financing instruments refer to the specific financial tools and mechanisms used to deploy capital in support of these business models. UNEP and IFC (2024) describe financing instruments as tools such as green bonds, equity or debt investments, revolving funds, and public-private partnerships, which are used to directly finance equipment purchases, provide working capital, fund programme design and implementation, or de-risk investments. These instruments are intended to support the implementation and scaling of innovative sustainable cooling solutions, particularly in contexts where affordability or access to capital present barriers to adoption (IFC & UNEP, 2024). In this regard, IFC and UNEP (2024) highlight that innovative business models for sustainable cooling are only viable if the appropriate financing mechanisms are widely available.

However, while UNEP & IFC refer to these arrangements as business models, not all conform to the definition commonly used in management literature. As defined by Foss and Saebi (2017) and Bocken et al. (2014), a business model describes a firm's logic for value creation, delivery, and capture, including the structure of stakeholder relationships and revenue generation. Within this framework, models such as CaaS, PAYGo, ESCOs, and contract energy management clearly qualify as business models, as they entail a reconfiguration of how value is exchanged and monetised between firms and users. In contrast, mechanisms like On-Bill or On-Wage Financing, though effective in overcoming affordability barriers, function more as payment mechanisms than as firm-level business models.

In sustainability transitions, the literature identifies servitisation, performance-based contracting, and inclusive access models as central to BMI. Bocken et al. (2014) emphasise that sustainable business models must reconfigure stakeholder relationships and value propositions to reduce environmental and social harm. Servitisation models like CaaS exemplify this by incentivising long-term efficiency, shifting lifecycle responsibility to providers, and reducing the pressure for asset ownership. Likewise, ESCO models internalise environmental performance by making provider revenue contingent on delivered energy savings. These models embody the core logic of sustainability-oriented BMI: aligning financial and environmental outcomes through structural innovation. PAYGo, on the other hand, occupies a more ambiguous position. According to Foss and Saebi (2017), BMI requires deliberate and non-trivial changes to the architecture of value creation and capture. On its own, PAYGo may function merely as a payment mechanism. However, as Palafox-Alcantar et al. (2024) suggest, when PAYGo is integrated into a firm's value proposition and delivery system, especially through digital platforms that enable access, monitoring, and risk-sharing, it can become part of a broader inclusive service model. In such cases, PAYGo may contribute to business model innovation by enabling access to underserved populations and reshaping how value is created and distributed.

Overall, BMI provides a crucial guide to sustainable cooling, not only by addressing current market failures but by leveraging the transformative potential of digital technologies. By incorporating digital infrastructure into value creation and service delivery, businesses can deliver more inclusive, scalable, and efficient cooling solutions.

2.2.1. BMI4Cool in the Global South

Recent research highlights critical differences in how BMI emerges and scales across developed and developing countries. Jankiewicz and Szulc (2024) demonstrate that, while servitisation significantly contributes to energy sustainability in both contexts, its presence is stronger in developed economies. The authors show that the intensity of servitisation tends to increase with the level of economic development, as more developed countries exhibit a stronger focus on the service sector. They argue that this is evidenced in the growing share of services in GDP, signalling a structural shift from traditional industrial or agricultural models toward service-oriented economies. Jankiewicz and Szulc (2024) argue that this is attributed to more favourable structural conditions, such as stable capital markets, mature infrastructure, and coherent regulatory frameworks that facilitate long-term service contracts. In contrast, the authors highlight that developing countries often face institutional and technical limitations that slow the diffusion of servitisation models, thus advocating for governments to introduce regulations that expand the service sector.

In the specific case of sustainable cooling, weak regulatory enforcement, limited institutional capacity, fragmented procurement practices, and high perceived investment risk are pointed out as major barriers in developing countries (Abramskiehn & Richmond, 2019; Della Maggiora et al., 2022; IFC & UNEP, 2024). While some policies and standards exist, such as those for energy efficiency, low-GWP refrigerants, or building codes, they are often poorly enforced, making it difficult to establish environments that are supportive of innovative service-based models (IFC & UNEP, 2024).

Additionally, public and private procurement practices also shape the viability of sustainable cooling business models. For instance, while bulk procurement in the public sector is seen as a mechanism to lower technology costs (IFC & UNEP, 2024), prevailing procurement preferences in government agencies continue to favour equipment ownership (Palafox-Alcantar et al., 2024) and low-cost expenditures, rather than lifecycle value (Abramskiehn & Richmond, 2019), all of which limits the adoption of service-based models. In this regard, Abramskiehn and Richmond (2019) note that traditional procurement practices are typically not designed to accommodate innovations that alter cash flow structures or operational responsibilities, thus creating a structural misalignment between how goods and services are purchased and how servitisation models function.

Despite the abovementioned challenges, it is in these developing contexts that some of the most relevant cooling innovations are emerging, driven by local entrepreneurs and donor-supported pilots (Palafox-Alcantar et al., 2024). For instance, CaaS has emerged in developing countries primarily in commercial and agricultural applications, particularly cold chains (Palafox-Alcantar et al., 2024). Its diffusion reflects a pluralistic pattern of innovation leadership rooted in the specific needs, constraints, and entrepreneurial strategies of developing economies (Palafox-Alcantar et al., 2024).

An important contribution of Palafox-Alcantar et al. (2024) is the argument that CaaS is not simply a transferred model from Global North energy transitions but rather a context-specific innovation gaining traction in the Global South. The study highlights that many of the most prominent cooling innovators originate in developing countries, where the absence of legacy cooling infrastructure allows for the direct leap to service-based delivery models. This marks a departure from the servitisation of heating systems in North America and Europe, which are typically layered onto existing infrastructure and focused on the residential sector (Palafox-Alcantar et al., 2024). Recognising this contrast is critical to avoid analytical frameworks that are overly centred on developed country experiences (Palafox-Alcantar et al., 2024).

2.2.2. Developing Markets: An Opportunity

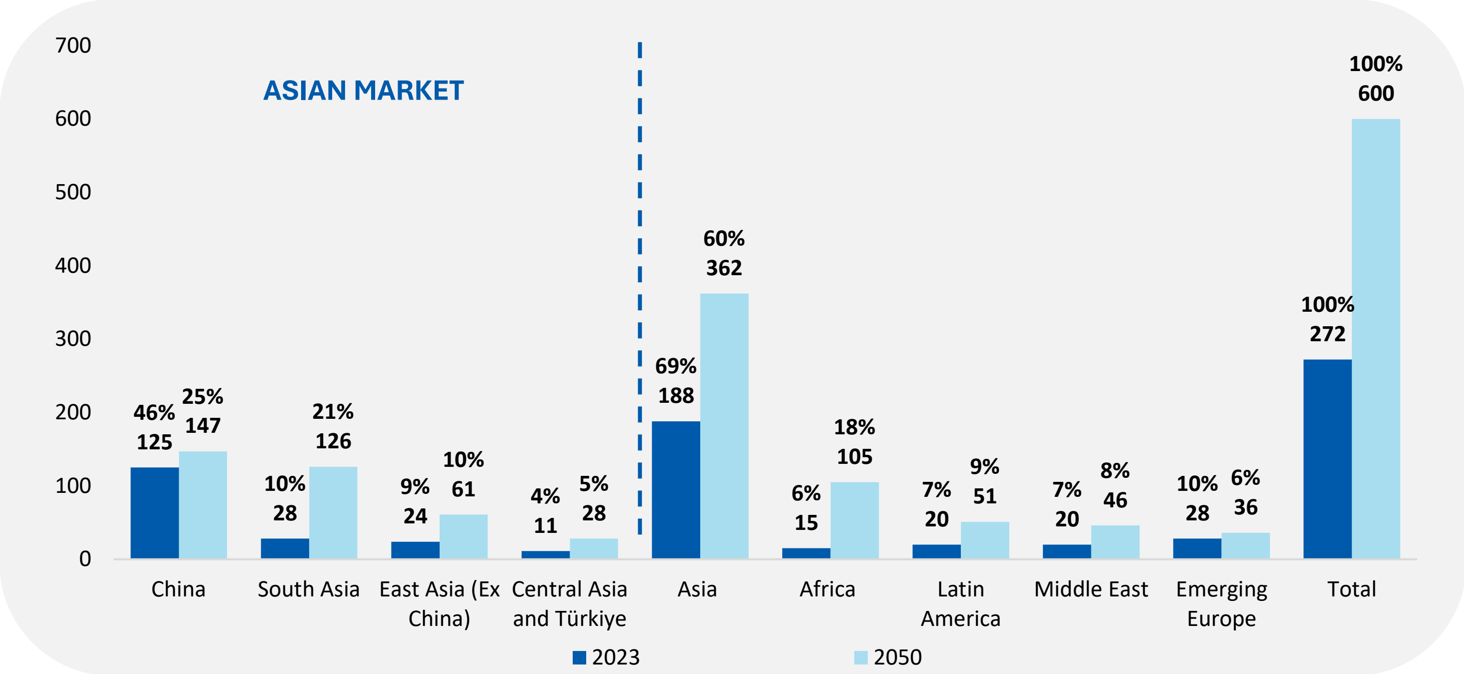
Estimates from IFC and UNEP (2024) show that in 2023, the active cooling market in developing economies was valued at USD 272 billion, representing 43% of the global total. This market is composed of three main segments: space cooling, refrigeration, and mobile cooling. Space cooling was the largest, accounting for USD 129 billion, with approximately 61% attributed to commercial and industrial uses and 39% to residential use. Refrigeration followed at USD 96 billion, driven primarily by non-residential applications, which made up about 67% of the segment, while household refrigeration accounted for the remaining 33%. Mobile cooling reached USD 47 billion, with passenger vehicles dominating the segment at 94% of the total.

Figure 2 compares cooling markets by regions between 2023 and 2050, highlighting Asia's dominant position. In 2023, this market was driven primarily by China, which represented 46% of the global market, characterised by its rapid urbanisation, rising incomes, and high cooling demand. In contrast, Africa accounted 6% of the market, attributed to lower per capita income and limited access to cooling. Emerging Europe, Latin America, and the Middle East each represented between 7% and 10%, shaped by varying combinations of economic capacity and climate conditions.

Looking ahead to 2050, IFC & UNEP (2024) project that the active cooling market in developing economies will grow to USD 600 billion. Under this baseline scenario, the share of developing countries in the global cooling market is expected to rise to 59%, with growth mostly pronounced in Africa and South Asia due to increasing population and economic development. Specifically, Africa's market is projected to increase sixfold, raising its global share from 6 to 18%. South Asia's market is expected to more than quadruple, increasing its share from 10% to 21%. In contrast, East Asia's share, including China, will decline from 55 to 35%, with China's market stabilising around USD 147 billion.

However, it should be noted that the baseline scenario used for these projections assumes a limited use of passive cooling strategies and only moderate cooling equipment improvement. Combining high-efficiency technologies with increased adoption of passive strategies could reduce electricity consumption for cooling in developing countries by 42% and lower total emissions by nearly 60% by 2050 (IFC & UNEP, 2024). This advanced scenario would enable consumers to realize cumulative net savings of approximately USD 1.8 trillion between 2025 and 2050 through reduced electricity use, even after accounting for the higher cost of equipment (IFC & UNEP, 2024). Additionally, this technology-driven scenario would reduce the need for new power infrastructure, generating a further USD 1.8 trillion in avoided power sector investment over the same period, primarily through reductions in peak electricity demand (IFC & UNEP, 2024).

Figure 2. Cooling Market Size in Developing Regions 2023-2050 (USD Billions)



Note: Percentages above each bar represent the region's share of the global total in that year.

Source: Own elaboration based on IFC & UNEP (2024).

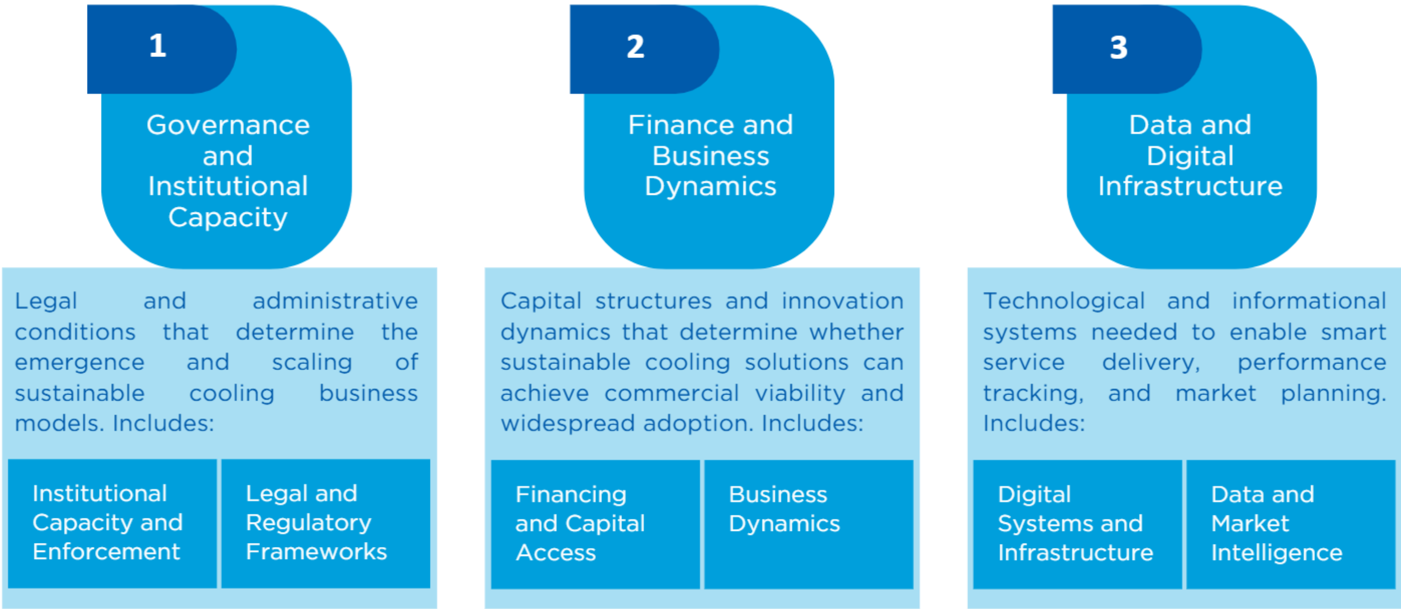
For developing countries facing rapid urbanisation and strained grid systems, these combined improvements represent a critical opportunity to reduce long-term energy costs and emissions while expanding access to sustainable cooling.

2.3. Dimensions of BMI4Cool

The literature reviewed highlights critical linkages between business model innovation and sustainable cooling. However, to systematically assess how enabling conditions vary across developing countries and shape the viability of innovative cooling businesses, this thesis introduces BMI for sustainable cooling (BMI4Cool) as an analytical framework. BMI4Cool captures innovations that incorporate digital infrastructure into value creation and service delivery to enable more inclusive, scalable, and efficient cooling solutions.

As illustrated in Figure 3, the framework is organized around three interrelated dimensions: Governance and Institutional Capacity, Finance and Business Dynamics, and Data and Digital Infrastructure. These dimensions emerged from the reviewed literature and capture the structural, institutional, and technological factors that influence the feasibility and scalability of BMI4Cool in the Global South.

Figure 3. Dimensions of BMI4Cool



Source: Own elaboration.

3. Research Methods and Data

This thesis adopts qualitative and quantitative methodologies with the goal of identifying relevant policy initiatives aimed at enabling BMI4Cool in developing countries. The main research question guiding this work is:

- *What policy instruments enable business model innovation for sustainable cooling in the Global South?*

Sub-questions derived from the above include:

- *What distinct country profiles exist for business model innovation for sustainable cooling in the Global South?*
- *Which policy instruments are most suitable for each profile to foster business model innovation?*

Phase 1: Systematic Literature Review

This phase establishes the conceptual foundation of the study by synthesising evidence across disciplines and identifying the full spectrum of policy tools relevant to enabling innovation in cooling markets. To achieve this, this study employs a Systematic Literature Review (SLR) to identify and structure the key policy instruments relevant to enable BMI4Cool in developing countries. The approach involves clearly defined inclusion criteria and structured procedures for search and screening, which help reduce bias and ensure reliability of findings. The search was structured according to the three dimensions that emerged from the initial literature review, outlined in Section 2.4: 1) Governance and Institutional Capacity, 2) Finance and Business Dynamics, and 3) Data and Digital Infrastructure.

The resulting evidence base provides both the theoretical grounding and the input for the mapping and clustering phases that follow.

Phase 2: Policy Instruments Mapping

The analytical approach adopted in this study draws on the instrument-based perspective outlined by Capano and Howlett (2020), who emphasise that policy effectiveness is shaped not only by political will or institutional arrangements but also by the specific tools governments use to translate goals into action. These tools are called policy instruments, which are understood as embedded components of governance that reflect ideational paradigms, influence actor behaviour, and shape policy outcomes. The authors argue that studying policy through its instruments provides a structured lens for understanding variation in government action.

Building on this approach, this phase is dedicated to mapping instruments relevant to BMI4Cool in the Global South. The goal is to systematically organise and interpret policy instruments discussed in the literature identified during Phase 1. The resulting inventory is not intended as an exhaustive checklist but as a structured framework to highlight institutional strengths and weaknesses, offering international organisations and policymakers a basis for assessing support strategies.

Phase 3: Clustering

The final phase translates the qualitative mapping of policy instruments into measurable variables, enabling a systematic comparison of institutional environments across countries. For such purposes, secondary indicators are identified to be used as proxies of a country's institutional capacity to implement the instruments identified in Phase 2. These indicators are drawn from global datasets and selected based on their conceptual alignment with the enabling conditions needed for effective instrument deployment.

The data constructed with these indicators is then processed using clustering techniques to construct a typology of countries, grouped according to shared institutional and structural profiles. This technique was chosen since it enables uncovering patterns of similarity among countries, thus revealing how different combinations of institutional and financial capacities shape the potential for business model innovation.

The countries analysed were the 147 countries listed in the Montreal Protocol's Article 5. The Montreal Protocol is particularly relevant in the context of sustainable cooling, as it governs the global phase-down of HFCs through the Kigali Amendment, which is an effort closely linked to improving the efficiency and climate impact of cooling technologies. Restricting the sample to Article 5 countries focuses the analysis on contexts where both the demand for sustainable cooling and the need for enabling policy support are most critical.

The resulting clusters do not measure readiness in a normative sense but highlight distinct enabling environments that influence how policies can support the emergence of BMI4Cool. This typology provides an analytical framework for interpreting national differences, identifying policy gaps, and informing context-specific strategies for international support and capacity-building.

Figure 4. Research Phases Summary

Source: Own elaboration.

Data Collection

To identify relevant literature, a targeted search was conducted across academic databases, including Scopus, Web of Science, and ProQuest. This process was grounded in the literature reviewed in Section 2, which informed keyword selection based on thematic patterns observed across sources. In addition to formal academic databases, Google Scholar was used to identify relevant grey literature, including technical reports, policy briefs, and working papers. This approach acknowledges that certain high-value publications, particularly from international organisations, public agencies, or think tanks, are not consistently indexed in traditional bibliographic databases.

Priority was given to sources that addressed cooling policy frameworks, financing mechanisms, and digital infrastructure conditions in developing countries, particularly where these factors were shown to influence the emergence or expansion of sustainable cooling business models. Studies with a narrowly technical or engineering focus were excluded unless they explicitly engaged with structural enablers of market development. The final literature set includes open-access, peer-reviewed articles, policy reports, and working papers published in English since 2020. For a detailed depiction of the article retrieval and keyword selection refer to Appendix II.

The dataset used for the clustering analysis was compiled using indicators from reputable sources such as the World Bank and IMF, with priority given to data from 2023 and 2024.

