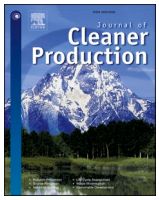
Journal of Cleaner Production 482 (2024) 144190

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro



# Servitization for the energy transition: The case of enabling cooling-as-a-service (CaaS)

P.G. Palafox-Alcantar [a,b,*], C. McElroy [a,b], P. Trotter [b,c], R. Khosla [a,b], A. Thomas [c], R. Karutz [d]

[a] Future of Cooling Programme, Oxford Martin School, University of Oxford, Oxford, UK
[b] Smith School of Enterprise and the Environment, School of Geography and the Environment, University of Oxford, Oxford, UK
[c] Schumpeter School of Business and Economics, University of Wuppertal, Wuppertal, Germany
[d] RWTH Aachen University, Aachen, Germany

ARTICLE INFO

Handling Editor: Zhifu Mi

*Keywords:*
Business model
Circular economy
Cooling
Servitisation
Servitization
Sustainability

ABSTRACT

As temperatures rise rapidly around the world, Cooling-as-a-Service (CaaS) promises to offer cooling solutions without requiring any initial outlay of funds. CaaS transfers the emphasis from ownership of cooling equipment to its prevision as a service by enabling users to pay for cooling according to usage. CaaS is an emerging servitization circular economy business model that is both attracting great attention and is not yet well-documented in the academic literature. Given that energy demand for cooling is set to triple in the upcoming decades, new cooling solutions are urgently needed to protect the thermal comfort, health and productivity of people around the world who will experience increased or new needs for cooling. Business model innovation for the servitization of cooling holds great potential to overcome existing barriers to the delivery of cooling that is accessible as well as energy and materially efficient. The paper's focus on cooling is a novel approach contributing to the limited information on how to implement servitization for sustainable energy transitions. The paper also contributes novel empirical insights about the current extent and varieties of CaaS. Through 32 qualitative interviews across 10 countries, we identify barriers and enablers of CaaS and discuss the degree to which these vary across different sectors and geographies of CaaS. From these findings we highlight key issues with CaaS implementation. 1) The complexity of measuring CaaS adoption worldwide. 2) The significance of geographical barriers and enablers for its growth. 3) The potential for Global South leadership with CaaS.

## 1. Introduction

The ongoing global sustainability transition towards net-zero emissions and decent living standards for all without compromising the ability of future generations to flourish requires new ways of doing business (Geissdoerfer et al., 2018b; Schot and Steinmueller, 2018). Environmentally, businesses have been a key driver of global greenhouse gas emissions, and rapid decarbonisation is needed to reach the goals of the Paris Agreements (Pye et al., 2020; Welsby et al., 2021). Socially, businesses are key to meet societal needs (Khosla et al., 2020), which is especially salient for developing economies, for instance, in the context of sub-Saharan Africa (SSA) where the private sector has been described to provide basic infrastructure needs that would otherwise be inaccessible (Batidzirai et al., 2021; Trotter and Brophy, 2022). The concept of Business Models (BMs), particularly Business Model Innovation (BMI), is widely recognised as a valuable analytical tool for examining how businesses are innovating to create new and diverse forms of value, both for sustainability transitions in general and for energy transitions specifically (Bocken et al., 2014; Bolton and Hannon, 2016; Geissdoerfer et al., 2018b). Technological advancements and behavioural changes are critical tools for driving transitions to sustainable cooling (Khosla et al., 2020). However, delivering sustainable cooling through BMI remains an underutilised yet essential lever, which this paper focuses on.