4. Results

4.1. Policy Instruments Mapping

4.1.1. Introduction to Policy Instruments

Policy instruments are the concrete tools and techniques that enable governments to generate, evaluate, and implement policy options to target specific problems (Capano & Howlett, 2020). Far from being neutral administrative tools, they embody particular forms of state intervention and are embedded in broader institutional, political, and ideational contexts (Capano & Howlett, 2020; Howlett, 2014). As Howlett and Rayner (2007) explain, these instruments can be understood as mechanisms by which governments mobilise or limit resources, whether informational, authoritative, financial, or organisational, to influence behaviours and guide outcomes. They are therefore better conceived as governance tools whose selection reflects not only technical judgments but also political and institutional decisions.

Rogge and Reichardt (2016) explore the concept of policy instruments within the domain of sustainability transitions, with a particular focus on innovation and energy policy. Their analysis distinguishes between instruments designed to stimulate technological development through supply-side measures, referred to as technology-push instruments, and those intended to generate demand for new technologies, known as demand-pull instruments. They emphasise that these instruments contribute to different phases of the innovation process and must be assessed based on their design features, target groups, and alignment with policy objectives. Importantly, Rogge and Reichardt (2016) argue that instruments should not be examined in isolation but as part of broader policy mixes, whose internal coherence and consistency significantly influence their effectiveness in guiding systemic change.

A policy mix refers to the full set of instruments applied within a specific domain, including their functions, interactions, and temporal dimensions (Rogge & Reichardt, 2016). Rather than focusing on the accumulation of tools, this perspective stresses the importance of consistency among instruments, coherence with broader objectives, and adaptability to evolving conditions. Howlett and Rayner (2007) highlight that policy mixes often result from historical layering and path dependency, which can produce inconsistencies and implementation challenges if not explicitly addressed.

Taking the dimensions identified in Section 2 as a foundation, the following analysis adopts this instrument-based perspective to describe policy initiatives that support BMI4Cool in developing countries. These initiatives possess different degrees of implementation but were selected based on their existent applicability in developing countries and supporting academic evidence.

4.1.2. Identified Policy Instruments

Dimension 1: Governance and Institutional Capacity

Policy instruments under this dimension serve the primary functions of addressing regulatory and institutional capacity challenges and defining the rules, procedures, and capacities through which cooling interventions are planned, regulated, and implemented.

Policy Instrument 1.1: MEPS and Labelling

Minimum Energy Performance Standards (MEPS) and energy labelling schemes are foundational policy instruments in sustainable cooling transitions (Lizana et al., 2022; Peters & Sayin, 2022). MEPS set mandatory efficiency thresholds for appliances, removing low-performing products from the market, while labelling schemes provide standardised information on product energy performance, typically through star ratings or efficiency classes (Lizana et al., 2022; Peters & Sayin, 2022).

Their relevance to sustainable cooling lies in their ability to reduce electricity demand from air conditioning systems, which are among the fastest-growing contributors to peak energy loads globally (Agarwal et al., 2024; Lizana et al., 2022; Peters & Sayin, 2022). In India, estimates show that the implementation of standards and labelling for room air conditioners could reduce electricity demand by approximately 30% by 2037, relative to a frozen technology baseline, where appliance efficiency remains fixed at current levels (Agarwal et al., 2024). In China, strengthening MEPS for room air conditioners could cut cumulative emissions by 12.8% between 2019 and 2050 while saving households and businesses around USD 380 billion (Khosla et al., 2022).

From the perspective of BMI, MEPS and labelling schemes arise as an enabling condition since they accelerate the uptake of efficient technologies. These instruments play a key role in transforming appliance markets by creating consumer demand for efficient products and pushing inefficient models out of circulation (Peters & Sayin, 2022). However, Lizana et al. (2022) caution that the current design of MEPS and related efficiency policies may unintentionally limit innovation by focusing too narrowly on a few performance metrics. They argue that such one-dimensional standards reinforce product-based models and call for a shift toward regulatory frameworks that account for occupant-centric outcomes, which support the emergence of service-based models.

Policy Instrument 1.2: Building Energy Codes and Passive Design Regulation

Building energy codes and passive design regulations constitute a critical instrument since they mandate minimum thermal performance requirements for buildings, including standards for insulation, orientation, shading, airtightness, and ventilation, among others (Lizana et al., 2022). These measures aim to reduce the thermal load on buildings, thereby minimising the energy required for space cooling and improving resilience to heat stress (Lizana et al., 2022; Peters & Sayin, 2022).

From the perspective of BMI, scholars highlight that reducing cooling demand through these instruments influences the overall economics by downsizing the required cooling systems and making more efficient solutions more feasible (Lizana et al., 2022; Mestarehi & Omar, 2025; Peters & Sayin, 2022). In this context, digital systems can significantly improve the energy performance of buildings by eliminating the unnecessary use of cooling equipment (Peters & Sayin, 2022). Integrating occupant-centric systems, such as operable windows, personal fans, cooled seats, or wearable cooling devices, could allow centralised systems to operate at higher set-point temperatures while still maintaining comfort (Lizana et al., 2022). This approach reduces the scale of installed capacity needed and supports models that deliver cooling as a service, by allowing providers to combine conventional equipment with adaptive, user-level technologies (Lizana et al., 2022).

As buildings become more digitally integrated, traditional models based on the purchase of individual appliances give way to service-based approaches that offer comprehensive energy management (Khosla et al., 2022; Marszal-Pomianowska et al., 2024).

Policy Instrument 1.3: Refrigerant Regulation

Refrigerant regulations refer to policy instruments that govern the use, handling, leakage prevention, and phase-down of high global warming potential refrigerants, particularly HFCs (Khosla et al., 2022; Peters & Sayin, 2022). These substances are used in most conventional cooling technologies and contribute directly to greenhouse gas emissions when leaked during operation, servicing, or disposal (Khosla et al., 2022; Lizana et al., 2022; Peters & Sayin, 2022).

Peters and Sayin (2022) emphasise that refrigerants, especially HFCs, are the fastest-growing source of GHG emissions globally due to increased cooling demand, warning that without intervention, cooling-related emissions could triple by 2100. Reducing leakage is described as equally critical as improving energy efficiency, since even a fully decarbonised grid would not eliminate refrigerant-related emissions (Khosla et al., 2022; Lizana et al., 2022; Peters & Sayin, 2022). Accordingly, refrigerant regulation is considered essential for meeting the goals of the Paris Agreement and the Kigali Amendment to the Montreal Protocol (Khosla et al., 2022; Lizana et al., 2022; Peters & Sayin, 2022).

While much of the literature focuses on environmental imperatives, its implications for BMI remain underexplored. Increasingly stringent refrigerant standards may, however, create synergies with service-based models (Della Maggiora et al., 2022; Peters & Sayin, 2022). Specifically, CaaS encourages the use of best available technologies and positions providers to internalise compliance responsibilities across the equipment lifecycle (Della Maggiora et al., 2022). By integrating monitoring, maintenance, and end-of-life handling into their service packages, such models could help align regulatory requirements with commercial incentives.

Policy Instrument 1.4: Cooling and Energy Planning

Cooling and energy planning refers to coordinated strategies developed at both national and sub-national levels to anticipate and manage current and future cooling needs (Khosla et al., 2022; Peters & Sayin, 2022). These strategies typically integrate energy efficiency, refrigerant transition, urban development, and infrastructure planning to align cooling demand with climate and development goals (Peters & Sayin, 2022).

At the national level, Peters and Sayin (2022) highlight the role of National Cooling Action Plans (NCAPs) in structuring cross-sectoral coordination, supporting investment alignment, and defining long-term goals. These plans help governments create the conditions necessary for deploying efficient cooling technologies and managing peak electricity demand. In 2022, 27 countries were developing holistic cooling plans in the context of the Kigali Amendment, aimed at examining and documenting methods and targets to make cooling more efficient and sustainable (Peters & Sayin, 2022). NCAPs provide the regulatory and programmatic frameworks that underpin policy instruments like MEPS, financial incentives, and digital infrastructure, all of which enable the operational viability of performance-based cooling models.

Beyond providing long-term policy direction, NCAPs can also create the enabling conditions for BMI. By signalling government commitment and aligning cross-sectoral investments, NCAPs reduce uncertainty for service-based models, which depend on predictable demand and supportive regulatory frameworks. Recent examples illustrate this potential: Cambodia's NCAP highlights mechanisms such as CaaS, on-bill financing, and bulk procurement to lower costs and expand access, while India's plan promotes market transformation measures such as bulk procurement of efficient appliances and investment in cold-chain infrastructure to support smallholder farmers (Sachar et al., 2022; UN.ESCAP et al., 2023). Scholars note that its cross-sectoral approach and demand aggregation measures help create market conditions that reduce uncertainty and open space for BMI4Cool (Sachar et al., 2022).

Policy Instrument 1.5: Performance-Based Public Procurement

Public procurement is referenced in several of the reviewed articles as a mechanism that supports the uptake of sustainable cooling technologies and services, therefore, enabling the emergence of a market for innovative solutions within this sector. Lizana et al. (2022) highlight that the dominance of product-based business models in the cooling sector is reinforced by current market structures, which include procurement practices that favour equipment sales over long-term service delivery. They emphasise the need to transition toward business models guided by service performance, which would require changes in how cooling solutions are commissioned and evaluated.

A notable example was India's EESL Super-Efficient Air Conditioning Program (ESEAP), aimed at accelerating the adoption of high-efficiency air conditioners (Singh & Gurumurthy, 2019; Stephens et al., 2022). Under this program, the Indian government committed to the bulk procurement of models that exceeded the highest available national energy performance standards to incentivize lower prices (Singh & Gurumurthy, 2019; Stephens et al., 2022). This program was implemented through the government-backed super ESCO named Energy Efficiency Services Limited (EESL), which oversaw the initiative. These mechanisms enabled the government to achieve over a 30% reduction in equipment prices through demand aggregation (Singh & Gurumurthy, 2019) .

These examples show that public procurement, when aligned with performance, efficiency, and innovation goals, can act as a device to support sustainable cooling and business model development.

Policy Instrument 1.6: Legal Recognition of Service-based Contracts

The legal recognition of service-based contractual models, such as Energy Performance Contracts (EPCs) and Energy Saving Agreements (ESAs), plays a critical role in expanding sustainable cooling markets in developing countries (Mohamad Munir et al., 2023). These instruments formalise the shift from capital-intensive asset ownership to performance-based service delivery, thereby lowering entry barriers for end-users and facilitating private sector participation in energy efficiency retrofits and clean cooling deployment (Shen et al., 2023). Service-based contracts operate on the principle of outsourcing energy services through formal agreements where payments are tied to delivered performance (Shen et al., 2023). For instance, EPCs allow ESCOs to invest in energy-saving measures and recover their investment through a share of verified savings (Shen et al., 2023).

The formalisation and legal validation of these models serve as a crucial policy instrument. They enable new business models to operate within predictable regulatory frameworks and provide assurances to service providers and investors. In turn, this encourages market entry by ESCOs, CaaS providers, and third-party investors, fostering a broader ecosystem of sustainable cooling services.

Dimension 2: Finance and Business Dynamics

The classification of instruments under this dimension is organised according to their primary function in addressing financing mechanisms and market and business dynamics that affect the adoption innovative models for sustainable cooling.

Policy Instrument 2.1: Capital Subsidies and Tax Incentives

Capital subsidies and tax incentives are widely recognised as key tools to reduce the upfront cost of high-efficiency cooling technologies, especially in developing countries where affordability constraints and capital scarcity hinder adoption (Peters & Sayin, 2022).

By lowering initial costs, these instruments can accelerate market uptake of sustainable equipment and lay the groundwork for innovative business models that depend on reliable consumer demand (Peters & Sayin, 2022).

Evidence from India highlights the potential benefits of fiscal measures to support the uptake of cooling appliances. Aggarwal and Agrawal (2022) estimate that a reduction in the Goods and Services Tax (GST) on super-efficient fans from 18% to 12-5% would reduce retail prices by 6-11%, improving affordability for consumers. The authors argue that such tax reforms would not only support immediate market uptake but also serve as a policy signal of long-term commitment to energy efficiency.

Moreover, Ablaza et al. (2021) discuss how these instruments applied in the energy sector laid the foundation for performance- and service-based models in Asia, by stimulating energy efficiency markets. For instance, fiscal incentives, capital subsidies, and income tax exemptions in China, combined with auditing requirements, contributed to the creation of a $17.6 billion ESCO market by 2018. In India, tax breaks and standardised contracting helped reach a $300 million market in that same year.

Fiscal tools can also discourage inefficient practices. Examples include import levies on high-GWP refrigerants, surcharges on inefficient appliances, and bans on second-hand equipment (Heubaum et al., 2023; IFC & UNEP, 2024; Kuhn et al., 2024). These instruments can also function as a way to generate revenue, which can be reinvested into other cooling strategies or financial support schemes, thus creating fiscal space to subsidize or incentivize more sustainable technologies (Heubaum et al., 2023; IFC & UNEP, 2024; Kuhn et al., 2024)

Kuhn et al. (2024) describe how Ghana has implemented environmental levies on new appliances and banned the import of second-hand refrigerators, with governmental oversight. However, enforcement remains uneven due to limited institutional capacity and corruption risks (Kuhn et al., 2024). As such, the effectiveness of fiscal disincentives depends on the capacity of institutions to enforce tax collection and import controls (IFC & UNEP, 2024; Kuhn et al., 2024). Similarly, Kalair et al. (2021) warn that fiscal initiatives may be affected by political influence and resource constraints in developing countries, thus hindering their effectiveness.

Policy Instrument 2.2: Concessional and Blended Finance Structures

Concessional finance refers to public or donor-backed capital offered at below-market terms through instruments such as concessional loans, guarantees, or grants to enable projects that would otherwise lack investment (Heubaum et al., 2023). Blended finance strategically combines such concessional resources with commercial capital, improving the risk-return profile of projects and aligning the objectives of donors, governments, and private investors (Heubaum et al., 2023; Shirai, 2023). Blended finance is increasingly applied to climate finance because the gap between required and available funding is too large for any single source, necessitating a focus on the needs and interests of private capital to leverage other forms of capital (Heubaum et al., 2023).

Warren (2020; 2023) highlights the chronic underinvestment in sustainable cooling within official development assistance (ODA), noting that only 0.04% of total ODA was allocated to cooling-related solutions according to 2019 data. To overcome this financing gap, the author calls for the targeted use of concessional finance to support early-stage business models and crowd in additional sources of funding. This approach is further illustrated in large-scale multi-country initiatives such as the World Bank's Clean Cooling Facility, which blends concessional resources from the Green Climate Fund (GCF) with commercial loans to finance cooling systems in Bangladesh, Kenya, El Salvador, and Sri Lanka (Heubaum, 2023; Shirai, 2023). These funds support interventions across agriculture, buildings, and health sectors by reducing investment risk and improving capital affordability.

These experiences show that concessional and blended finance structures are vital for overcoming early-market failures and enabling the diffusion of sustainable cooling technologies in developing countries (Heubaum et al., 2023; Shen et al., 2023; Shirai, 2023). While their designs vary, they share the common function of adjusting the risk-return ratio to catalyse projects that would not otherwise reach scale under commercial conditions. To maximize their impact, these instruments are often embedded in broader financial ecosystems that include performance-based incentives, technical assistance, and demand aggregation strategies (Heubaum et al., 2023; Shen et al., 2023).

Policy Instrument 2.3: Results-Based Financing

Results-Based Financing (RBF) ties funds disbursement to the achievement of pre-defined and independently verified outcomes (Heubaum et al., 2023; Stephens et al., 2022). As such, rather than subsidising inputs or technology costs upfront, RBF schemes reward implementers only once measurable results, such as verified emission reductions, are demonstrated (Heubaum et al., 2023; Stephens et al., 2022). This structure reduces the risk of underperformance (Heubaum et al., 2023), aligns incentives among stakeholders (Heubaum et al., 2023; Shirai, 2023), and encourages innovation and accountability in service delivery (Shirai, 2023; Stephens et al., 2022).

In the context of energy access programs, Stephens et al. (2022) highlight how RBF promotes the expansion of performance-oriented models in developing countries. Examples of this include the EnDev Program, funded by the Netherlands, Germany, Norway and Switzerland; the Universal Energy Facility (UEF), sponsored by Sustainable Energy for All and other partners; and the World Bank's Global Partnership for Results-Based Approaches (GPRBA) (Stephens et al., 2022). For instance, the UEF disburses funds to energy providers in countries like Sierra Leone, Benin, and Madagascar only after they deliver and verify functional off-grid electricity connections (UEF, 2024).

For sustainable cooling, the relevance of RBF lies in its structural compatibility with service-based business models. Providers like CaaS or ESCOs could be rewarded for demonstrated efficiency gains or reduced refrigerant leakage, aligning financial incentives with long-term performance. However, the literature stresses that RBF is not typically designed to drive technology development or market-wide transformation (Stephens et al., 2022). As such, RBF is best viewed as a complementary instrument that creates accountability and fosters incremental innovation in service delivery but requires integration with broader policy and financial frameworks to contribute meaningfully to BMI4Cool.

Policy Instrument 2.4: Advance Market Commitments

Advance Market Commitments (AMCs) are a financing instrument in which public or philanthropic actors commit in advance to purchasing a specified quantity of a product or service once it meets certain performance, affordability, or accessibility criteria (Stephens et al., 2022; Warren et al., 2023). They are designed to scale innovation and accelerate market transformation by creating guaranteed demand (Stephens et al., 2022; Warren et al., 2023). This reduces the risk of investing in products with high capital cost, therefore incentivising private-sector investment in new technologies that may otherwise be commercially unviable in their early stages (Stephens et al., 2022; Warren et al., 2023).

In sustainable cooling, AMCs are particularly well-suited to support technology scale-up and market formation and are preferable for interventions that require large-scale uptake or significant innovation (Stephens et al., 2022). Drawing on lessons from vaccine development, Stephens et al. (2022) propose AMC prototypes tailored to cooling that combine guaranteed demand with affordability and performance safeguards. For BMI, such commitments could provide predictable markets for service providers and manufacturers, facilitating investment in efficient technologies.

However, despite their benefits, AMCs face several implementation challenges, such as the risks of mispricing due to information asymmetries, which can lead to under-incentivising participation or overpaying producers (Stephens et al., 2022; Warren et al., 2023). A particularly critical concern in developing countries is the risk posed by weak or corrupt institutions, which can undermine the credibility of the mechanism and compromise compliance (Warren et al., 2023). As such, effective AMC deployment requires strong, trustworthy public institutions to manage contracts and ensure transparent disbursement.

India's ESEAP, introduced earlier in Policy Instrument 1.5, provides a mixed example of bulk procurement and AMCs, which ensured the bulk procurement of models that achieved specific efficiency standards, thus reducing prices while encouraging innovation (Singh & Gurumurthy, 2019; Stephens et al., 2022). However, technology uptake by consumer was limited due to low awareness and a lack of accessible financing (Singh & Gurumurthy, 2019).

The Indian experience with the ESEAP shows the importance of complementing AMC instruments with additional measures that address downstream barriers to adoption. As Stephens et al. (2022) emphasise, AMCs should be accompanied by supportive policies to mitigate potential drawbacks. They propose instruments such as consumer credit facilities linked to future energy savings, buyer aggregation platforms, targeted subsidies or tax incentives for efficient options, and regulations to internalize distribution, installation, and maintenance costs.