This paper examines the servitization business model, where companies shift from selling products to selling the services those products provide (Baines et al., 2017). A well-known example is Rolls Royce's transition to sell engine power as "power-by-the-hour", rather than jet

* Corresponding author. Future of Cooling Programme, Oxford Martin School, University of Oxford, Oxford, UK.
*E-mail addresses:* giovani.palafox-alcantar@smithschool.ox.ac.uk (P.G. Palafox-Alcantar), caitlin.mcelroy@smithschool.ox.ac.uk (C. McElroy), philipp.trotter@smithschool.ox.ac.uk (P. Trotter), radhika.khosla@smithschool.ox.ac.uk (R. Khosla), anne-marie.thomas@uni-wuppertal.de (A. Thomas), robin.karutz@rwth-aachen.de (R. Karutz).

https://doi.org/10.1016/j.jclepro.2024.144190
Received 3 January 2024; Received in revised form 17 October 2024; Accepted 8 November 2024
Available online 9 November 2024

engines themselves, and Michelin's "tyre-by-the-mile" (Stahel, 2016). In these models, the consumers receive the desired performance without owning or maintaining the product, theoretically incentivising manufacturers to enhance product efficiency and longevity. This realignment of incentives has driven recent research on servitization, especially in the energy sector (Park, 2022), as it embeds resource efficiency and makes energy services more accessible (Mukoro et al., 2022; Trotter and Brophy, 2022).

The literature on servitization for the energy transition has grown quickly in recent years (Baines et al., 2017; Park, 2022; Raddats et al., 2019). This paper aims to address two key gaps in the existing research. First, although the literature on servitization is expanding, there remains a significant lack of empirical evidence on the most effective implementation of servitization models. The majority of recent studies are either conceptual (Park, 2022; Singh et al., 2022; Tauqeer and Bang, 2018), or focus on the design of specific energy servitization applications (Adwek et al., 2020; Kizilcec and Parikh, 2020; Okkonen and Suhonen, 2010; Wasserbaur et al., 2023). It remains unclear which aspects of servitization transitions companies are struggling with, and to what extent these challenges are context-specific across different geographies and cooling sectors. Second, to the best of our knowledge, the existing literature on energy servitization has predominantly focused on heat and electricity-related services (Adwek et al., 2020; Knuckles, 2016; Park, 2022; Singh et al., 2022; Wasserbaur et al., 2023). As a consequence, this study is the first to focus on Cooling-as-a-Service (CaaS), addressing a significant gap in the literature (Khosla et al., 2020). Despite the growing body of work on energy and "as-a-service" models, CaaS has been overlooked in empirical studies and conceptual discussions (Singh et al., 2022).

The expected global energy demand for space cooling will triple by 2050, with the necessary increased power generation capacity matching that of the United States, European Union and Japan in 2018 (International Energy Agency, 2018). This demand increase is driven by population and economic growth, as well the growing need to protect the health and productivity of people around the world given the impacts of climate change (Khosla et al., 2022). In the coming decades, vast regions like the African continent, as well as areas that have historically not required cooling, such as Northern Europe, will face a growing need for cooling solutions (Miranda et al., 2023). This surge in demand creates a unique opportunity to rethink how cooling is provided, with CaaS offering a promising yet largely overlooked approach (Palafox-Alcantar et al., 2022). This paper contributes to the understanding of CaaS by exploring its complex BMI, and provides new knowledge and analysis on how CaaS is a rapidly emerging trend and the role it can play in innovation leadership.

This paper focuses on CaaS, a specific energy-related servitization model, to explore the barriers and enablers of its implementation and implications for sustainable cooling. CaaS is a burgeoning area offering an empirical lens through which to investigate the sustainability benefits of servitization. These benefits remain contested both empirically (e.g., measurement and generalisability) and theoretically (e.g., power dynamics and environmental impact) (Sarancic et al., 2023). Unlike more established energy servitization models, CaaS is emerging in response to the rapid global demand for cooling, with examples ranging from food cooling in sub-Saharan Africa to residential space cooling in Singapore.

Using 32 semi-structured interviews with CaaS providers, public sector experts, and NGOs, along with secondary data, we provide novel insights into CaaS across various sectors and geographies. This paper contributes to both the empirical understanding of CaaS and the broader servitization literature by identifying key enablers and barriers, and highlighting the contextual variations that affect its implementation. From these findings, we offer evidence-based recommendations for scaling CaaS and advancing the role of servitization in achieving sustainable energy transitions.