Policy Instrument 2.5: Grants for Innovation and Demonstration

Grants for demonstration and pilot implementation support the testing and validation of innovative cooling technologies, business models, or policy approaches under real-world conditions (Warren, 2020; Warren et al., 2023). According to Warren (2020), demonstration funding is critical for advancing technology and innovation in sectors that are otherwise overlooked by traditional climate finance, including sustainable cooling. These interventions are essential to validate the performance and scalability of cleaner cooling technologies and business models in local contexts and to generate the policy insights needed for replication and investment readiness (Warren, 2020).

A notable example is the IFC's TechEmerge Sustainable Cooling Innovation (TE-SCI) program, aimed at supporting early-stage, sustainable cooling solutions. Between 2019-2024, the program supported 79 pilots in developing countries intended to test sustainable cooling technologies (IFC & UNEP, 2024). These pilots focused on key themes such as cold chains, temperature-controlled logistics, urban cooling, and CaaS and encompassed USD 5.2 million in grant funding with in-kind and cash contributions (IFC & UNEP, 2024). Importantly, TechEmerge targeted innovators whose capital-intensive business models and long return cycles typically fell outside traditional venture capital profiles, therefore, de-risking early-stage deployment and demonstrating the viability of climate-smart cooling solutions (IFC & UNEP, 2024). However, many promising TechEmerge recipients struggled to secure capital following their initial support and many discovered there were very few funding sources available to help small companies achieve the scale and revenue that would make them attractive for commercial investment (IFC & UNEP, 2024).

Another type of grants are innovation competitions, which are public or donor-led mechanisms that provide financial incentives, visibility, and technical validation to accelerate sustainable cooling solutions (IFC & UNEP, 2024; Stephens et al., 2022). These instruments are used to crowd in early-stage innovators, support performance-based technology selection, and foster international collaboration (IFC & UNEP, 2024; Stephens et al., 2022). Within developing countries, they have become a strategic tool to identify scalable and locally appropriate innovations that address affordability, energy intensity, and climate impact in the cooling sector (IFC & UNEP, 2024; Stephens et al., 2022). One of the most prominent examples is the Global Cooling Prize (GCP), launched in 2018 by a consortium of public and private entities (Dixit & Bhasin, 2021; IFC & UNEP, 2024). The Prize offered up to USD 3 million in total prize money for cooling technologies[1] that met the requirement of achieving five times lower climate impact, and attracted participation from both multinational manufacturers and startups (Dixit & Bhasin, 2021).

Beyond new technologies, grants can also pilot institutional and policy innovations, such as performance-based procurement or tariff reforms, allowing governments and firms to test models in real-world settings and generate lessons for replication (Gogoi et al., 2023; Warren, 2020; Warren et al., 2023).

Policy Instrument 2.6: Public-Private Partnerships

Public-private partnerships (PPPs) are increasingly recognised as collaborative frameworks to mobilise investment and expertise for sustainable infrastructure delivery in developing countries, combining public and private sector efforts to achieve development goals (IFC & UNEP, 2024). In the context of sustainable cooling, PPPs are particularly relevant because they enable governments not only to design and partially fund initiatives, but also to offer direct incentives to consumers, entrepreneurs, providers, and investors (Gogoi et al., 2023; IFC & UNEP, 2024).

PPPs are identified as instruments that accelerate the commercialisation of emerging technologies, de-risk early-stage business models, and enhance access to essential infrastructure for low-income populations (Gogoi et al., 2023). This is particularly relevant where service provision has historically been dominated by the public sector, and where private sector participation depends on clearly structured risk-sharing arrangements (Gogoi et al., 2023). However, they are operationalised through different forms, depending on the context. For instance, some authors identify blended finance structures as a special type of PPPs (Shirai, 2022), while others highlight public-private buyer's club (IFC & UNEP, 2024) and PPP-ESCO models (Ablaza et al., 2021) as relevant forms of this type of partnership.

In Morocco, a public–private buyers' club was established by government agencies, commercial banks, and farmer cooperatives to aggregate demand and negotiate lower prices for super-efficient ACs with climate-friendly refrigerants, significantly improving affordability through collective procurement (UNEP & IFC, 2024, p. 24). In Asia, Ablaza et al. (2021) document the emergence of customised PPP contracts as alternatives to

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[1] https://globalcoolingprize.org/

traditional EPCs, including the development of a PPP–ESCO model to facilitate energy efficiency improvements in the public sector. This approach was applied, for instance, in a large-scale LED streetlighting project in Malaysia, which received technical support from ADB in the design of technical specifications, business case model, and legal due diligence (Ablaza et al., 2021).

The above shows that PPPs are not a uniform instrument but a strategic modality through which public and private actors can jointly develop sustainable cooling infrastructure and services. In terms of enabling conditions for effective PPPs, authors highlight legal and policy frameworks to support performance-based contracting, procurement reform to accommodate hybrid arrangements, and institutional coordination to align public sector objectives with private sector capabilities (Gogoi et al., 2023).

Dimension 3: Data and Digital Infrastructure

The following instruments are selected based on their primary function in supporting the development of robust data ecosystems and digital infrastructure, which were identified as essential elements for the implementation of advanced technologies that facilitate servitisation models, usage-based billing, maintenance automation, and energy performance tracking.

Policy Instrument 3.1: Smart Metering and Sensor Mandates

This instrument refers to regulatory or planning measures that require the installation of smart meters and digital sensors to monitor electricity consumption and system performance. Smart metering and sensor technologies are increasingly recognised as foundational tools for enhancing the efficiency and sustainability of energy services (Peters & Sayin, 2022; UN.ESCAP et al., 2021a) since they enable granular monitoring of consumption, temperature, humidity, and other performance variables, which are essential for usage-based billing models and system optimisation through real-time data (Pachauri et al., 2024; UN.ESCAP et al., 2021a).

Applications in developing countries illustrate both potential and challenges. In Nigeria, sensors deployed in agricultural cold chains reduced food waste and informed real-time decisions in fresh produce logistics, particularly when integrated with mobile applications for inventory management (Onwude et al., 2023). In India, national programmes such as the Smart Grid Vision (2013) and the Smart Meter National Programme (2017) sought to install 250 million smart meters across the country by 2022, while the Results-Linked Distribution Reform Package (2021) established metering-based energy accounting and TOU tariffs for consumers (Poudineh et al., 2021).

However, despite strong national commitments, the implementation of smart metering in India faced several limitations. As of 2020, one million smart meters had been installed nationwide, falling significantly short of government targets (Poudineh et al., 2021). While the central government supported procurement through various schemes, responsibility for rollout lay with state-owned electricity distribution companies, which, as noted by Poudineh et al. (2021), were in poor financial condition and lacked the technical and institutional capacity to manage this process effectively. In addition, many state-level grids were not upgraded to support two-way communication, remote data collection, or real-time load management (Poudineh et al., 2021).

Taken together, these cases show that smart metering and sensor mandates can be important enablers of BMI4Cool. Their effectiveness, however, depends on complementary policies that secure technical integration, institutional uptake, and consistency with wider grid and tariff reforms. Scaling service-based cooling requires ICT-enabled grids to support decentralised energy management (Poudineh et al., 2021) as well as broad mobile coverage to enable real-time monitoring and user interaction (Onwude et al., 2023).

Policy Instrument 3.2: Data Collection and Dissemination Standards

Data collection and dissemination standards refer to measures that require the structured gathering, standardisation, and sharing of disaggregated data relevant to cooling. The instrument is highly relevant to identify the magnitude of cooling needs, as well as to benchmark performance of cooling equipment for the implementation of MEPS and labelling schemes (Pillai et al., 2022; Poudineh et al., 2021; UN.ESCAP et al., 2021a).

International organisations strongly advocate for the integration of data components into NCAPS. For example, the UN ESCAP NCAP Methodology explicitly includes the development of Data Assessment Frameworks to guide the systematic collection of information on cooling demand, energy use, and refrigerant impacts (UN.ESCAP et al., 2021b). Cambodia's NCAP, launched in 2023, applies this methodology and uses these frameworks to augment the efficacy of its strategies by supporting the identification of key data inputs, the estimation of cooling demand, and the definition of strategies (UN.ESCAP et al., 2023). In this regard, UN.ESCAP et al. (2023) highlight that the experience in Cambodia and other countries demonstrate how improved cooling data enables the definition of more comprehensive action plans.

The literature distinguishes between active and passive cooling data needs. Active cooling requires information on market size, appliance performance, refrigerant use, and technology outlooks, while passive cooling requires data on building material performance and compliance with codes to inform design guidelines (UN.ESCAP et al., 2023). Urban temperature and heat island data are also needed to support planning and prioritisation (UN.ESCAP et al., 2023).

From the perspective of BMI, data standards are a prerequisite for scaling digital and service-based models. In fact, lack of knowledge around potential levels of demand and market size for sustainable cooling across countries, sectors, and applications, is seen as a concrete risk by stakeholders (IFC & UNEP, 2024). As such, instruments aimed at closing these gaps are essential for conducive environments of BMI within this sector.

Table 1. Summary of Policy Instruments

Dimension	Instrument	Description	Implication for Sustainable Cooling
1. Governance and Institutional Capacity	1.1 MEPS and Labelling	Sets efficiency thresholds and labels for appliances.	Removes inefficient products, builds demand for efficient ones.
	1,2 Building Energy Codes and Passive Design Regulation	Thermal and passive design standards for buildings.	Lowers cooling loads, supports integrated service models.
	1.3 Refrigerant Regulation	Controls use and phase-down of high-GWP refrigerants.	Promotes low-emission tech and lifecycle compliance.
	1.4 Cooling and Energy Planning (e.g., NCAPs)	National plans linking cooling to energy and climate goals.	Provides certainty for investment and service-based models.
	1.5 Performance-Based Public Procurement	Public procurement based on efficiency and lifecycle value.	Creates markets for high-performance solutions.
	1.6 Legal Recognition of Service-Based Contracts	Validates EPCs, ESAs, and similar contracts.	Enables ESCOs and CaaS to operate under legal certainty.
2. Finance and Business Dynamics	2.1 Capital Subsidies and Tax Incentives	Fiscal measures to targeting technology innovations.	Increases affordability and signals market commitment.
	2.2 Concessional and Blended Finance	Financial mechanisms targeting sustainable cooling projects.	De-risks early models and crowds in private capital.
	2.3 Results-Based Financing (RBF)	Links funding to verified outcomes.	Rewards efficiency gains and supports performance models.
	2.4 Advance Market Commitments (AMCs)	Guarantees future purchases at agreed terms.	Stimulates innovation and ensures demand.
	2.5 Grants for Innovation and Demonstration	Funds for early pilots and competitions.	Tests viability, reduces investor risk.
	2.6 Public-Private Partnerships (PPPs)	Joint public-private delivery frameworks.	Mobilises capital, shares risk, enables hybrid models.
3. Data and Digital Infrastructure	3.1 Smart Metering and Sensor Mandates	Mandates digital monitoring tools.	Supports usage-based billing and efficiency verification.
	3.2 Data Collection and Dissemination Standards	Requires structured collection and sharing of cooling data.	Reduces uncertainty, supports planning and scaling.

Source: Own elaboration.

4.2. Clustering of Article 5 Countries

4.2.1. Dataset Construction and Indicators

The dataset was constructed taking as a foundation the published list of 147 prioritised countries in the Article 5[1] of the Montreal Protocol, which is one of the main agreements currently governing cooling efforts worldwide. It is important to note that this classification has been periodically revised through meeting decisions. For instance, Malta was reclassified as operating under Article 5 in Decision V/4 (1993) and later removed from the list at its request in Decision XVI/40 (2004). While such revisions are reflected in the current published list, others, such as Kuwait, the Republic of Korea, Saudi Arabia, Singapore and the United Arab Emirates, and UAE's reclassification as a non-Article 5 party in Decision V/4, are not consistently applied. To address these inconsistencies, the original classification was retained to ensure reproducibility and provide a well-documented reference framework.

Building on the three identified dimensions, a set of indicators was selected to operationalise the enabling conditions for BMI4Cool. The indicators were chosen for their conceptual relevance, cross-country comparability, and empirical grounding in the literature. It is important to note that these indicators do not measure the instruments themselves, but rather the systemic environment that enables them. They serve as proxies to assess how effectively Article 5 countries can generate the institutional, financial, and digital conditions required for policy instruments to function. As these proxies capture broader enabling conditions rather than individual measures, they do not have a one-to-one relationship with specific policy instruments. Table 2 and Table 3 summarise these relationships and the rationale for their selection.

Indicators for Dimension 1 were drawn from the 2023 Regulatory Indicators for Sustainable Energy (RISE) and the Worldwide Governance Indicators (WGI). Within the RISE dataset, Minimum Energy Performance Standards (*MEPS*) captures the existence of legally enforceable efficiency standards for appliances, including penalties for non-compliance (ESMAP, 2025); Heating and Cooling Renewables (*RECOOL*) measures whether countries integrate renewable thermal solutions for heating and cooling through instruments such as mandates, bans, building codes, and concessional financing (ESMAP, 2025); and Incentives and Mandates for Energy Utility Programs (*INC*) assesses whether

[1] Listo f Article 5 Parties: https://ozone.unep.org/classification-parties. Last accessed November 14, 2025.

utility regulations support energy efficiency activities, including time-of-use (TOU) tariffs and metering mechanisms within the residential, commercial, and industrial sectors (ESMAP, 2025). Together, these metrics provide insight into how actively governments pursue energy efficiency, with higher scores indicating a more favourable policy environment for performance- and service-based models.

From the WGI, the Regulatory Quality (*RQUAL*) indicator captures perceptions of a government's ability to formulate and implement policies and regulations that promote private sector development, covering burden and transparency of government regulation, competition policy, ease of doing business, openness of public procurement, and adaptability of legal frameworks (World Bank, 2024). This indicator is presented in a standardised format, with a scale that ranges from -2.5 (lowest) to 2.5 (highest). RQUAL provides a system-level perspective on institutional capacity, which is essential to assess the feasibility of implementing the policy instruments identified in this study.

For Dimension 2, the Financing Mechanisms for Energy Efficiency (*FIN*) from the RISE dataset was used as a proxy for all instruments within the dimension. The indicator captures diversity of sector-specific financial instruments and national support to energy-efficiency investments through credit, guarantees, bonds and performance contracts (ESMAP, 2025). FIN does not directly measure innovation grants, advance market commitments, or results-based financing; however, it is used as a broad proxy to measure the efforts related to the presence of financing frameworks for energy efficiency.

The AI Preparedness Indicator (*AIPI*) was used as a proxy for all instruments in Dimension 3. It assesses a country's preparedness for AI adoption based on four dimensions: digital infrastructure, human capital and labour market policies, innovation and economic integration, and regulatory frameworks (IMF, 2025). Each dimension aggregates a set of sub-indicators, including broadband penetration, secure servers, and internet accessibility to STEM education, legal adaptability, and R&D investment (IMF, 2025). The index is normalised on a 0 to 1 scale, with higher scores indicating stronger structural digital foundations (IMF, 2025).

Lastly, GDP per capita was included as a proxy for economic capacity, allowing policy instruments to be interpreted in the context of resource availability. To account for scale differences, GDP per capita (2023, PPP, current USD) was used instead of total GDP and transformed into the natural logarithm (log GDP per capita). This approach allows for a more comparable representation of economic capacity across countries of different sizes.

The missingness threshold of 25% led to the exclusion of 45 countries, mostly small island developing states, microstates, or politically isolated regimes. Four additional countries were removed due to missing GDP values. AIPI showed about 8% missingness, which was addressed by imputing values using subregional means. The final sample contained 98 observations. A full list of excluded and reclassified countries is provided in Appendix III.

Table 2. Summary of Clustering Indicators and Sources

Dimension	Indicators	Name	Year	Source
Governance and Institutional Capacity	Minimum Energy Performance Standards	MEPS	2023	RISE/ESMAP
	Heating and Cooling Renewables	RECOOL	2023	RISE/ESMAP
	Incentives & Mandates: Energy Utility Programs	INC	2023	RISE/ESMAP
	Regulatory Quality	RQUAL	2023	World Bank
Finance and Business Dynamics	Financing Mechanisms for Energy Efficiency	FIN	2023	RISE/ESMAP
Data and Digital Infrastructure	AI Preparedness Index	AIPI	2023	IMF
Economic capacity	GDP per capita, PPP (current international $)	GDP	2023	World Bank

Source: Own elaboration based on ESMAP (2025), IMF (2025), World Bank (2024).

Table 3. Matrix Linking Instruments and Indicators

Dimension	Policy Instruments	MEPS	RECOOL	INC	RQUAL	FIN	AIPI	Proxy coverage note
Governance and Institutional Capacity	1.1 MEPS and Labelling Schemes	D			I			MEPS measures presence of standards; RQUAL indirectly reflects enforcement quality.
	1.2 Building Energy Codes and Passive Design Regulation		P		I			RECOOL partially reflect efficiency design rules; RQUAL indirect measure of enforcement quality.
	1.3 Refrigerant Regulation		P		I			RECOOL partially covers regulation of cooling; RQUAL indirect measure of enforcement quality.
	1.4 Cooling and Energy Planning		P		I			RECOOL partially captures integration of renewables in planning; RQUAL indirect measure of institutional coordination.
	1.5 Performance-Based Public Procurement			P	I		I	INC partially reflects performance and service-based energy regulation; RQUAL and AIPI indirectly reflect administrative and digital capability.
	1.6 Legal Recognition of Service-Based Contracts			P	I		I	
Finance and Business Dynamics	2.1 Capital Subsidies and Tax Incentives					P		FIN captures financial support for energy efficiency, which is an enabling condition.
	2.2 Concessional and Blended Finance Structures					P		
	2.3 Results-Based Financing						I	AIPI indirectly indicates digital monitoring capacity.
	2.4 Advance Market Commitments					I		FIN indirectly reflects enabling financial schemes for energy efficiency.
	2.5 Grants for Innovation and Demonstration						I	AIPI indirectly reflects innovation and digital infrastructure capacity.
Data and Digital Infrastructure	3.1 Smart Metering and Sensor Mandates			I			P	AIPI partially measures digital infrastructure supporting metering and data governance systems.
	3.2 Data Collection and Dissemination Standards			I			P	FIN indirectly reflects enabling environments for energy utility programs.

Note: The classification distinguishes direct, partial, and indirect relationships, clarifying whether each indicator measures, partially covers, or indirectly enables the corresponding policy instrument.

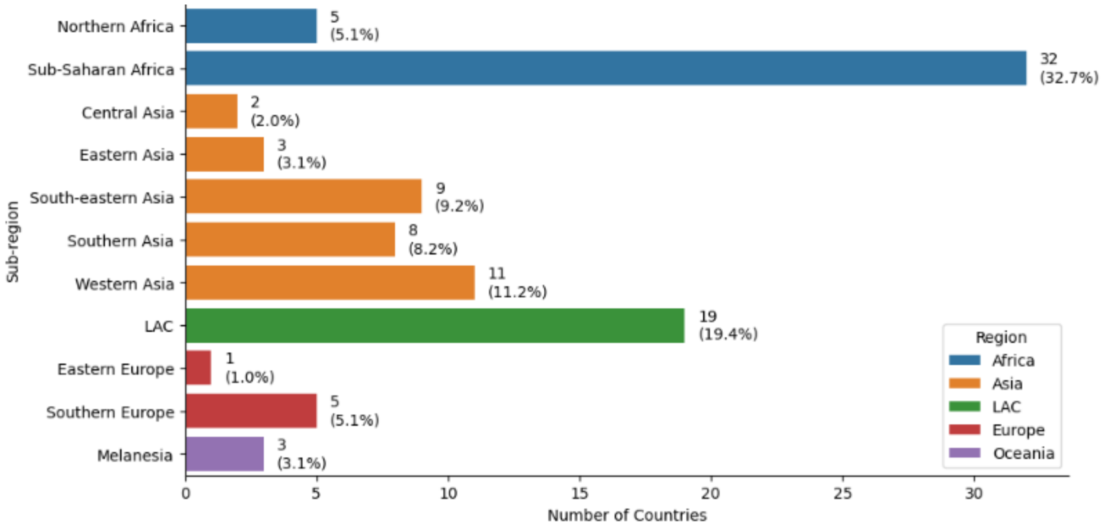
D = direct proxy P = partial proxy I = indirect proxy.