## 2. Background

### 2.1. Business Model Innovation (BMI) for the energy transition

In management literature, BMs are typically referred as a firm's combination of value proposition, value capture approach, and value networks needed for value creation (Foss and Saebi, 2017). This included how a company creates value, its customer and revenue model, and the necessary partnerships to deliver this value (Bocken et al., 2014; Foss and Saebi, 2017; Wesseling et al., 2020). The BM is particularly useful to understand how companies adapt to changing value creation needs during transition processes (Trotter and Brophy, 2022; Wesseling et al., 2020).

BMI focuses on adapting or overhauling these components to seize new opportunities during transitions (Bolton and Hannon, 2016; Foss and Saebi, 2017). Innovations can range from minor adjustments to more significant industry-wide changes, referred to as architectural or complex BMI, depending on their novelty to the firm or industry (Foss and Saebi, 2017).

BMI has become especially relevant with the rise of new technologies and sustainability goals, as companies look for new ways to create value in the energy transition (Geissdoerfer et al., 2018b; Pieroni et al., 2019). While the literature is yet only indicative, it links complex BMI to sustainability transitions, indicating that systemic changes are required deliver on sustainability goals (Boons and Lüdeke-Freund, 2013; Trotter and Brophy, 2022). However, complex BMI diverges from other innovation types, such as, process or product innovation (Chesbrough, 2010; Zott et al., 2011), and poses challenges requiring firms to shift from established methods of value creation and resource allocation (Chesbrough, 2010; Guldmann and Huulgaard, 2020) while engaging a broader range of stakeholders (Bocken et al., 2014; Geissdoerfer et al., 2018a; Guldmann and Remmen, 2018; Roome and Louche, 2016).

The global energy transition has led to diverse BMI approaches aimed at sustainability, including innovations in energy generation, distribution, storage, access and trade (International Renewable Energy Agency, 2019). For example, the "prosumer" model allows consumers to both produce and sell home-generated clean energy, disrupting traditional energy markets (Richter, 2013). Circular BMs also aim to reduce resource inputs and emissions by closing loops and switching to renewable energy sources (Geissdoerfer et al., 2018a; Sumarsono et al., 2023). The next section explores servitization BMs for the energy transition.

### 2.2. Servitization Business Models for the energy transition

The energy transition has created significant opportunities for servitization-based BMs. These models are commonly classified into three types: product-oriented (enhancing product value through complementary services), use-oriented (selling services instead of assets), and result-oriented (selling specific outcomes) (Hockerts and Weaver, 2002; Pelli and Lähtinen, 2020; Yang and Evans, 2019)9). Use- and results-oriented servitization models, in particular, align environmental and economic goals by incentivising energy efficiency. For instance, sellers retain ownership of assets like solar PVs or air conditioning units, in energy efficient technology to improve business profitability and reduce environmental impact (International Renewable Energy Agency, 2019; Park, 2022).

Result-oriented models further drive sustainability by focusing on product longevity, reusability, efficient resource use (Doni et al., 2019), with recycling and remanufacturing strategies becoming more profitable (Kühl et al., 2019; Yang and Evans, 2019). For users, servitization BMs lower the barrier to adopting sustainable technologies, such as district heating or heat pumps, by reducing upfront costs (Okkonen and Suhonen, 2010; Singh et al., 2022). Additionally, servitization can promote social sustainability by improving access to essential energy services, as seen with "Pay-as-you-go" energy models in East Africa,

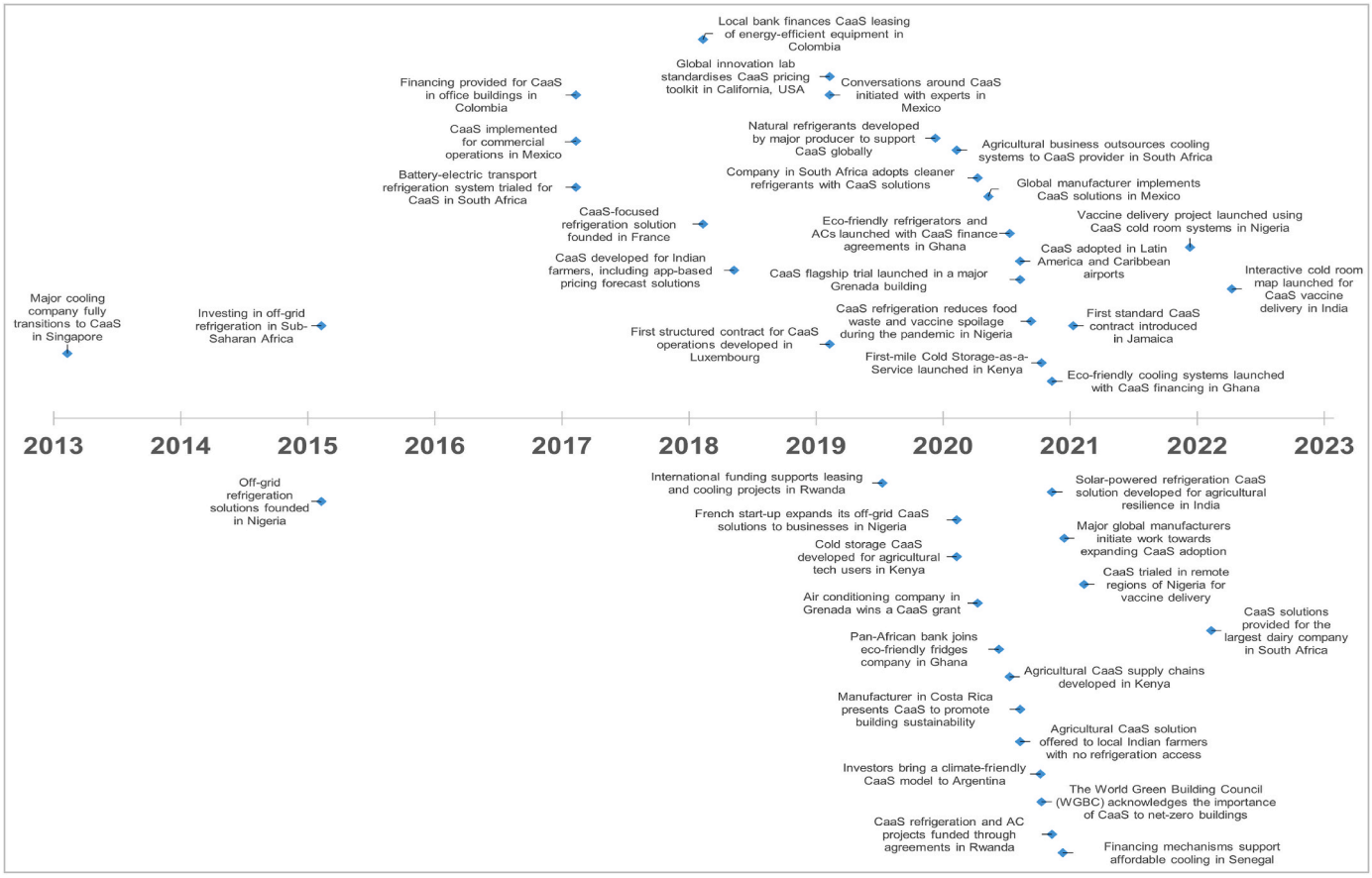



**Fig. 1.** Timeline of significant events for the development of CaaS providers.

which have replaced hazardous kerosene lamps (Trotter et al., 2017, 2019).

While these benefits extend to the Global South, CaaS also holds potential for the Global North, where climate change is increasing demand for cooling (Khosla et al., 2020; Miranda et al., 2023). However, literature on CaaS remains scarce and has mostly focused on technical analyses of district cooling networks – only one form of CaaS (ESMAP, 2020). Studies like Martínez-Ruiz et al. (2023) focus on technical aspects of district cooling, and other reviews examine the integration of renewables into these systems (Jon Chua et al., 2023), but do not address CaaS delivered to individuals or small businesses. Our work contributes to the knowledge of CaaS by also focusing on companies offering the service to individual clients.