Source: Own elaboration based on ESMAP (2025), IMF (2025), World Bank (2024).

4.2.2. Characteristics of Article 5 Countries

The analysis covers 98 of the 147 Article 5 countries outlined in the Montreal Protocol. As shown in Figure 5, most countries are located in Africa (37.8%), followed by Asia (33.7%). Latin America and the Caribbean (LAC), Europe and Oceania each account for 10-19% of the sample.

Figure 5. Number and Share of Article 5 Countries by Sub-region



Source: Own elaboration.

Across indicators, countries show marked disparities (Table 4). MEPS and INC record the highest mean values of 39.95 and 43.10, respectively, showing that countries have a moderate implementation of energy efficiency and utility program mandates. In contrast, RECOOL and FIN show poor results, with mean values of 20.51 and 33.50, respectively, with one quarter of the observations scoring 0 on both variables. Notably, all energy-related variables present a wide dispersion, with minimum values between 0-5 and maximum values around 77-100, showing wide heterogeneity across observations.

RQUAL averages –0.38, reflecting systemic limits in enforcement and rule of law, while AIPI averages 0.42, indicating moderate digital readiness. GDP per capita ranges from USD 920 to USD 143,786, although 75% of countries fall below USD 22,265, highlighting sharp economic disparities.

However, these statistics should be carefully analysed considering regional discrepancies, reflected in Table 5. In terms of the energy efficiency indicators, Europe and Asia show above-average performance across all variables, Africa and Oceania present uniformly weaker results, and LAC has a mixed energy profile. Institutional quality and digital readiness are generally constrained in Africa and Oceania, both notably below sample average. Asia, LAC, and Europe show more favourable results, with both indicators surpassing Article 5 mean values.

Table 4. Summary Statistics of Article 5 Countries

Indicator	Mean	Std. Dev.	Min	25th %tile	Median	75th %tile	Max
MEPS	39.95	29.98	0.00	8.33	43.75	66.32	100.00
RECOOL	20.51	21.62	0.00	0.00	16.67	33.33	77.78
INC	43.10	20.99	5.00	30.00	42.50	53.33	100.00
FIN	33.50	32.06	0.00	0.00	33.33	50.00	100.00
RQUAL	-0.38	0.74	-2.07	-0.91	-0.48	0.12	2.31
AIPI	0.42	0.11	0.18	0.33	0.41	0.49	0.80
GDP per capita	17,917	23,031	920	4,090	10,669	22,265	143,786

Source: Own elaboration.

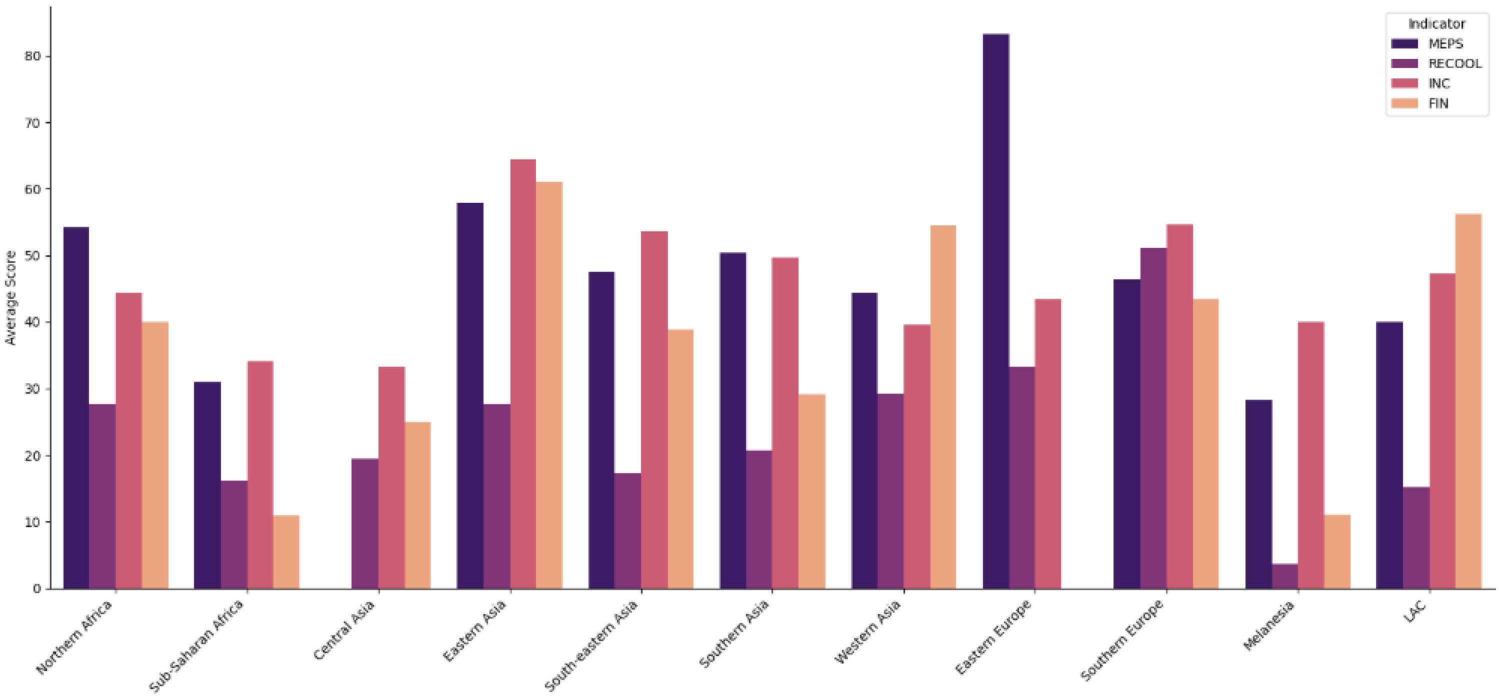
Table 5. Average Scores per Variable, by Region and Sub-Region.

REGION	SUB-REGION	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
Africa	Northern Africa	54.17	27.78	44.33	40.00	-0.78	0.41	12,324
	Sub-Saharan Africa	31.03	16.15	34.17	10.94	-0.78	0.33	4,190
	Average	34.16	17.72	35.54	14.86	-0.78	0.34	5,290
Asia	Central Asia	0.00	19.44	33.33	25.00	-1.34	0.43	13,564
	Eastern Asia	57.87	27.78	64.44	61.11	0.20	0.62	31,796
	South-eastern Asia	47.53	17.28	53.70	38.89	0.02	0.50	29,759
	Southern Asia	50.35	20.69	49.62	29.17	-0.84	0.40	11,244
	Western Asia	44.44	29.29	39.55	54.55	0.39	0.52	49,778
	Average	45.24	23.2	47.74	42.93	-0.13	0.49	31,147
Europe	Eastern Europe	83.33	33.33	43.33	0.00	0.11	0.48	17,747
	Southern Europe	46.39	51.11	54.67	43.33	0.19	0.50	25,499
	Average	52.55	48.15	52.78	36.11	0.18	0.49	24,207
LAC	LAC	39.91	15.2	47.19	56.14	-0.18	0.45	19,797
Oceania	Melanesia	28.24	3.70	40.00	11.11	-0.51	0.29	3,643
Article 5 Average		39.95	20.51	43.10	33.50	-0.38	0.42	17,917

Source: Own elaboration.

However, when analysed per sub-region, it is possible to verify heterogeneity within continents. Figure 6 shows the mean score of energy efficiency indicators. As it shows, Eastern Europe has a considerably high MEPS score (83.33), but a low FIN (0); however, it is only comprised of one country. Southern Europe is the only sub-region that seems to consistently perform across energy efficiency indicators, all of which are between 43-55 points. Eastern Asia shows relatively strong results in MEPS, FIN, and INC, however, scores poorly in RECOOL. Northern Africa, South-eastern Asia, Southern Asia, Eastern Asia, and LAC exhibit a similar pattern: moderate performance across MEPS, INC, and FIN, but low scores in RECOOL. By contrast, Sub-Saharan Africa, Central Asia, and Melanesia display uniformly lower scores across all four indicators, with particularly limited progress in FIN.

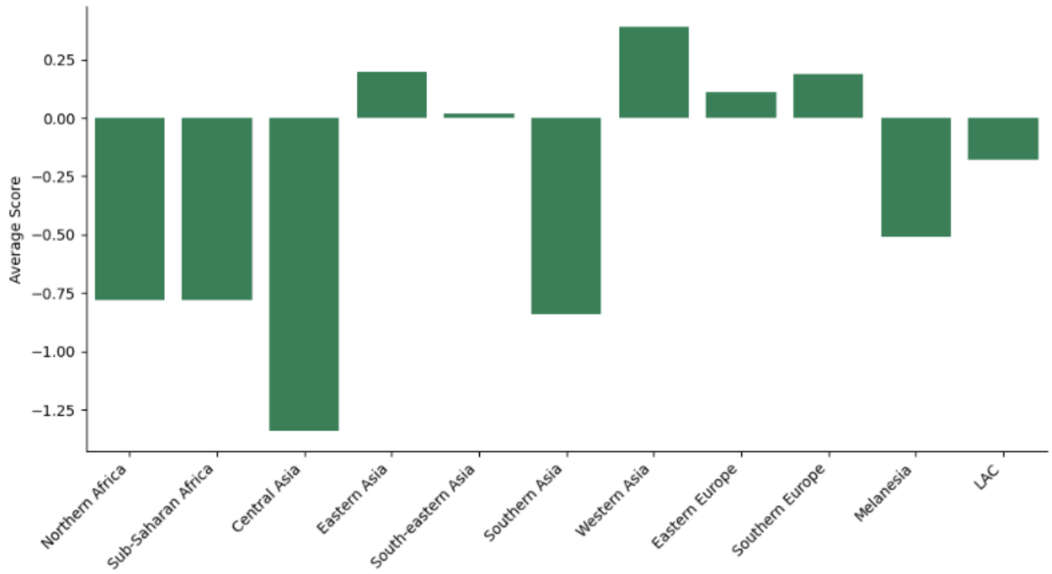
Figure 6. Energy Efficiency Indicators by Sub-Region



Source: Own elaboration.

In the case of RQUAL, as shown in Figure 7, most sub-regions fall below zero, indicating a general lack of confidence in institutional effectiveness. Central Asia (–1.34) exhibits the lowest average score, followed by Southern Asia (–0.84), Sub-Saharan Africa (–0.78), and Northern Africa (–0.78). Melanesia and LAC also score negatively, though less severely. Only Eastern Asia, South-eastern Asia, Western Asia, Eastern Europe, and Southern Europe record positive scores, suggesting a relatively better regulatory environment. However, it should be noted that, in the case of South-eastern Asia, the positive result is mostly driven by Singapore, without which the score goes down from 0.02 to –0.27.

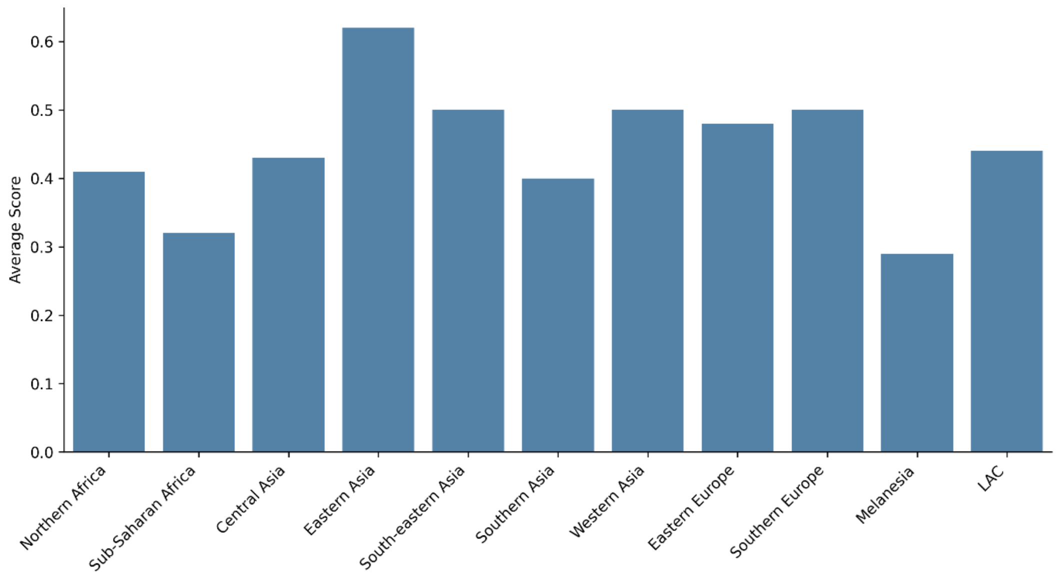
Figure 7. Regulatory Quality by Sub-Region



Source: Own elaboration.

Lastly, AIPI reveals moderate but uneven progress towards emerging technologies across sub-regions. The index ranges from 0.29 in Melanesia to 0.62 in Eastern Asia, with most sub-regions clustering between 0.40 and 0.50. While Eastern Asia stands out as the most digitally ready, several others, such as South-eastern Asia, Southern Europe, and Western Asia, also demonstrate relatively strong digital foundations. In contrast, Sub-Saharan Africa and Melanesia exhibit the lowest scores, reflecting significant limitations to support AI-driven transformation.

Figure 8. AIPI by Sub-Region



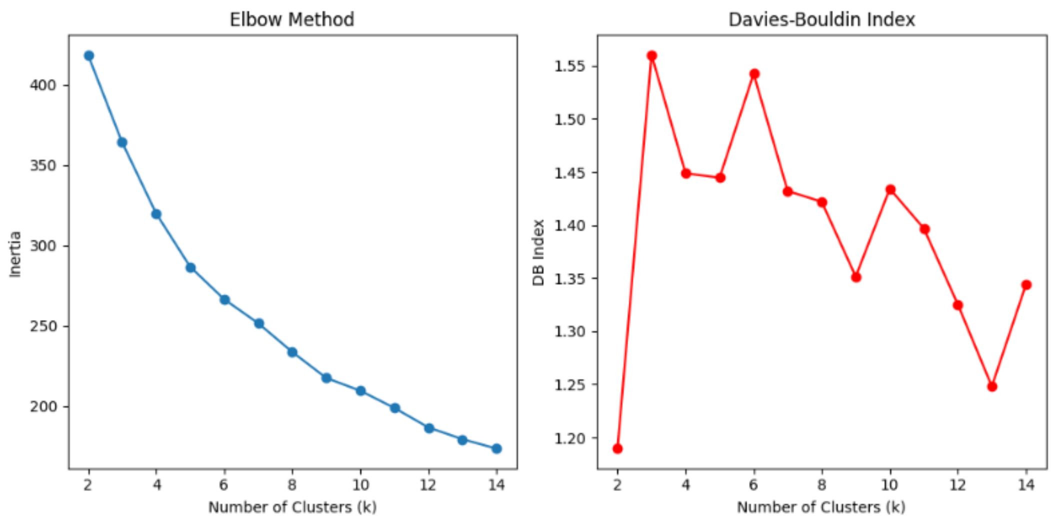
Source: Own elaboration.

4.2.3. Clustering Method and Rationale

To identify groups of Article 5 parties with similar enabling environments for sustainable cooling, an unsupervised clustering method was applied. The clustering was based on the seven key indicators outlined before: MEPS, RECOOL, INC, RQUAL, FIN, AIPI, and log GDP per capita. All variables were standardised using z-scores to ensure comparability across different units and scales. A multivariate correlation and multicollinearity check were performed. While RQUAL and AIPI showed strong correlation, the Variance Inflation Factor (VIF) values remained below conventional thresholds, so all variables were maintained for clustering. The results of these analyses can be found on Appendix IV.

To determine the optimal number of clusters, the Elbow method and the Davies–Bouldin Index were calculated for values of k ranging from 2 to 15. The Davies–Bouldin score showed the lowest values at k = 2 and k= 13; however, the Elbow method indicated that inertia dropped slightly from k = 2 to approximately k = 6. A test was conducted using k = 6 to assess interpretability, but the clusters were highly uneven, with one containing nearly 32% of the sample. Further tests were conducted with k = 12 and k = 13; however, results were too spread out, with several clusters containing only 1 observation. To balance interpretability and clustering cohesion, the final clustering number chosen was k = 9, which was the next low DB Score. A full list of tested models can be found on Appendix V.

Figure 9. Elbow Method and DB Score Analysis



Source: Own elaboration.

4.2.4. Results and Interpretation

Overview of Clusters

The clustering applied to Article 5 countries resulted in the distinction of nine clusters. Table 6 shows the average of all selected variables for each cluster, along with the total number of countries within each group.

Table 6. Averages per Cluster

CLUSTER	N	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
0	9	69.91	30.86	69.26	87.04	-0.05	0.51	22,797
1	26	15.97	6.41	23.33	5.13	-1.02	0.32	3,964
2	13	27.35	12.39	38.21	47.44	-0.80	0.36	8,345
3	7	75.79	21.43	48.57	71.43	0.83	0.60	60,870
4	14	46.23	51.51	51.21	47.62	0.03	0.50	21,702
5	6	62.73	50.93	60.00	11.11	-0.92	0.32	6,305
6	11	19.32	8.08	31.21	28.79	0.09	0.47	29,087
7	11	60.86	11.62	57.88	13.64	-0.33	0.41	9,788
8	1	79.17	11.11	100.00	50.00	2.31	0.80	143,786
Sample Mean	98	39.95	20.51	43.10	33.50	-0.38	0.42	17,917

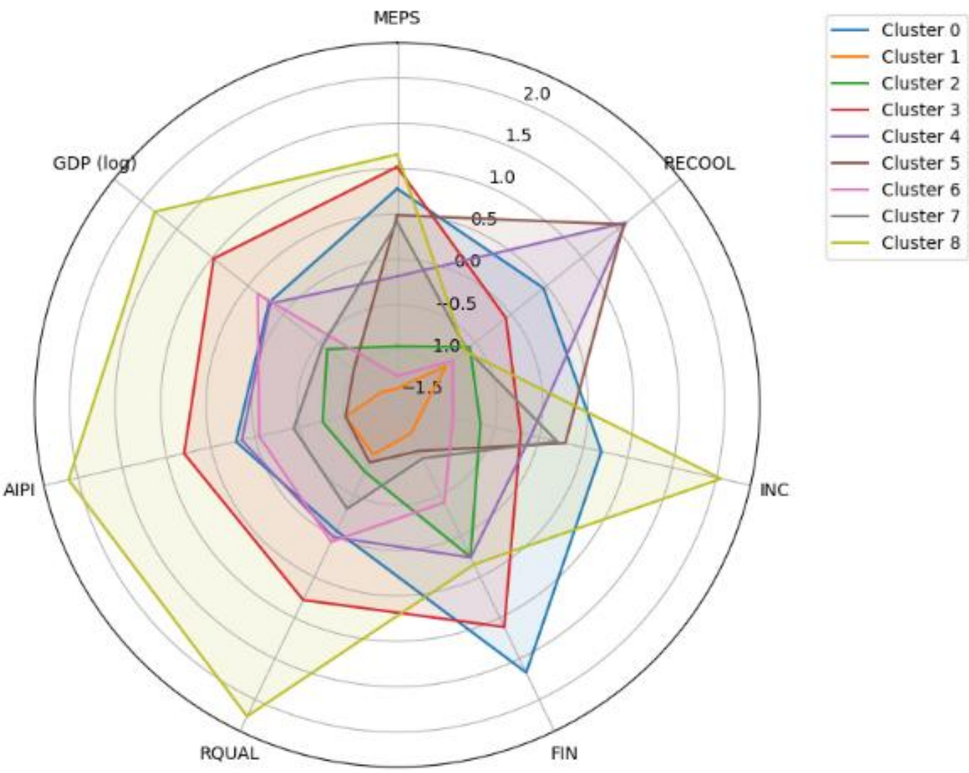
Source: Own elaboration.