This paper helps understand three significant dimensions of CaaS by studying it as a complex BMI. First, the paper shows how CaaS makes low-carbon cooling more accessible, reshapes value capture (selling cooling services rather than equipment), and expands stakeholder networks (local residents, municipalities and financiers). Second, it shows a historical analysis of real-world development of CaaS which is rapidly emerging across different sectors and geographies, offering a unique opportunity to study sector-specific barriers and enablers (Fig. 1). Third, CaaS exemplifies the growing pluralism in global innovation leadership with leaders emerging from the Global South, such as ColdHubs in Nigeria. CaaS thereby allows for a more pluralistic and inclusive analysis of context-specific challenges and innovation success stories than in the existing energy servitization literature (Singh et al., 2022).

### 2.3. CaaS and the enablers and barriers of servitization

While most research on energy servitization focuses on heating (Britton et al., 2021; Brown et al., 2022; Fell, 2021; Gillham et al., 2023), cooling differs in several important ways. First, heating servitization is concentrated in developed markets like North America and Europe, which have established infrastructures (Gillham et al., 2023). CaaS is emerging in regions without prior cooling systems. Second, heating models primarily target the residential sector, while CaaS is more prevalent in commercial spaces and cold chains. Lastly, heating servitization involves diverse technologies, whereas CaaS primarily focuses on air conditioners and refrigeration units.

Our study expands on the literature by exploring CaaS at a specific stage of BMI, a crucial topic as global cooling demand becomes more central to energy resource management (Pavanello et al., 2021). Cooling needs vary across industries, so we categorise CaaS into five cooling sectors: Industrial (e.g., pre-mixed concrete), Commercial, Cold Chains, Buildings, and Cross-Sector. This allows an examination of sector-specific dynamics (Zhang and Banerji, 2017), while identifying common barriers and enablers across the cooling landscape (Stegehuis et al., 2023).

Interestingly, most CaaS businesses are independent of incumbent cooling manufacturers, unlike traditional servitization models, which are driven by product manufacturers (Kanatlı and Karaer, 2022). Palo et al. (2019) unearth servitization BMs contestation, by studying the challenges of traditional BMs and servitization models finding their efficiencies, as they both respond and contribute to changing market conditions and customer expectations. This independence presents opportunities to challenge existing cooling BMs and create, new innovative pathways that can leapfrog the outdated infrastructures.

Further, existing studies highlight the need for a clear value proposition for success in competitive cooling markets like Indonesia (Suganda and Gabriel, 2021). Other literature focuses on specific servitization applications such as residential heating (Gillham et al., 2023) or digitalisation (Chirumalla et al., 2023). However, there is limited

analysis of the factors enabling CaaS implementation, particularly in diverse global contexts.

In assessing the current extent of CaaS adoption across sectors, and the barriers and enablers to its implementation, Cultural values significantly influence the perception and uptake of CaaS. For instance, some communities may prioritise short-term economic gains over long-term sustainability, impacting CaaS adoption (Kanatlı and Karaer, 2022). Furthermore, CaaS adoption is influenced by the socio-technical context, as energy use, comfort and cleanliness vary across cultures. Lastly, CaaS models may be successful in one region but may encounter resistance in others due to local cultural specificities (Lafuente et al., 2019).

By considering the interplay of culture and innovation, we provide a more nuanced understanding of CaaS adoption and suggest ways forward for culturally informed models. These must resonate with local communities and promote sustainable and equitable energy transitions.

## 3. Methods and Data

### 3.1. Data collection and sample description

This study sought to conduct a thematic analysis of enablers and barriers to CaaS implementation from a wide range of businesses and relevant experts and in this process also mapped the emerging landscape of CaaS. The study was primarily conducted using semi-structured interviews in which the key topics addressed were understanding the context of the emergence of the specific instance of CaaS and the barriers and enablers to its implementation. Two different types of stakeholders were interviewed sequentially. The first, represented as category A included servitization experts in CaaS, policy advisors, and investors. The second, category 'C', included directly involved stakeholders in the delivery of CaaS such as service providers and end users. Data was collected using a top-down approach. Using the interviews in the first phase to inform and understand the business value of CaaS and later study servitization enablers and barriers specifically relevant to individual CaaS businesses.

Ethical approval was obtained from the University of Oxford Central Research Ethics Committee to ensure the participants' confidentiality (reference SOGE 1A2020-159). To retain confidentiality, the recordings were assigned a letter and number according to their stakeholder category and participation number respectively (e.g., A8 corresponds to the participant expert in finance and regulation assigned number 8, and C31 corresponds to the recording on end-user perspectives assigned number 31) (see Table 1).

Our data consists of both primary and secondary source data. Primary-source data was collected through semi-structured interviews with stakeholders already engaging with a community of CaaS practitioners organised by BASE, a Swiss non-profit and UNEP partner supporting investment and market mechanisms for climate solutions. The variability of countries and cooling sectors of operation of the interviewees are shown in Table 2. Notably, there are multiple interviewees that work across different sectors and in different geographies (mainly from the first interviewees groups – A). This was deemed justifiable as it was crucial to understand the CaaS value proposal from a non-practitioner point of view before speaking with more specific sector-and-country service users and providers. We interviewed seventeen companies between September 2022 and March 2023. Secondary-source data were recordings from the webinar sessions from the CaaS e-summit organised by BASE in December 2021, and involved 55 stakeholders from different organisations from 10 distinct countries.

### 3.2. Data analysis

Thematic analysis is a method for developing, analysing and interpreting patterns across a qualitative dataset, which involves systematic processes of data coding to develop themes as the ultimate analytic purpose. Thematic analysis is – more or less – a method for data analysis, rather than a methodology (Braun and Clarke, 2022) The tested software NVivo Pro was used to carry out the analysis. Thematic content analysis was used to identify common patterns across the interviews and seminars, involving familiarization, coding, theme generation, review, definition, write-up, and quote inclusion.

The interview data was analysed to extract common themes around barriers and enablers and these were mainly coded (labelled) in five broader patterns as shown in Table 3. The rationale behind the choice was to have a comprehensive, and granular analysis to discuss interrelationships between categories and sub-categories, and to connect categories and sub-categories to relevant servitization theories. In qualitative research, sectorial analysis is a method that groups similar

**Table 1**
Data overview.

| Recordings | Category | Data type | Description | Average length | Total |
|---|---|---|---|---|---|
| 17 | A and C | Primary source | Interviews with companies and experts | 00:53:45 | 15:13:53 |
| 15 | A and C | Secondary source | Seminars with over 55 stakeholders | 00:53:17 | 13:19:21 |
| 15 | A | | Consultants/Advisors - Finance - Policy | 00:51:00 | 12:44:56 |
| 17 | C | | CaaS providers - CaaS clients | 00:55:47 | 15:48:18 |

**Table 2**
Sectors and countries of operation of recordings.

| | | Sector | | | | |
|---|---|---|---|---|---|---|
| | | Cold Chains | Commercial | Buildings | Industrial | Cross-Sectors |
| **Country** | Nigeria | C3,C9,C19,C22 | | | | |
| | France | C3,C19 | | | | |
| | Singapore | | C4,C19, A24 | C4,C19, A24 | C4,C19, A24 | C4 |
| | India | | C2,C22 | C6,C22 | C2,C22 | A26 |
| | Mexico | | | C1,C31 | C1,C31 | |
| | United Kingdom | | | | | A11 |
| | Germany | | | | C12,C13,C14,C15,C16,C17 | |
| | Netherlands | | A7,A24 | A7,A24 | | |
| | South Africa | C19,C31 | C19,C31 | | | C30 |
| | United States | | A8,A21,A24 | A21 | | A20,A26,A28,A29 |
| | Cross-Geographies | | | | | A5,A10,A18, A21,C23,A25,A27,A32 |

Note: Letter 'A' represents the participant group with CaaS experts, policy advisors, and investors, while Letter 'C' covered service providers and end-users.