These results show distinctive profiles within each cluster. For instance, Clusters 0 and 3 stand out for their consistent relatively good performance across all efficiency policies, most of which are above the Article 5 sample average. However, Cluster 3 shows better results in RQUAL, AIPI and GDP per capita, while Cluster 0 has a better performance in energy efficiency initiatives. Cluster 8 also shows a considerably good performance across key enabling variables; however, it should be noted that it is only comprised of Singapore, which may indicate that this is an outlier country with notably advanced capacities.

By contrast, Cluster 1 shows consistently lower scores across all indicators, thus reflecting a highly constrained environment. Specifically, RQUAL (-1.02), AIPI (0.32), and GDP per capita (USD 3,964) are the lowest among all clusters. Cluster 5 presents a similar institutional and economic profile, with the second-lowest RQUAL (−0.92), AIPI (0.32), and GDP per capita (USD 6,305). Although Cluster 5 achieves high scores in several energy efficiency indicators, these results should be interpreted with caution, as weak institutional capacity and limited economic resources may hinder policy implementation . Similarly, Cluster 2 is another low performer, with constrained RQUAL (-0.80), AIPI (0.36), and GDP per capita (USD 8,345).

Lastly, Clusters 4, 6, and 7 present mixed profiles, combining strengths in certain areas with notable gaps in others. Cluster 4 shows a balanced profile with moderate scores in energy efficiency, AIPI (0.50), RQUAL (0.03), and GDP per capita (USD 21,702). Cluster 6 shows mostly constrained energy policies but has moderate RQUAL (0.09) and AIPI (0.47), as well as high GDP per capita (USD 29,087). Cluster 7 combines moderate RQUAL (−0.33) and AIPI (0.41) with constrained GDP per capita (USD 9,788) and mixed energy efficiency results.

Figure 10. Cluster Profiles (Z-score Normalised)



Source: Own elaboration.

Cluster 0 Profile

As Table 7 shows, Cluster 0 consists of 9 countries, with the largest representation from LAC (n=5), followed by countries from Eastern Asia (n=1), Northern Africa (n=1), South-eastern Asia (n=1), and Western Asia (n=1).

The cluster is characterised by consistently high energy efficiency scores. MEPS (69.91), INC (69.26), and FIN (87.04) stand out as the strongest, with seven countries obtaining full score in the latter. RECOOL (30.86) is the weakest indicator. In terms of energy efficiency, Brazil stands out as the leader, with high scores in MEPS (91.67), INC (90.00), and FIN (100.00). However, most countries show a combination of very high scores with moderate-to-low ones. For instance, Mexico combines high MEPS (100.00) and FIN (100.00), with moderate RECOOL (55.56) and INC (46.67), while Uruguay has high INC (80.00) and FIN (100.00), with moderate RECOOL (44.4) and low MEPS (25.00).

Table 7. Cluster 0 Results per Country

SUB-REGION	COUNTRY	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
Eastern Asia	China	73.61	22.22	80.00	33.33	-0.36	0.64	25,179
LAC	Brazil	91.67	33.33	90.00	100.00	-0.30	0.50	21,176
LAC	Ecuador	72.22	16.67	46.67	100.00	-0.72	0.44	15,919
LAC	Mexico	100.00	55.56	46.67	100.00	-0.17	0.53	24,855
LAC	Panama	56.94	0.00	73.33	100.00	0.12	0.50	39,803
LAC	Uruguay	25.00	44.44	80.00	100.00	0.68	0.55	34,471
Northern Africa	Morocco	52.78	33.33	56.67	100.00	-0.06	0.43	9,843
South-eastern Asia	Thailand	75.00	44.44	90.00	50.00	0.16	0.54	23,519
Western Asia	Jordan	81.94	27.78	60.00	100.00	0.22	0.48	10,412
Cluster 0 Average		69.91	30.86	69.26	87.04	-0.05	0.51	22,797

Source: Own elaboration.

RQUAL (−0.05) and AIPI (0.51) are moderate, but relatively good when compared to the sample averages. Uruguay (0.68) registers a higher RQUAL, indicating comparatively stronger enforcement capacities. At the opposite end, Ecuador (−0.72) shows weaker institutional capacity relative to its peers. Regarding digital readiness, most members have a moderate readiness, with China having the most advanced ecosystem (0.64), and Morocco (0.43) and Ecuador (0.44) registering the lowest AIPI values.

The cluster's GDP per capita averages USD 22,797, but its distribution is highly uneven. Panama (USD 39,803) and Uruguay (USD 34,471) form the upper tier. A middle group, including Mexico (USD 24,855), China (USD 25,179), and Thailand (USD 23,519), aligns closely with the cluster mean. At the lower end Morocco (USD 9,843) and Jordan (USD 10,412) record the lowest GDP per capita figures.

Cluster 1 Profile

Cluster 1 contains approximately 26% of the sample. As Table 8 shows, the largest representation is from Sub-Saharan Africa (n=17), followed by countries from Southern Asia (n=2), LAC (n=2), Central Asia (n=1), Melanesia (n=1) and Northern Africa (n=1).

The cluster is characterised by consistently low performance across all variables. Energy efficiency indicators score below 24, showing a constrained environment for performance-based initiatives. Intra-cluster variability is high, with many countries scoring zero across the energy efficiency indicators: 46% in MEPS, 65% in RECOOL, and 85% in FIN. This concentration of zero values highlights the fragmented and limited nature of efficiency policies within the cluster.

RQUAL (−1.02) indicates a severely constrained regulatory quality with only Benin achieving a relatively good RQUAL score (−0.30). All other members display severely constrained capacities, with Turkmenistan (−2.07), Somalia (−1.88), and Sudan (−1.60) recording the lowest values in the cluster. AIPI (0.32) also reflects limited innovation readiness, with Turkmenistan and Sudan registering the highest AIPI scores, at 0.43 and 0.41 respectively. Conversely, Central African Republic (0.18), Ethiopia (0.25), and the Democratic Republic of Congo (0.25) are placed at the bottom of the distribution.

In terms of GDP per capita, most countries in the cluster display limited economic capacity, with 65% falling below the cluster average of USD 3,964. This average is influenced by the wealthier members, namely Turkmenistan (USD 19,829), Angola (USD 8,047), and Honduras (USD 7,178), without which the average decreases by 25%. At the other end of the spectrum, Burundi (USD 920), the Central African Republic (USD 1,257), and Somalia (USD 1,557) record the lowest values.

Table 8. Cluster 1 Results per Country

SUB-REGION	COUNTRY	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
Central Asia	Turkmenistan	0.00	11.11	16.67	0.00	-2.07	0.43	19,829
LAC	Honduras	16.67	0.00	30.00	0.00	-0.55	0.34	7,178
LAC	Haiti	1.39	11.11	26.67	33.33	-1.39	0.27	3,281
Melanesia	Solomon Islands	29.17	0.00	30.00	0.00	-0.78	0.29	2,801
Northern Africa	Sudan	55.56	0.00	10.00	0.00	-1.60	0.41	2,421
South-eastern Asia	Myanmar	15.28	11.11	20.00	0.00	-1.44	0.33	5,953
Southern Asia	Afghanistan	0.00	0.00	20.00	33.33	-1.27	0.40	2,202
Southern Asia	Nepal	48.61	0.00	26.67	0.00	-0.66	0.35	5,395
Sub-Saharan Africa	Somalia	0.00	0.00	20.00	0.00	-1.88	0.32	1,557
Sub-Saharan Africa	Sierra Leone	0.00	16.67	16.67	0.00	-1.06	0.30	3,371
Sub-Saharan Africa	Niger	50.00	0.00	30.00	0.00	-0.82	0.33	1,875
Sub-Saharan Africa	Malawi	4.17	0.00	43.33	0.00	-0.77	0.34	1,830
Sub-Saharan Africa	Mozambique	33.33	33.33	10.00	0.00	-0.71	0.26	1,678
Sub-Saharan Africa	Liberia	0.00	16.67	20.00	0.00	-0.92	0.37	1,795
Sub-Saharan Africa	Tanzania	0.00	0.00	43.33	0.00	-0.59	0.35	4,019
Sub-Saharan Africa	Guinea	38.89	0.00	20.00	0.00	-1.08	0.32	4,334
Sub-Saharan Africa	Ethiopia	16.67	0.00	10.00	50.00	-1.02	0.25	3,061
Sub-Saharan Africa	Congo	0.00	0.00	10.00	0.00	-1.24	0.28	6,850
Sub-Saharan Africa	Congo, Dem. Rep.	0.00	0.00	51.67	0.00	-1.41	0.25	1,616
Sub-Saharan Africa	Central African Republic	0.00	16.67	43.33	0.00	-1.47	0.18	1,257
Sub-Saharan Africa	Burkina Faso	33.33	0.00	30.00	0.00	-0.49	0.31	2,755
Sub-Saharan Africa	Benin	38.89	16.67	10.00	0.00	-0.30	0.36	4,130
Sub-Saharan Africa	Burundi	0.00	0.00	5.00	0.00	-0.99	0.29	920
Sub-Saharan Africa	Angola	0.00	0.00	20.00	0.00	-0.76	0.26	8,047
Sub-Saharan Africa	Madagascar	0.00	33.33	16.67	0.00	-0.80	0.31	1,808
Sub-Saharan Africa	Uganda	33.33	0.00	26.67	16.67	-0.52	0.35	3,098
Cluster 1 Average		15.97	6.41	23.33	5.13	-1.02	0.32	3,964

Source: Own elaboration.

Cluster 2 Profile

Cluster 2 is comprised of 13 countries, with the majority located in Sub-Saharan Africa (n=4), followed by Southern Asia (n=2), LAC (n=2), Central Asia (n=1), Melanesia (n=1), Northern Africa (n=1), Southern Asia (n=1), and Western Asia (n=1).

The cluster is characterised by consistently low performance across most variables. In the energy efficiency dimension, MEPS (27.35) and RECOOL (12.39) show weak results, both with several countries scoring zero. INC (38.21) and FIN (47.44) are moderate, with most countries showing moderate-to-low scores.

Table 9. Cluster 2 Results per Country

SUB-REGION	COUNTRY	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
Central Asia	Kyrgyz Republic	0.00	27.78	50.00	50.00	-0.62	0.43	7,298
LAC	Bolivia	37.50	0.00	20.00	50.00	-1.18	0.38	10,925
LAC	Nicaragua	44.44	33.33	36.67	66.67	-0.88	0.33	8,320
Melanesia	Papua New Guinea	0.00	11.11	46.67	33.33	-0.64	0.29	4,668
Northern Africa	Algeria	70.83	11.11	41.67	50.00	-0.95	0.37	16,824
South-eastern Asia	Cambodia	0.00	0.00	33.33	33.33	-0.68	0.37	7,431
South-eastern Asia	Lao PDR	0.00	27.78	40.00	33.33	-0.93	0.33	9,292
Southern Asia	Bangladesh	56.94	0.00	50.00	50.00	-0.91	0.38	9,148
Sub-Saharan Africa	Côte d'Ivoire	61.11	0.00	33.33	50.00	-0.12	0.37	7,227
Sub-Saharan Africa	Cameroon	0.00	0.00	40.00	50.00	-0.91	0.34	5,406
Sub-Saharan Africa	Mali	27.78	16.67	43.33	33.33	-0.68	0.30	3,168
Sub-Saharan Africa	Nigeria	44.44	0.00	10.00	50.00	-0.94	0.34	6,207
Western Asia	Lebanon	12.50	33.33	51.67	66.67	-1.01	0.42	12,575
Cluster 2 Average		27.35	12.39	38.21	47.44	-0.80	0.36	8,345

Source: Own elaboration.

Regarding RQUAL (−0.80), the cluster has constrained enforcement capacities with scores ranging from moderate values in Côte d'Ivoire (−0.12) to notably low results in Bolivia (−1.18) and Lebanon (−1.01). In terms of AIPI (0.36), the cluster's performance is generally low, with countries such as Papua New Guinea (0.29) and Mali (0.30) with very low readiness, and others like Kyrgyz Republic (0.43) and Lebanon (0.42) with moderate values, closer to sample average.

In terms of GDP per capita, most countries cluster between USD 6,000-10,000. The upper tier is comprised of countries such as Algeria (USD 16,824), Lebanon (USD 12,575), and Bolivia (USD 10,925), while the bottom tier includes Cameroon (USD 5,406), Papua New Guinea (USD 4,668), and Mali (USD 3,168).

Cluster 3 Profile

Cluster 3 has a total of 7 countries, with Western Asia (n=3) accounting for approximately half of the cluster. Its performance is over all good, although energy efficiency policies have mixed scores. Most countries have notably high scores in at least two out of the four variables, indicating targeted commitments with efficiency initiatives. For instance, the Republic of Korea has perfect scores in MEPS (100.00) and FIN (100.00), but notably low RECOOL (11.11) scores. Similarly, Saudi Arabia has high MEPS (81.94) and FIN (66.67), but low INC (30.00). Other countries, such as Costa Rica and the United Arab Emirates, have more balanced performances.

Table 10. Cluster 3 Summary per Country

SUB-REGION	COUNTRY	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
Eastern Asia	Republic of Korea	100.00	11.11	63.33	100.00	1.12	0.73	52,204
LAC	Chile	68.06	44.44	40.00	83.33	0.93	0.59	32,801
LAC	Costa Rica	83.33	33.33	56.67	50.00	0.54	0.54	28,075
South-eastern Asia	Malaysia	72.22	11.11	53.33	50.00	0.66	0.63	36,417
Western Asia	United Arab Emirates	66.67	33.33	56.67	100.00	1.04	0.63	76,110
Western Asia	Qatar	58.33	0.00	40.00	50.00	0.98	0.53	128,919
Western Asia	Saudi Arabia	81.94	16.67	30.00	66.67	0.52	0.58	71,565
Cluster 3 Average		75.79	21.43	48.57	71.43	0.83	0.60	60,870

Source: Own elaboration.

This cluster displays relatively good RQUAL (0.83) and AIPI (0.60), thus signalling relatively good enforcement quality and digital readiness. In terms of their regulatory quality, the Republic of Korea (1.12) and the United Arab Emirates (1.04) reflect the best institutional capacity, while Costa Rica (0.54) and Saudi Arabia (0.52) represent the worst environments, but still moderate. Regarding digital readiness, the top performers are the Republic and Korea (0.73), followed by the United Arab Emirates (0.63) and Malaysia (0.63). Qatar (0.53) appears as the least digitally ready, even though its score is moderate and above sample average, thus showing there is a relatively good innovation potential.

Lastly, GDP per capita of these countries is mostly high, with countries such as Qatar (USD 128,919), the United Arab Emirates (USD 76,110), and Saudi Arabia (USD 71,565) displaying notably high GDP levels, when compared to Costa Rica (USD 28,075) and Chile (USD 32,801).

Cluster 4 Profile

Cluster 4 has a total of 14 countries, with a mix across Western Asia (n=3), Southern Europe (n=5), Sub-Saharan Africa (n=1), Southern Asia (n=1), South-eastern Asia (n=1), Northern Africa (n=1), and Eastern Asia (n=1).

The performance of this cluster is overall moderate. Energy variables are clustered around 46-52, showing emerging efforts to support efficiency mechanisms and initiatives. RQUAL (0.03) and AIPI (0.50) sit at middle values, indicating that regulatory and digital capacities are moderate.

In the case of energy policies, India stands out with high scores across MEPS (83.33), RECOOL (71.11), INC (77.00), and FIN (50.00). Others, such as North Macedonia, Indonesia, and Sri Lanka, show balanced profiles clustered between 40–60. Some display sharper contrasts: Georgia records high RECOOL (77.78) but low MEPS (12.50), INC (36.67), and FIN (16.67), while Armenia shows strong FIN (83.33) alongside weaker results in MEPS (45.83), RECOOL (38.89), and INC (30.00).

Table 11. Cluster 4 Summary per Country

SUB-REGION	COUNTRY	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
Eastern Asia	Mongolia	0.00	50.00	50.00	50.00	-0.18	0.48	18,005
Northern Africa	Tunisia	48.61	66.67	66.67	50.00	-0.62	0.47	14,010
South-eastern Asia	Indonesia	47.22	38.89	43.33	50.00	0.30	0.52	15,416
Southern Asia	India	83.33	71.11	77.00	50.00	-0.14	0.49	10,324
Southern Asia	Sri Lanka	65.28	33.33	46.67	50.00	-0.51	0.44	14,456
Southern Europe	Albania	55.56	33.33	33.33	16.67	0.17	0.53	21,260
Southern Europe	Bosnia and Herzegovina	50.00	33.33	53.33	50.00	-0.14	0.43	22,509
Southern Europe	North Macedonia	43.06	44.44	46.67	50.00	0.43	0.48	24,387
Southern Europe	Montenegro	33.33	77.78	66.67	50.00	0.37	0.50	30,597
Southern Europe	Serbia	50.00	66.67	73.33	50.00	0.14	0.54	28,744
Sub-Saharan Africa	South Africa	66.67	44.44	56.67	50.00	-0.22	0.50	15,194
Western Asia	Armenia	45.83	38.89	30.00	83.33	0.05	0.49	21,534
Western Asia	Georgia	12.50	77.78	36.67	16.67	0.95	0.53	25,072
Western Asia	Türkiye	45.83	44.44	36.67	50.00	-0.23	0.54	42,326
Cluster 4 Average		46.23	51.51	51.21	47.62	0.03	0.50	21,702

Source: Own elaboration.

Regarding RQUAL, most countries have a moderate profile, falling within the –0.5-0.5 range. Georgia stands out with a strong RQUAL score of 0.95, while Sri Lanka, and Tunisia have weak scores of –0.51 and –0.62, respectively. In relation to AIPI, all cluster members score between 0.43-0.54, thus indicating moderate and emerging digital readiness. The best performing countries are Serbia (0.54) and Türkiye (0.54), while the bottom tier is comprised of Sri Lanka (0.44) and Bosnia and Herzegovina (0.43).

Regarding economic capacity, these countries show a high GDP per capita. Türkiye (USD 42,326) and Montenegro (USD 30,597) lead, almost triplicating the lowest tier comprised of Tunisia (USD 14,010) and India (USD 10,324).

Cluster 5 Profile

Cluster 5 has a total of 6 countries, most of which are in Sub-Saharan Africa (n=5), and only one in Southern Asia (n=1). The performance of this cluster is mostly weak. While MEPS (62.73), RECOOL (50.92), and INC (60.00) score moderately, FIN is notably low (11.11). Most countries show mixed results across these variables, with moderate-to-high scores across MEPS, RECOOL and INC. The key gap within this cluster is FIN, where approximately 67% of cluster members have a score of zero. In this case, only Iran and Rwanda show positive results.

However, the above policy efforts are not matched by RQUAL (–0.93), which leans towards limited institutional capacities. Iran (–1.69) and Zimbabwe (–1.34) stand out as the two countries with the lowest scores, while Rwanda (0.12) is the only one with a positive, yet moderate score. The scenario is similar in the case of AIPI (0.32), given that most countries show limited digital readiness. Rwanda has the highest score (0.44) and Mauritania (0.23) and Chad (0.23), the lowest.

This cluster records the second-lowest GDP per capita among all groups, averaging USD 6,305. Disparities are wide, from Iran at USD 17,660 to Zimbabwe at USD 3,820, with most countries below USD 4,000.

Table 12. Cluster 5 Summary per Country

SUB-REGION	COUNTRY	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
Southern Asia	Iran	90.28	50.00	73.33	50.00	-1.69	0.38	17,660
Sub-Saharan Africa	Mauritania	27.78	50.00	56.67	0.00	-1.00	0.23	6,946
Sub-Saharan Africa	Rwanda	76.39	77.78	46.67	16.67	0.12	0.44	3,399
Sub-Saharan Africa	Chad	62.50	50.00	80.00	0.00	-1.16	0.23	2,932
Sub-Saharan Africa	Togo	75.00	33.33	53.33	0.00	-0.49	0.32	3,072
Sub-Saharan Africa	Zimbabwe	44.44	44.44	50.00	0.00	-1.34	0.30	3,820
Cluster 5 Average		62.73	50.92	60.00	11.11	-0.93	0.32	6,305

Source: Own elaboration.

Cluster 6 Profile

Cluster 6 contains 11 countries, with more than half of its members located in LAC (n=6), followed by Western Asia (n=3), Southern Asia (n=1), South-eastern Asia (n=1).

The performance of energy efficiency metrics is mostly weak. MEPS (19.32), RECOOL (8.08), INC (32.21), and FIN (28.79) are well below sample averages. When analysing intra-cluster variations, it is possible to note that countries have mixed profiles, combining high performance in a few variables with poor results in others. Such is the case of Argentina, Colombia, and Guatemala, which have high FIN, but lower INC and non-existent MEPS and RECOOL. Only four countries (Dominican Republic, Philippines, Kuwait, and Oman) show efforts across the four indicators, although their performance lags in most of them.

In terms of RQUAL (0.09), while the cluster value is positive and above the sample average, it is possible to observe variations among countries. For instance, Maldives (–0.67) scores the lowest, while Bahrain (1.08) displays notably good results. Regarding AIPI (0.47), most countries show moderate digital readiness, with only Guatemala (0.39) showing some limitations. Oman (0.53) appears as the one with the most advanced AI readiness.

In terms of GDP per capita (USD 29,087) this cluster shows high resource capacity. Bahrain (USD 64,171) and Kuwait (USD 53,025) are among the wealthier members, while Guatemala (USD 13,745) and Philippines (USD 10,986) are the ones at the bottom.

Table 13. Cluster 6 Summary per Country

SUB-REGION	COUNTRY	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
LAC	Argentina	0.00	0.00	40.00	66.67	-0.48	0.47	30,082
LAC	Colombia	0.00	0.00	20.00	50.00	0.10	0.49	20,944
LAC	Dominican Republic	26.39	16.67	30.00	33.33	0.17	0.47	25,840
LAC	Guatemala	0.00	0.00	30.00	50.00	-0.29	0.39	13,745
LAC	Peru	6.94	0.00	40.00	0.00	0.29	0.49	17,011
LAC	Paraguay	30.56	0.00	30.00	0.00	-0.08	0.41	17,564
South-eastern Asia	Philippines	65.28	11.11	30.00	50.00	0.16	0.50	10,986
Southern Asia	Maldives	0.00	11.11	30.00	0.00	-0.67	0.40	24,735
Western Asia	Bahrain	29.17	0.00	36.67	0.00	1.08	0.52	64,171
Western Asia	Kuwait	37.50	16.67	20.00	50.00	0.32	0.46	53,025
Western Asia	Oman	16.67	33.33	36.67	16.67	0.43	0.53	41,851
Cluster 6 Average		19.32	8.08	31.21	28.79	0.09	0.47	29,087

Source: Own elaboration.

Cluster 7 Profile

Cluster 7 contains 11 countries and has a varied regional mix, including Eastern Europe (n=1), LAC (n=2), Melanesia (n=1), Northern Africa (n=1), South-eastern Asia (n=1), and Sub-Saharan Africa (n=4).

The energy efficiency performance of this cluster is moderate-to-weak. Even though MEPS (60.86) and INC (57.88) show relatively good results, RECOOL (11.62) and FIN (13.64) are low, thus showing mixed efforts. In terms of intra-cluster characteristics, 55% of countries score zero in RECOOL and FIN. Zambia is the only country that displays efforts across the four indicators; however, the scores are not high. Some countries display particularly high scores in some indicators, but these are localised in one or two rather than consistent across the set. For instance, Jamaica displays high INC (90.00) and Kenya high MEPS (75.00), but the other indicators remain moderate-to-low.

On the other hand, while RQUAL (–0.33) is better than sample average, it is still moderate. In the case of RQUAL, Moldova (0.11) and Jamaica (0.10) are the only ones that display positive results, while Pakistan has the lowest score (–0.90).

Similarly, AIPI (0.41) is closely aligned with sample values showing moderate digital readiness. However, while countries such as Viet Nam (0.48) and Moldova (0.48) show promising results in terms of their readiness, other members like Vanuatu (0.29) present constrained environments.

Table 14. Cluster 7 Summary per Country

SUB-REGION	COUNTRY	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
Eastern Europe	Moldova	83.33	33.33	43.33	0.00	0.11	0.48	17,747
LAC	Jamaica	27.78	0.00	90.00	50.00	0.10	0.43	11,467
LAC	El Salvador	69.44	0.00	70.00	33.33	-0.31	0.39	12,680
Melanesia	Vanuatu	55.56	0.00	43.33	0.00	-0.12	0.29	3,461
Northern Africa	Egypt	43.06	27.78	46.67	0.00	-0.67	0.39	18,525
South-eastern Asia	Viet Nam	73.61	0.00	73.33	33.33	-0.38	0.48	15,034
Southern Asia	Pakistan	58.33	0.00	73.33	0.00	-0.90	0.37	6,037
Sub-Saharan Africa	Ghana	66.67	16.67	53.33	0.00	-0.18	0.43	7,556
Sub-Saharan Africa	Kenya	75.00	33.33	30.00	0.00	-0.39	0.45	6,307
Sub-Saharan Africa	Senegal	66.67	0.00	63.33	16.67	-0.35	0.40	4,778
Sub-Saharan Africa	Zambia	50.00	16.67	50.00	16.67	-0.50	0.37	4,077
Cluster 7 Average		60.86	11.62	57.88	13.64	-0.33	0.41	9,788

Source: Own elaboration.

GDP per capita values (USD 9,788) show limited economic capacity when compared to other clusters. The top tier includes Egypt (USD 18,525) and Moldova (USD 17,747), while the bottom tier includes Vanuatu (USD 3,461) and Zambia (USD 4,077). The difference between these tiers, with the highest values approximately five times greater than the lowest, underlines marked disparities in economic capacity across the cluster.

Cluster 8 Profile

Cluster 8 consists solely of Singapore, which scores exceptionally in INC (100.00), RQUAL (2.31), AIPI (0.80), and GDP (143,786). As previously mentioned, Singapore was reclassified as non-operating under Article 5 so it will be excluded from further analysis.

Table 15. Cluster 8 Summary per Country

SUB-REGION	COUNTRY	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP per capita
South-eastern Asia	Singapore	79.17	11.11	100.00	50.00	2.31	0.80	143,786

Source: Own elaboration.

Summary of Cluster Performance

The results obtained were further structured by grouping clusters into performance tiers, which were defined by classifying indicators scoring more than 20% above the median scale value as high and those scoring more than 20% below the median as low; all others were considered moderate. To ensure a balanced assessment, MEPS, RECOOL, INC, and FIN were evaluated jointly as components of a shared energy efficiency policy environment. Since they capture closely related aspects of national energy policy, overall performance was assessed based on their combined pattern rather than on individual scores.

Clusters such as 0 and 3, which exhibit at least two energy efficiency indicators rated as high, were therefore considered to have strong energy policy environments. When combined with high or moderate performance in RQUAL, AIPI, and GDP, these clusters were classified within the high tier.

At the other end, clusters with two or more energy efficiency indicators rated as weak were considered to face constrained energy policy environments. Within this group, a distinction was made between clusters with weak performance in RQUAL, AIPI, and GDP per capita, such as clusters 1, 2, and 5, and those with mostly moderate performance on these variables, such as clusters 6 and 7. The former were classified in the low tier, reflecting a clearly constrained environment, while the latter were classified as middle-low, indicating some scope for improvement in regulatory and digital readiness.

Lastly, cluster 4 shows consistently moderate values across all indicators but stands out for its higher economic capacity, positioning it within the middle-high performance tier.

Table 16. Summary of Cluster Performance Tiers

PERFORMANCE	CLUSTER	MEPS	RECOOL	INC	FIN	RQUAL	AIPI	GDP
HIGH	0	High	Weak	High	High	Moderate	Moderate	High
	3	High	Weak	Moderate	High	High	High	High
MIDDLE-HIGH	4	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	High
MIDDLE-LOW	6	Weak	Weak	Weak	Weak	Moderate	Moderate	High
	7	Moderate	Weak	Moderate	Weak	Moderate	Moderate	Weak
LOW	1	Weak	Weak	Weak	Weak	Weak	Weak	Weak
	2	Weak	Weak	Moderate	Moderate	Weak	Weak	Weak
	5	Moderate	Moderate	Moderate	Weak	Weak	Weak	Weak

Source: Own elaboration.

5.Discussion

5.1. Policy Implications

The clustering analysis presented in this thesis enables a more differentiated understanding of the structural and institutional conditions that shape the feasibility of BMI4Cool across Article 5 countries. Rather than assuming a universal pathway to innovation, the typology highlights how enabling conditions vary widely, revealing both opportunities and constraints for tailored support. A summary of this discussion can be found in Table 17.

5.1.1. High Performers: Clusters 0 and Cluster 3

Clusters 0 and 3 display enabling environments that align closely with the policy conditions identified in the literature for scaling innovative business models in sustainable cooling. Both clusters record high scores in energy efficiency indicators, particularly MEPS, combined with moderate-to-high RQUAL and AIPI, indicating the presence of coherent policy frameworks that can facilitate market transformations.

Peters and Sayin (2022) emphasise that MEPS and labelling schemes are pivotal regulatory instruments for transforming appliance markets by accelerating the uptake of efficient technologies. In this context, the strong MEPS performance observed in both clusters reflects environments capable of supporting a shift toward performance-based initiatives. Moreover, in light of the good results in terms of AIPI and MEPS, countries within these clusters could benefit from introducing smart metering and sensor mandates. As discussed by the literature, these are essential instruments to support cooling efficiency by enabling demand management and forecasting (Peters & Sayin, 2022; UN.ESCAP et al., 2021a). It should be noted, however, that Cluster 3, outperforms Cluster 0 in regulatory capacity and digital readiness, suggesting an immediate potential to implement and scale such models.

Furthermore, these clusters show good scores in relation to the implementation of utility incentives programs, suggesting that performance and service-based contracts may be emerging, thus laying the foundation to transition from capital-intensive asset ownership to performance-based service delivery, which are essential for market transformation (Shen et al., 2023).

While both clusters share a strong overall profile, differentiated approaches may be required. For Cluster 0, whose RQUAL while above-average is negative, strengthening regulatory technical capacity could help ensure that service- or performance-based contracts are effectively designed, implemented, and enforced. For Cluster 3, which has a stronger regulatory and digital capacity, more direct support toward scaling and commercialising advanced service-based models may be more fitting.

Both clusters also perform strongly in terms of the financial mechanisms available for energy efficiency programmes and initiatives, a condition repeatedly emphasised in the literature as critical for scaling market-based sustainable cooling solutions (Warren, 2020). In this context, grants for demonstration and innovation could be particularly effective, as the existing financial infrastructure is well positioned to manage and disburse targeted public climate finance. As described by Warren (2020), these grants support the testing and validation of innovative cooling technologies, business models, and policy approaches under real-world conditions, helping bridge the gap between research and full-scale commercialisation.

Finally, the comparatively low efforts to integrate renewable energy into heating and cooling planning present a clear opportunity for improvement in both clusters. Deploying demonstration grants in this area could accelerate the introduction of renewable-based cooling solutions, leveraging the cluster's good regulatory, financial, and digital foundations. These interventions would enable both clusters to build on their already favourable enabling environments while ensuring stronger alignment with long-term decarbonisation objectives.

5.1.2. Middle-High Performers: Cluster 4

Cluster 4 presents a relatively balanced enabling environment, with moderate results in MEPS, RECOOL, INC, and FIN. While these values suggest progress in energy efficiency, renewable integration, and institutional support, the literature highlights that clear and supportive policy frameworks are essential to enable the transition toward service- and performance-based approaches (Palafox-Alcantar et al., 2024).

NCAPs could play a central role in this process by integrating long-term efficiency targets with cooling objectives, aligning regulatory frameworks, financing schemes, and technology deployment pathways. In this regard, the literature highlighted the benefits of these strategies, aimed at integrating energy efficiency, refrigerant transition, urban development, and infrastructure planning to align cooling demand with climate and development goals (Peters & Sayin, 2022). These plans help governments create the conditions necessary for deploying efficient cooling technologies and managing peak electricity demand (Peters & Sayin, 2022). In the specific case of this cluster, NCAPs could provide a comprehensive framework to support the emerging moderate efforts, bringing together all relevant stakeholders and combining efforts to ensure effective implementation.

Although RQUAL and AIPI in this cluster are above the sample average, the moderate presence of initiatives addressing energy efficiency limits the potential to expand performance- and service-based cooling models. As Shen et al. (2023) note, service-based contracts require not only regulatory capacity but also incentive frameworks that reward verified performance outcomes. Expanding performance-based approaches would therefore require aligning regulatory capacity with market conditions that explicitly reward performance, alongside the establishment of mechanisms to verify outcomes. In this context, and leveraging the cluster's relatively strong AI readiness, smart metering and sensor mandates could support performance verification and incentive alignment, complementing existing MEPS, INC, and FIN efforts.

In sum, while this cluster presents a promising emerging landscape, immediate actions should focus on ensuring that performance- and service-based models have the necessary frameworks to scale.

5.1.3. Middle-Low Performers: Cluster 6 and Cluster 7

Clusters 6 and 7 present enabling environments that are more fragmented, where certain foundations exist but are insufficient to sustain the transition towards market-based sustainable cooling models. The literature makes clear that weak or inconsistent policy mixes are a critical barrier in such contexts, as isolated instruments rarely generate systemic change(Howlett & Rayner, 2007; Rogge & Reichardt, 2016). In both clusters, the absence of coherent financial and regulatory frameworks constrains the viability of BMI, even where moderate digital capacities could potentially support it.

For Cluster 6, relatively favourable economic and digital conditions point to unexplored opportunities for introducing advanced service-based models, yet these opportunities are undermined by underdeveloped energy efficiency policies. As Lizana et al. (2022) note, narrowly designed or absent standards reinforce product-based models and hinder innovation. Introducing stronger MEPS, combined with building codes and renewable integration policies, would be essential first steps to create a market environment in which performance-based contracts such as CaaS or ESCOs can operate. Once such regulatory foundations are in place, instruments like smart metering and sensor mandates could leverage the cluster's moderate digital readiness, enabling usage-based billing and efficiency verification that are necessary for service-oriented approaches (Peters & Sayin, 2022; UN.ESCAP et al., 2021a).

Cluster 7 faces a different configuration. Here, efficiency mandates exist but are weakened by limited financial mechanisms and regulatory enforcement. The literature highlights that financial de-risking is indispensable for scaling sustainable cooling (Shen et al., 2023; Warren, 2020). In this regard, concessional and blended finance structures could help mobilise private capital and address the affordability barriers that currently prevent adoption (Heubaum et al., 2023; Shirai, 2023). Complementary pull instruments, such as results-based financing or advance market commitments, could also be introduced at later stages to reward verified performance and guarantee demand, both of which encourage providers to invest in service-based delivery models (Stephens et al., 2022; Warren et al., 2023).

Across both clusters, regulatory capacity shows moderate results, which suggests there is potential to introduce service-based contracts in public procurement as a way to incentivize business model innovation. In such contexts, technical cooperation should be focused on targeted support for the legal recognition and implementation of service-based contracts to ensure they create pathways for providers to operate within predictable frameworks while shifting incentives towards lifecycle performance (Shen et al., 2023; Mohamad Munir et al., 2023).

In sum, Clusters 6 and 7 lack coherent policy mixes rather than regulatory capacity per se. For Cluster 6, the priority lies in building energy efficiency frameworks so that existing economic and digital capacities can be mobilised. For Cluster 7, the central challenge is the absence of robust financing mechanisms, which limits the scalability of emerging efficiency initiatives. While they require support in different areas, both clusters would benefit from strengthening their regulatory frameworks in ways that are specifically targeted to address their unique weaknesses.

5.1.4. Low Performers: Cluster 1, Cluster 2, and Cluster 5

Clusters 1, 2, and 5 represent the weakest enabling environments, where systemic gaps across governance, energy efficiency, and digital capacity combine to severely limit the prospects for market-based sustainable cooling. The literature underscores that in such contexts, even incremental improvements are unlikely to generate meaningful transformation without significant external support (Warren, 2020; IFC & UNEP, 2024). Furthermore, weak or non-existent policy frameworks leave little basis for innovation, given that the absence of reliable policy instruments undermines R&D and investment (Rogge & Reichardt, 2016).

In Clusters 1 and 2, efficiency mandates are either absent or poorly enforced, leaving appliance markets dominated by inefficient products. As Lizana et al. (2022) argue, the absence of effective MEPS not only allows inefficient technologies to persist but also prevents the creation of consumer demand for sustainable alternatives. Strengthening these foundational standards is therefore an essential entry point. However, the literature cautions that standards alone are insufficient in low-capacity settings, since they require monitoring, enforcement, and complementary instruments to be effective (Peters & Sayin, 2022).

A particular challenge in these clusters is the limited innovation readiness infrastructure, which constrains the deployment of crucial technologies for service-based models. As Singh et al. (2022) note, servitisation models such as CaaS or PAYGo depend on digital enablers, yet these remain largely absent in the weakest performers. This reinforces the need for technical cooperation on digital foundations, such as metering infrastructure and data collection frameworks (UN.ESCAP et al., 2023).

A defining constraint across these clusters is their weak regulatory quality, which falls well below the Article 5 average. As Rogge and Reichardt (2016) argue, even ambitious policy strategies cannot alter innovation pathways unless they are operationalised through coherent and enforceable instruments. In these countries, fragmented governance and limited institutional capacity mean that even basic measures such as MEPS or labelling schemes are unlikely to generate market transformation without sustained enforcement. The literature stresses that this lack of regulatory credibility deters private investment and prevents service-based models from taking root (Abramskiehn & Richmond, 2019; Lizana et al., 2022). For this reason, technical cooperation in low performers should prioritise strengthening regulatory structures by building monitoring and enforcement capacity, improving transparency in procurement, and creating predictable legal environments. Only by addressing these institutional weaknesses can subsequent financial or digital interventions have lasting impact.