**Table 3**
Thematic analysis coding categories of barriers and enablers.

| | Categories | | | | |
|---|---|---|---|---|---|
| | Cultural | Finance | Infrastructure | Internal Operations | Policy |
| **Sub-categories** | Awareness and Communication<br>Client Expectations<br>Resistance to Change | Accessibility<br>Availability<br>Cost of Capital | Existing Cooling Infrastructure<br>Energy Availability<br>Land and Location | Sourcing<br>Technical Operations<br>Sales<br>Maintenance | Processes<br>Instruments<br>Strategies |

cases or entities based on their attributes, characteristics, or patterns (Frades and Matthiesen, 2010). It helps researchers discover hidden structures, relationships, or typologies in the data by organising it into meaningful clusters (Hennig and Meila, 2015). We then identified common themes which helped to create the barriers and enablers classifications, and to explore the diversity or homogeneity within the interview data. The analysis was performed using the Pearson correlation coefficient (Ahlgren et al., 2003) because it is more suitable for examining similarities and differences of coding based on the shared barriers/enablers classifications (Deng et al., 2021). Sectorial analysis provides a visualisation of sources or nodes to easily find similarities and differences. For example, how similar are the barriers discussed by the various interviewees? Or how different is the coding at policy, regulations and cultural enablers?

## 4. Results

### 4.1. Overview

Barriers to CaaS implementation from across the data were separated into the identified categories and sub-categories. Fig. 2 shows the distribution of relevant statements across these categories. Cultural and financial barriers were as the most commonly raised. In particular, cultural factors including a lack of awareness and communication about CaaS and resistance to change were important. Lack of awareness was centred around limited understanding of CaaS itself and the broader context and significance of sustainability and sustainable BMs. This was tightly interwoven with resistance to change, as clients and providers exhibited risk aversion and a preference for established ownership models. This resistance is also fuelled by a lack of client trust and uncertainty surrounding the viability of the new CaaS BM. The journey towards adopting CaaS faces a diverse range of challenges that span across various categories. Fig. 2 shows the amount of quotes coded under the barriers categories and sub-categories. Cultural factors such as Awareness and Communication and Resistance to Change emerge as a significant impediment, with a lack of awareness and effective communication taking centre stage. The public's limited understanding of CaaS, compounded by low education in sustainability topics, hampers the urgency to transition to sustainable BMs.

Financial barriers formed another critical cluster of challenges. Clients' hesitancy to invest in long-term service agreements and difficulties in accessing funds, especially concessional ones, limit the financial accessibility of CaaS. Ensuring affordability while maintaining quality poses a conundrum, further exacerbated by uncertainties in savings and performance, which in turn are influenced by global disruptive events. These financial hurdles intersect with technical infrastructure constraints, such as energy availability, cooling infrastructure design, and maintenance complexities. The combination of these challenges underscores the multifaceted nature of the CaaS landscape. For example, policy-related barriers and technical operational challenges add complexity to the ecosystem. Ambiguities in regulations, inadequate policy support, and difficulties in achieving consensus impede CaaS adoption. Insufficient interaction with construction designers and lack of data for performance assessment further contribute to operational challenges.

In contrast, the enablers reflect the intricate web of considerations required *for* the adoption of CaaS. Fig. 3 shows the distribution of relevant statements about enablers across the key categories and sub-categories. Cultural, Financial, and Policy categories were the most discussed. In the cultural dimension, "Awareness and Communication" emerge as key enablers, underscoring the importance of educating clients about the benefits of CaaS and raising awareness through