Table 17. Summary of BMI4Cool Cluster Profiles, per Tier

Performance	Cluster	Energy Efficiency	Regulatory Quality	Digital Readiness	GDP per capita	Key Insights for Sustainable Cooling BMI	Priority Instruments	**Quick Wins**
High	0	Moderate -High	Moderate	Moderate	High	Strong base for service-based models; opportunity to embed renewable-based cooling. Higher GDP per capita may support adoption.	Smart metering and sensor mandates, demonstration grants for renewable-based cooling.	Pilot CaaS or ESCO project using digital monitoring.
	3	Moderate -High	High	High	High		Advance Market Commitments, concessional/blended finance for renewable integration.	Pilot renewable-based cooling project financed through blended finance.
Moderate-High	4	Moderate	Moderate	Moderate	High	Moderate base for service-based models, requires strengthening of digital foundations. Higher GDP per capita may support adoption.	NCAPS, smart metering, performance-based procurement and verification.	Define NCAP with associated sustainable cooling roadmap.
Moderate-Low	6	Weak	Moderate	Moderate	High	Moderate base for service-based models; models should be designed considering financial capacity of user base.	MEPS and labelling, building codes and passive design, refrigerant regulation.	Pilot service-based models in public institutions.
	7	Moderate -Weak	Moderate	Moderate	Weak		Concessional and blended finance, results-based financing, legal recognition of service-based contracts.	Blended-finance pilot for efficient cooling in public institutions.
Low	1	Weak	Weak	Weak	Weak	Severe constraints; need basic institutional strengthening and digital foundations before innovation is possible.	MEPS and labelling, institutional capacity building for monitoring and enforcement, data standards.	Technical-assistance pilot on MEPS.
	2	Moderate -Weak	Weak	Weak	Weak		MEPS, digital infrastructure investments (smart metering, data frameworks), regulatory capacity building.	Metering and data-collection programme for key public buildings.
	5	Moderate -Weak	Weak	Weak	Weak		Capital subsidies and tax incentives, concessional and blended finance, procurement reform to support lifecycle-based purchasing.	Public procurement pilot for high-efficiency equipment.

Note: High performers are defined as clusters with average indicator values above 20% of the sample mean, while weak performers fall below 20% of the sample mean. Cluster 8, composed solely of Singapore, is treated as an outlier and excluded from comparative analysis due to its exceptional institutional and digital capacity.

Source: Own elaboration.

5.1.5. Policy Pathways for BMI4Cool

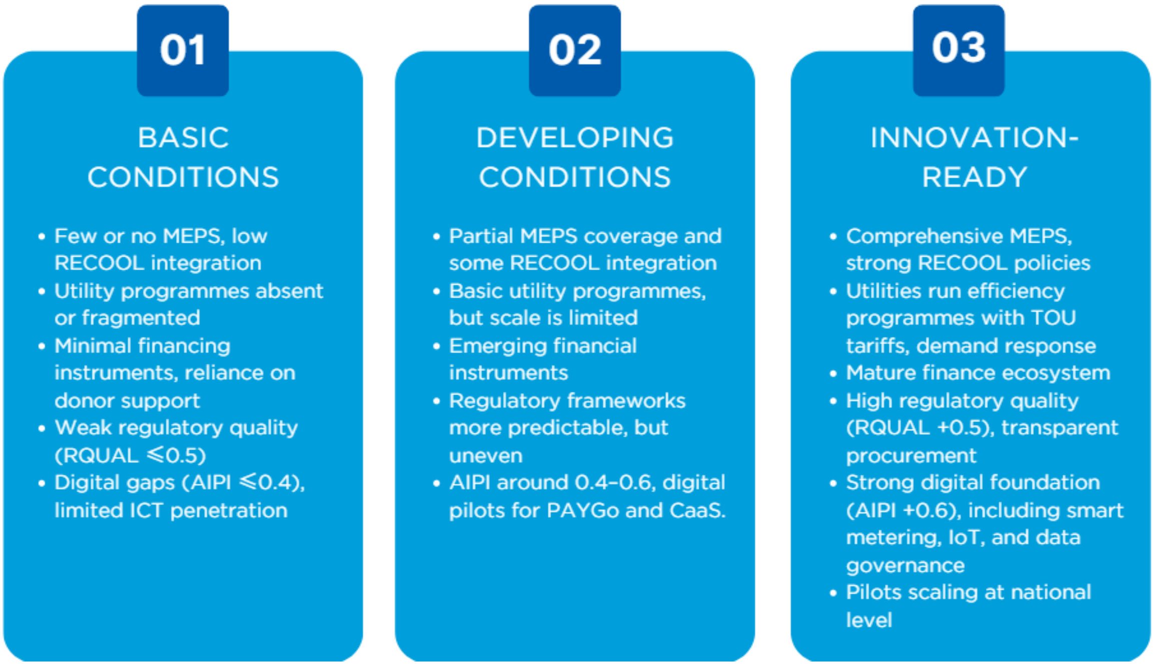
To complement the cluster analysis, Figure 11 synthesises the findings into a stylised policy pathway that illustrates how countries can progressively build an enabling environment for BMI4Cool. The pathway distinguishes three stages, basic, developing, and innovation ready, which reflect cumulative improvements in regulatory capacity, energy efficiency policy design, financing mechanisms, and digital readiness. Rather than representing a linear checklist, the pathway highlights the specific combinations of enablers required to move from minimum compliance-oriented systems toward performance and service-based cooling models.

At early stages, policy mixes tend to prioritise foundational regulation and minimum energy performance standards, with limited mechanisms to reward measured outcomes or support innovative delivery models. Progression toward a developing stage requires the expansion of incentive frameworks and financing mechanisms that reduce risk for providers and create demand for efficiency-oriented services. Reaching an innovation ready stage depends on the integration of digital enablers, such as data infrastructure and performance verification mechanisms, which allow regulators and markets to shift to outcome-based models.

Crucially, regulatory enforcement quality underpins this progression, since performance based and service-oriented cooling models depend on credible enforcement to ensure that standards, incentives, and verified outcomes are consistently applied.

Importantly, the relevance of this pathway extends beyond innovation objectives alone. Strengthening sustainable cooling ecosystems can also generate broader social benefits by reducing heat-related health risks, improving labour productivity, and ensuring that low-income and vulnerable populations gain access to reliable and affordable cooling. Embedding such equity considerations within national policy mixes would ensure that sustainable cooling transitions contribute simultaneously to environmental and developmental goals.

Figure 11. Policy Pathways for BMI4Cool



Source: Own elaboration.

5.2. Limitations

This study is subject to several limitations that shape the scope and interpretation of its findings.

First, the analysis is constrained by the uneven and incomplete nature of digital transformation in the Global South. Beyond basic provisions such as metering requirements or data collection initiatives, few policy instruments explicitly address the foundational digital and infrastructural conditions required for digitalisation in sustainable cooling. In many contexts, ageing energy infrastructure, limited grid reliability, and weak data systems undermine the feasibility of more advanced digital interventions, even where such initiatives are formally introduced. As a result, sustainable cooling continues to be governed primarily through efficiency and access frameworks, while the deeper structural constraints to digital transformation remain largely unaddressed in policy debate.

Second, the use of indicators as proxies introduces inherent limitations. Variables such as MEPS, RECOOL, INC, and FIN capture aspects of energy efficiency, but they cannot fully reflect the quality of implementation or the degree of enforcement. Additionally, broader indicators such as RQUAL and AIPI provide insight into regulatory quality and digital readiness but are not specific to the cooling sector. This abstraction means that the clusters illustrate relative enabling conditions, but they cannot substitute for in-depth, country-level analysis.

Third, data availability constrained the coverage of the study. Only Article 5 countries with sufficiently complete data were included, excluding 49 countries, many of them small island developing states and fragile contexts where cooling needs are acute. Imputation techniques were applied to fill some missing values, but this inevitably introduces additional uncertainty into the dataset.

Fourth, the clustering method itself entails methodological limitations. The choice of variables, standardisation, and the number of clusters influence the resulting typology. Although robustness checks were performed, the clusters should not be understood as fixed categories. Rather, they serve as an exploratory device to highlight structural differences and guide differentiated policy discussions. To strengthen the validity of this typology, future research should triangulate these results with in-depth case studies to assess the validity of the clusters.

Fifth, the use of the originally published Article 5 countries may add additional limitations. For instance, some countries have graduated from Article 5 status, reflecting improved conditions. By maintaining the original classification, this analysis may not fully capture these transitions or the heterogeneity they introduce within the sample. Future research could address this limitation by incorporating updated classification criteria or by explicitly modelling countries' transition dynamics. Such approaches would better capture how enabling environments evolve alongside formal development status, providing a more nuanced understanding of the relationship between development classification and sustainable cooling policy capacity.

Finally, the analysis offers only a cross-sectional snapshot of enabling conditions in 2023. It does not capture the dynamic nature of policy reform, donor programmes, or the diffusion of innovation. Given the rapid evolution of both energy and digital policy agendas, future research would benefit from a longitudinal approach to track how policy mixes evolve over time and how they affect the emergence of sustainable cooling markets.

6. Conclusions and Outlook

This thesis has examined the enabling conditions for sustainable cooling in Article 5 countries, focusing on the extent to which existing policy mixes can support business models such as CaaS, ESCOs, and PAYGo. By clustering countries according to governance, financial, and digital indicators, the analysis has highlighted the structural heterogeneity that shapes opportunities and constraints across the Global South.

The findings show that high-performing clusters are characterised by coherent efficiency policies, moderate to strong regulatory quality, and emerging digital readiness. These conditions align with the policy instruments identified in the literature as crucial for scaling service-based models, including MEPS, labelling, and performance verification tools. For these countries, immediate priorities involve building on established frameworks to pilot advanced business models and integrate renewable energy solutions.

A distinct group of middle high performers occupies an intermediate position. These countries display moderate institutional and efficiency performance alongside higher economic capacity but lack the policy coherence and digital depth required to fully support advanced business models. Without appropriate enforceable frameworks, these environments risk stagnating rather than transitioning toward service-based models.

Middle-low performers display fragmented policy mixes. While some conditions such as economic capacity or partial efficiency mandates exist, they are undermined by the absence of complementary instruments. In these contexts, differentiated interventions are required: strengthening efficiency frameworks where they are weak, and expanding financial de-risking mechanisms where mandates exist but cannot yet be scaled.

The low-performing clusters reveal systemic institutional constraints, particularly in regulatory quality. Here, even basic measures such as MEPS or labelling struggle to take hold. The implication is that technical cooperation must prioritise capacity building in regulatory enforcement and procurement, while also deploying targeted pilots and grants to generate early evidence and demand pull.

Taken together, the typology underscores that there is no single pathway toward sustainable cooling. Instead, policy strategies must be differentiated according to structural conditions. This contributes to the literature on policy mixes by demonstrating that coherence and complementarity across instruments matter as much as their presence. Weakness in one domain, whether governance, finance, or digitalisation, can significantly constrain the viability of models such as CaaS, ESCOs, or PAYGo.

The analysis also highlights a critical frontier for future action. While efficiency and renewable integration are increasingly addressed in policy frameworks, the foundational conditions for digital transformation remain largely underdeveloped. Digitalisation is rarely treated as a systemic enabler, and where advanced tools are introduced, they are often undermined by legacy infrastructure and institutional constraints. Addressing these foundational gaps represents both a limitation of current policy approaches and a central opportunity for international organisations and development partners to align sustainable cooling with broader digital transformation agendas.

In conclusion, this thesis provides an early, structured typology of enabling environments for sustainable cooling business model innovation. It shows that while progress has been made in efficiency and access, sustained scaling will depend on closing persistent gaps in regulatory enforcement, financial de-risking, and foundational digital infrastructure. Addressing these gaps through differentiated and cooperative policy strategies will be essential for delivering sustainable, inclusive, and scalable cooling solutions in the Global South.

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Appendices

Appendix I

The case of Cooling-as-a-Service

Within the cooling industry, CaaS arises as a versatile business model adaptable across diverse cooling applications (IFC & UNEP, 2024; Palafox-Alcantar et al., 2024). Palafox-Alcantar et al. (2024) identifies five broad sectors where CaaS is being implemented: industrial, commercial, cold chains, buildings, and cross-sector applications. Similarly, UNEP & IFC (2024) discuss the deployment of CaaS in institutional buildings, food supply chains, and district-level infrastructure, reinforcing the view that CaaS is a scalable and modular business model innovation. This sectoral flexibility underscores CaaS's potential as a cross-cutting solution in the transition to sustainable cooling.

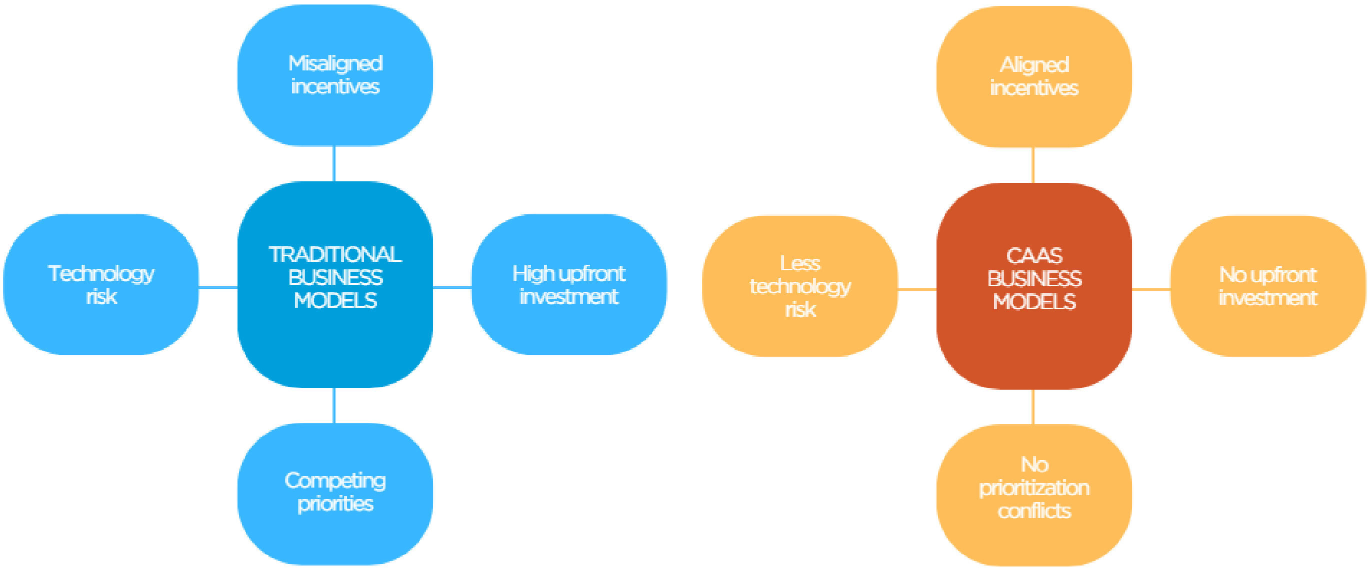
CaaS addresses many of the challenges associated with the traditional cooling business by enabling customers to pay for the cooling service received, typically measured by output or usage, such as per unit of cold air or per ton hour of refrigeration, rather than directly purchasing the cooling equipment and paying for the electricity bills (Abramskiehn & Richmond, 2019; Della Maggiora et al., 2022). As such, the provider retains ownership of the equipment and is responsible for its installation, operation, and maintenance, consequently linking the efficiency of the cooling system to its profit (Abramskiehn & Richmond, 2019; Della Maggiora et al., 2022).

This structure creates several direct incentives. In the case of providers, a clear incentive is installing and maintaining the most efficient and reliable technology since reducing operational costs directly improves their profitability (Abramskiehn & Richmond, 2019; Della Maggiora et al., 2022). Furthermore, providers are incentivised to deploy systems that are modular so that components are reusable or recyclable at the end of the service provision (Abramskiehn & Richmond, 2019). As such, this model supports circular economy principles through long-term equipment design, modularity, reuse, and recycling (Della Maggiora et al., 2022).

For consumers, their incentives lie in reducing the monthly fee paid. As this model eliminates the need for upfront investments on equipment and installation, the fee paid by customers is higher than what they would have paid with conventional ownership models, since it includes the equipment, operations, maintenance, and profit margins of the provider (Abramskiehn & Richmond, 2019). However, this introduces a key motivation for the customer, who has a stronger incentive to minimize cooling use, thereby further lowering electricity consumption, costs, and GHG emissions (Abramskiehn & Richmond, 2019).

Moreover, CaaS facilitates the deployment of cleaner technologies since the elimination of upfront investment helps reduce the perceived risk associated with the implementation of new and lesser-known technologies (Abramskiehn & Richmond, 2019; Della Maggiora et al., 2022). Therefore, CaaS reshapes the incentives each stakeholder has across the cooling chain, lowers entrance barriers to access cleaner technologies, and shifts the financial and performance responsibility to service providers, encouraging long-term efficiency (Della Maggiora et al., 2022).

Figure 12. Traditional Business Models vs. CaaS



Source: Own elaboration based on Abramskiehn and Richmond (2019) and Della Maggiora et al. (2022).

Lastly, literature highlights the unique position CaaS models hold to improve efficiency in developing countries. In their analysis, Abramskiehn and Richmond (2019) compared CaaS to over twenty-five existing financial instruments and service models to assess its distinct value proposition, concluding that unlike traditional models such as ESCOs or district cooling systems, CaaS is particularly well suited for emerging markets, where limited capital, high energy costs, and growing cooling demand require innovative financing solutions that reduce risk and promote efficient, low-emission technologies. From analysis conducted within the Mexican market, the authors highlight that this model enabled savings of up to 23% of cooling costs for customers and reduced emissions from electricity and leakage by up to 40%.

Characteristics of CaaS Contracts

In evaluating the viability of service-based models for clean cooling, Abramskiehn and Richmond (2019) offer a detailed analysis of how the CaaS model is operationalised, particularly within the context of emerging markets. Their study outlines the contractual, technical, and financial components that enable the implementation and scalability of the model. Although the report describes these mechanisms in detail, it is important to note that the model, at the time of writing, was still in early stages of real-world deployment, with implementation efforts underway but not yet fully realised.

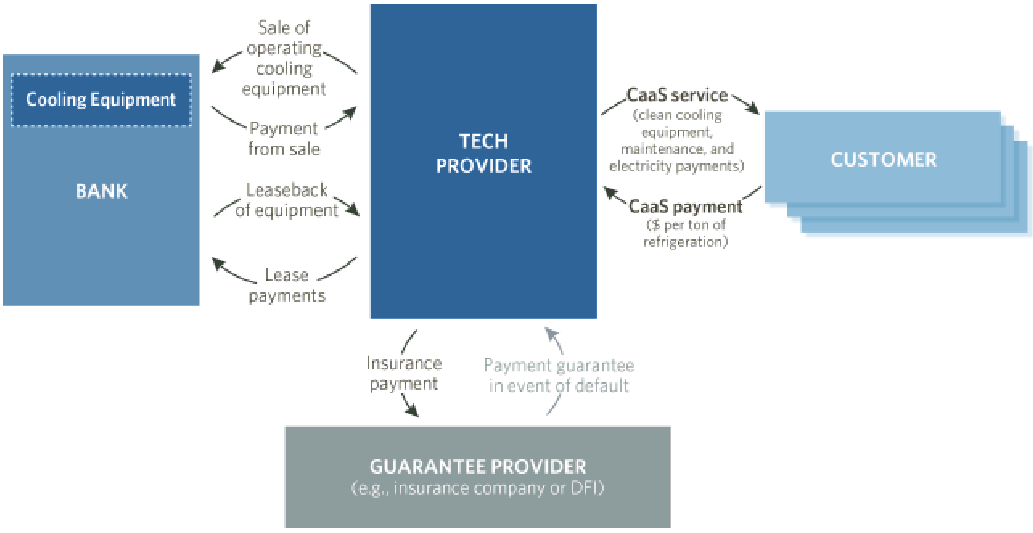
At the core of the CaaS framework is a standardised service agreement that replaces traditional equipment ownership with a pay-per-use structure. Importantly, this contract is structured as a service agreement rather than a lease to ensure that it remains off the customer's balance sheet. This distinction preserves the customer’s borrowing capacity and lowers financial barriers to adoption. The responsibility for installation, performance, and maintenance is transferred entirely to the technology provider. This party not only owns the equipment but is also accountable for electricity payments and any necessary repairs. Electricity costs are passed through at cost rather than marked up, reinforcing the alignment between efficiency and profitability.

The authors highlight the model’s emphasis on modularity and end-of-life flexibility, allowing for equipment reuse or redeployment, especially in cases of customer contract termination. These design choices not only extend the usable life of high-efficiency systems but also align the model with circular economy principles.

To support providers' capital needs, the model incorporates flexible recapitalisation mechanisms. Two primary approaches are explored: 1) sale-leaseback arrangements, in which a financial institution purchases the cooling equipment and leases it back to the provider; and 2) the creation of special purpose vehicles (SPVs), which can own and operate multiple CaaS contracts while outsourcing operations to a technology partner. In both, risks are managed through payment guarantees that protect against customer default.

The report outlines these recapitalisation mechanisms with a focus on their structural roles in enabling provider access to external finance. In the case of the sale-leaseback arrangement, a financial institution purchases the cooling equipment and leases it back to the service provider for a term that does not exceed the CaaS contract period. This transaction is described as asset-backed, with the customer contract serving as additional collateral. A payment guarantee, either from an insurance company or investment fund, may be included to protect the equipment provider from customer payment default. At the end of the contract, ownership of the equipment returns to the technology provider.

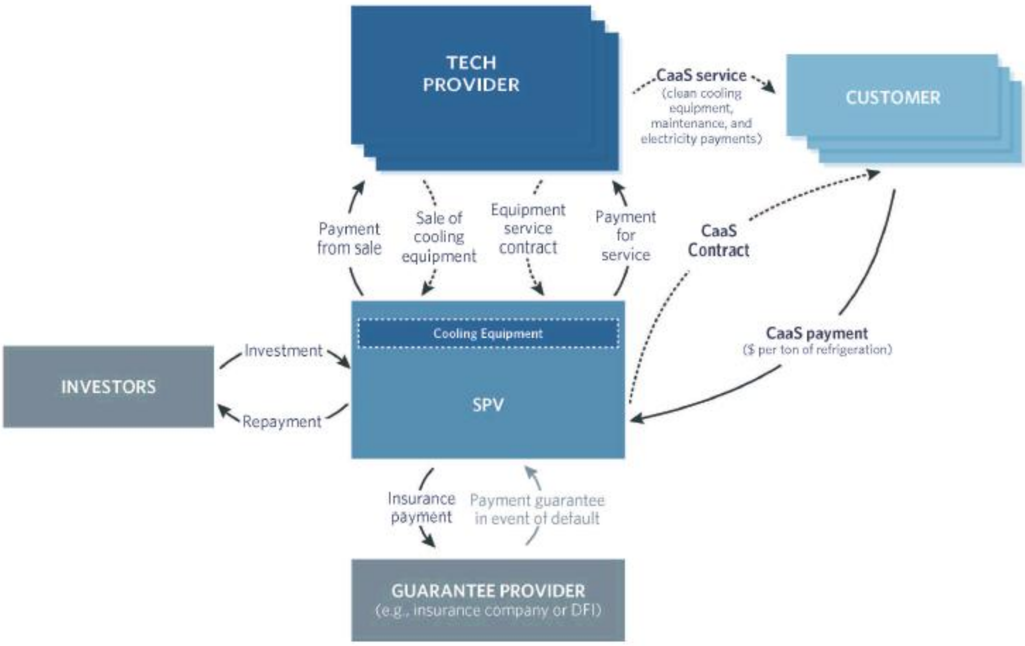
Figure 13. CaaS Model Using Sale-Leaseback



Source: Abramskiehn and Richmond (2019).

On the other hand, the SPV structure is presented as an alternative recapitalisation approach in which a special purpose vehicle, owned by multiple investors, purchases the equipment and signs the CaaS contracts with clients. The technology provider remains responsible for operation and maintenance, including utility payments, but does not retain ownership of the equipment. Similar to the sale-leaseback model, a payment guarantee may be used to mitigate risk. The report notes that this structure is under exploration for implementation in several markets, including Jamaica.

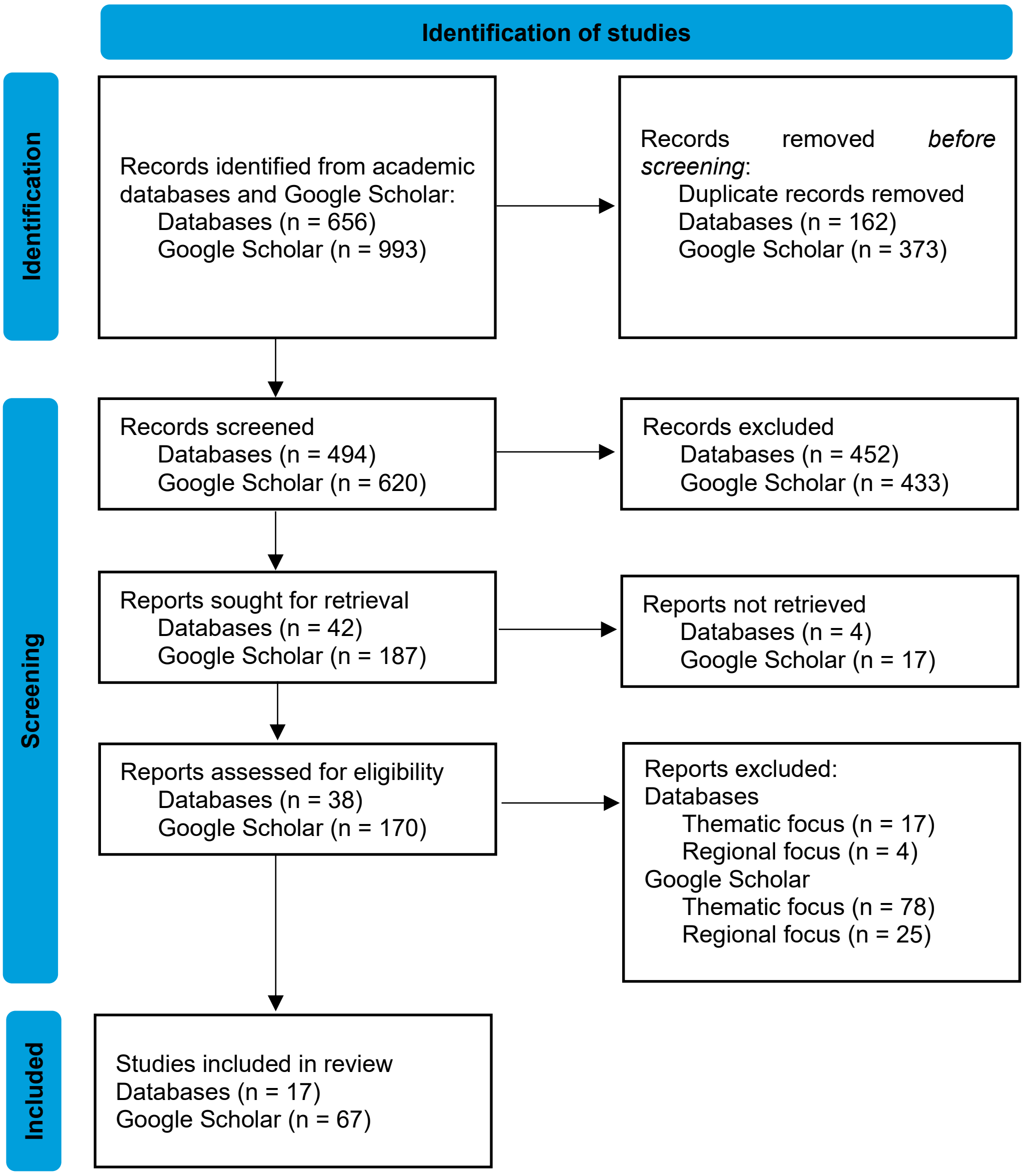
Figure 14. CaaS Model Using SPV



Source: Abramskiehn and Richmond (2019).

Appendix II

PRISMA Flowchart and Keywords Used



	Keywords
1. Governance and Institutional Capacity	“cooling policy"
	"sustainable cooling" AND "policy"
	“regulatory framework" AND "sustainable cooling/cooling”
	“public procurement" AND "sustainable cooling/cooling”
2. Finance and Business Dynamics	“Cooling as a Service”
	“Energy Service Company/ies" AND "sustainable cooling/cooling”
	“Pay-as-you-go" AND "sustainable cooling/cooling”
	“business model" AND "sustainable cooling/cooling”
	“climate finance" AND "sustainable cooling/cooling”
3. Data and Digital Infrastructure	“data" AND "sustainable cooling”
	“innovation" AND "sustainable cooling”
	"data" AND "cooling markets"
	“digital readiness" AND "sustainable cooling/cooling”
	“digitalisation" AND "sustainable cooling/cooling”

Appendix III

List of Countries Excluded

Missingness above 25%			
COUNTRY	CTY_CODE	ART5	Missing Variables Count
Cook Islands	COK	ART 5	6
Niue	NIU	ART 5	6
Democratic People's Republic of Korea	PRK	ART 5	6
Cuba	CUB	ART 5	6
Equatorial Guinea	GNQ	ART 5	5
Grenada	GRD	ART 5	5
St. Kitts and Nevis	KNA	ART 5	5
Kiribati	KIR	ART 5	5
Nauru	NRU	ART 5	5
Marshall Islands	MHL	ART 5	5
Tuvalu	TUV	ART 5	5
Tonga	TON	ART 5	5
Samoa	WSM	ART 5	5
Dominica	DMA	ART 5	5
Micronesia (Federated States of)	FSM	ART 5	5
Sao Tome and Principe	STP	ART 5	5
Palau	PLW	ART 5	5
Antigua and Barbuda	ATG	ART 5	5
Comoros	COM	ART 5	4
Cabo Verde	CPV	ART 5	4
Bahamas	BHS	ART 5	4
St. Lucia	LCA	ART 5	4
Libya	LBY	ART 5	4
Guyana	GUY	ART 5	4
Iraq	IRQ	ART 5	4
Fiji	FJI	ART 5	4
Gabon	GAB	ART 5	4
Gambia	GMB	ART 5	4
Guinea-Bissau	GNB	ART 5	4
Djibouti	DJI	ART 5	4
Belize	BLZ	ART 5	4
Brunei Darussalam	BRN	ART 5	4
Barbados	BRB	ART 5	4
Bhutan	BTN	ART 5	4
Botswana	BWA	ART 5	4
Mauritius	MUS	ART 5	4
Namibia	NAM	ART 5	4
Trinidad and Tobago	TTO	ART 5	4
Timor-Leste	TLS	ART 5	4
Syrian Arab Republic	SYR	ART 5	4

Seychelles	SYC	ART 5	4
Suriname	SUR	ART 5	4
Eswatini	SWZ	ART 5	4
Lesotho	LSO	ART 5	4
St. Vincent and the Grenadines	VCT	ART 5	4
Holy See	VAT	NON-ART 5	7
San Marino	SMR	NON-ART 5	6
Andorra	AND	NON-ART 5	5
Monaco	MCO	NON-ART 5	5
Liechtenstein	LIE	NON-ART 5	5
Iceland	ISL	NON-ART 5	4
Estonia	EST	NON-ART 5	4
Cyprus	CYP	NON-ART 5	4
Lithuania	LTU	NON-ART 5	4
Latvia	LVA	NON-ART 5	4
Luxembourg	LUX	NON-ART 5	4
Malta	MLT	NON-ART 5	4
Slovenia	SVN	NON-ART 5	4

Missing GDP values		
COUNTRY	**CTY_CODE**	**ART5**
Eritrea		ART 5
South Sudan		ART 5
Venezuela (Bolivarian Republic of)		ART 5
Yemen, Rep.		ART 5

Reclassified Countries

Decision V/4 (1993)[1]:

- Cyprus, Kuwait, the Republic of Korea, Saudi Arabia, Singapore and the United Arab Emirates reclassified as non-article 5 Parties
- Malta and Bahrain reclassified as Article 5 Parties

Decision XVI/40 (2004)[2]:

- Malta was removed from the list of developing countries and reclassified as a non-article 5

Decision XVII/2 (2005)[3]:

- Cyprus removed from the list of developing countries and reclassified as a non-article 5

Decision XXV/16 (2016) [4]:

- Croatia removed from the list of developing countries and reclassified as a non-article 5

Decision XIX/19[5]:

- Romania removed from the list of developing countries and reclassified as a non-article 5

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[1] Source: https://ozone.unep.org/treaties/montreal-protocol/meetings/fifth-meeting-parties/decisions/decision-v4-classification-certain-developing-countries-not-operating-under-article-5-and . Accessed November 15, 2025.

[2] Source: https://ozone.unep.org/treaties/montreal-protocol/meetings/sixteenth-meeting-parties/decisions/decision-xvi40-request-malta-be-removed-list-developing-countries-under-montreal-protocol . Accessed November 15, 2025.

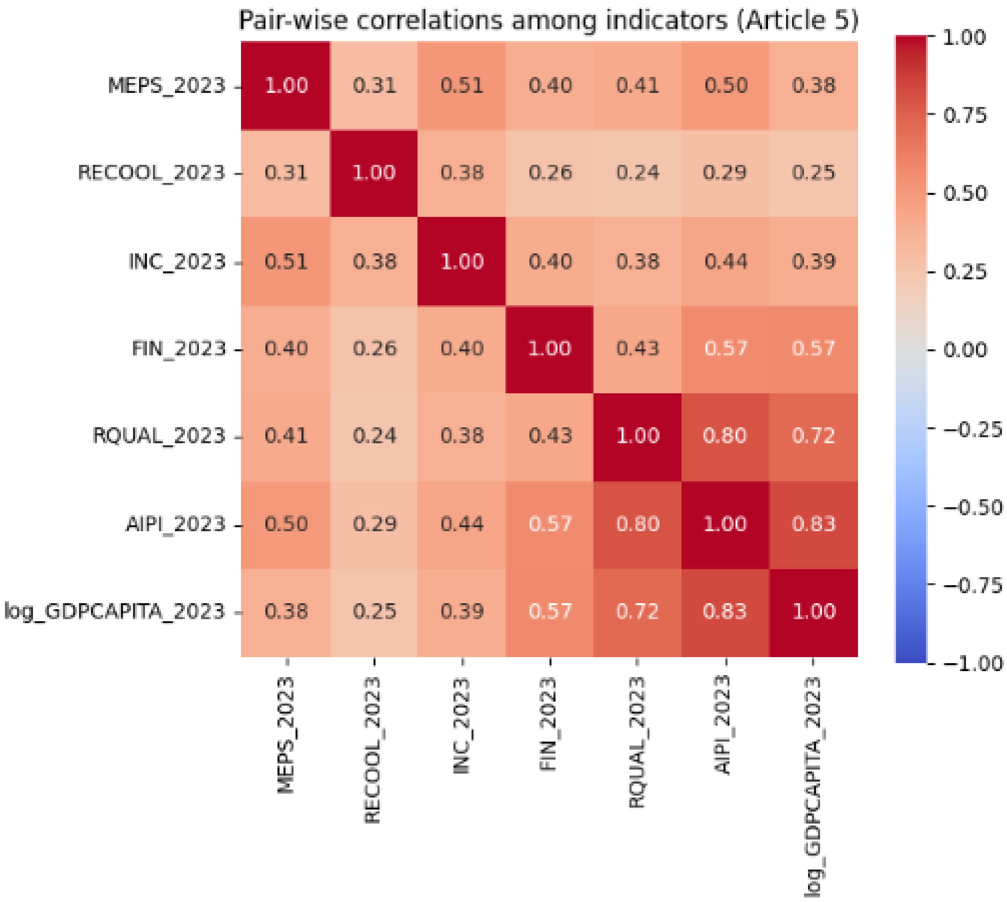
[3] Source: https://ozone.unep.org/treaties/montreal-protocol/meetings/seventeenth-meeting-parties/decisions/decision-xvii2-request-cyprus-be-removed-list-developing-countries-under-montreal-protocol#:~:text=To%20note%20the%20request%20by,the%20year%202005%20and%20thereafter; . Accessed November 15, 2025.

[4] Source: https://ozone.unep.org/treaties/montreal-protocol/meetings/twenty-fifth-meeting-parties/decisions/decision-xxv16-request-croatia-be-removed-list-developing-countries-under-montreal-protocol . Accessed November 15, 2025.

[5] Source: https://ozone.unep.org/treaties/montreal-protocol/meetings/nineteenth-meeting-parties/decisions/decision-xix19-request-romania-be-removed-list-developing-countries-under-montreal-protocol . Accessed November 15, 2025.

Appendix IV

Multicollinearity and VIF Analysis



	VARIABLE	VIF
5	AIPI_2023	4.930684
6	log_GDPCAPITA_2023	3.538809
4	RQUAL_2023	2.849127
3	FIN_2023	1.658852
0	MEPS_2023	1.593424
2	INC_2023	1.564444
1	RECOOL_2023	1.208158

Appendix V

Test	Variables	Method	N	K	Analysis	Hopkins
1	MEPS, RECOOL, INC, FIN, RQUAL, AIPI	**K-Means**	102	5-10	No clear clustering in Elbow and DB test. High intra-cluster variability. Clustering ignored economic capacity.	0.34
2	PCA_ENERGY, RQUAL, AIPI	**K-Means**	102	6, 8	Soft bends at 6 and 8. High intra-cluster variability. High correlation between RQUAL and AIPI (0.8). Clustering ignored economic capacity.	0.25
3	MEPS, RECOOL, INC, FIN, RQUAL, AIPI, GDP (country values)	**K-Means**	97	3	Sharp bend at k=3, however, not useful for interpretation. Mostly driven by GDP. High intra-cluster variability. Fixed correlation problems, but lower Hopkins scores	0.24
4	MEPS, RECOOL, INC, FIN, RQUAL, AIPI, GDP country values (log)	**K-Means**	97	2,14		0.35
5	MEPS, RECOOL, INC, FIN, RQUAL, AIPI, Log GDP (per capita)	**K-Means**	98	2,9, 12, 13	k = 13 : 2 clusters with 1 k= 12: 1 cluster with 1	0.36
6	PCA_ENERGY, RQUAL, AIPI, Log GDP (country values)	**K-Means**	97	2,14	Elbow and DB show mixed results. More nuanced intra-cluster variability with higher Ks. Fixed correlation problems, but lower Hopkins scores. PCA did not improve clustering.	0.24
7	PCA_ENERGY, RQUAL, AIPI, GDP (country values)	**K-Means**	97	3	Sharp bend at k=3, however, not useful for interpretation. Mostly driven by GDP so it is probably clustering by economic size. High intra-cluster variability Fixed correlation problems, but lower Hopkins scores	0.13
8	MEPS, RECOOL, INC, FIN, RQUAL, AIPI, GDP (country values), TOTALRISK	**K-Means**	60	8	Clear bend at k=8. Medium-intra cluster variability. No correlation problems, low Hopkins score. Population at risk reduced the sample to 40%-	0.26
9	PCA_ENERGY, RQUAL, AIPI, GDP (country values), TOTALRISK	**K-Means**	60	8	Clear bend at k=8. Medium-intra cluster variability. No correlation problems, low Hopkins score. Population at risk reduced the sample to 40%. PCA did not improve clustering.	0.18
10	PCA_ENERGY, RQUAL, AIPI, GDP (country values), TOTALRISK	**Hierarchical**	60	7	Medium-intra cluster variability No correlation problems, Low Hopkins score. PCA did not improve clustering. Very similar results as K-means.	0.18