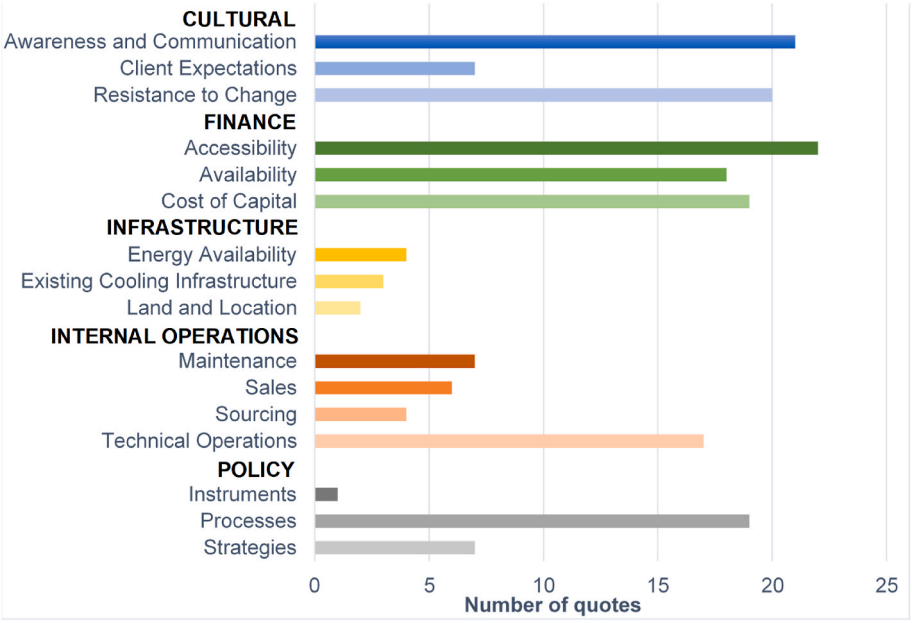



**Fig. 2.** Codes per barrier category and sub-category.

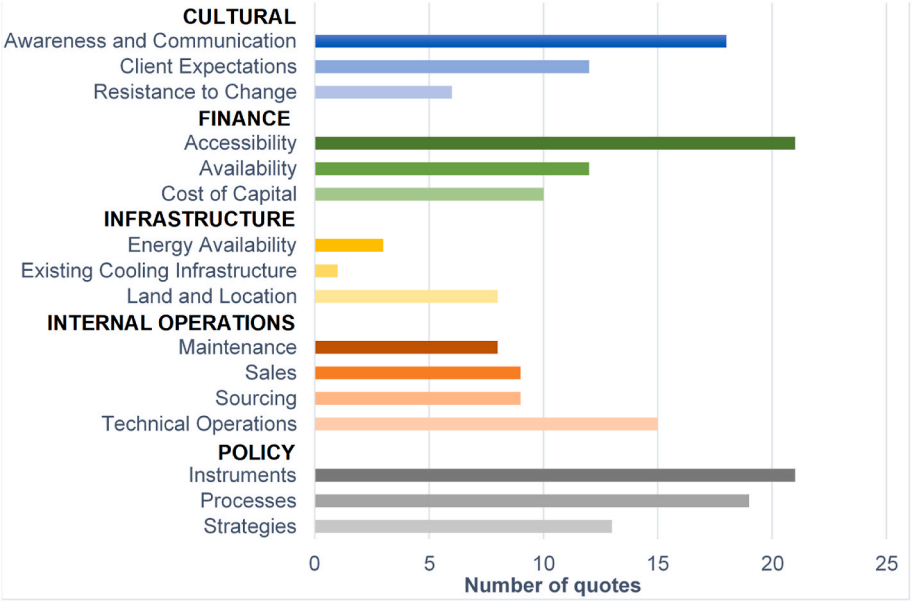



**Fig. 3.** Codes per enabler category and sub-category.

demonstration projects and media coverage to demonstrate a serious commitment to sustainability and build servitization aware clients and providers.

Finance enablers like "Accessibility" stress the importance of financial accessibility to service providers for projects, while "Availability" highlights the need for diverse funding sources, guarantees, and simplified payment processes. "Cost of Capital" focuses on lowering the financial complexities and associated costs, and "Investment in Research and Development" highlights the value of innovation in driving sustainable financing models. Infrastructure underscores the importance of "Energy Availability" through increased renewable energy generation and "Existing Cooling Infrastructure" optimisation. "Land and Location" emphasise design considerations for CaaS-enabled buildings and the potential for district cooling. The adaptability of CaaS to various geographical locations recognizes the need for customisation to local contexts.

Policy focuses on creating an enabling regulatory environment is also emerged as a critical set of enablers. This includes "Instruments" that advocate for policies that incentivise CaaS, such as efficient tax arrangements and service provider ratings; “Processes" that stress clear guidelines, gradual regulatory improvements, and fast policy implementation and "Strategies" including the importance of public sector procurement, expert opinions, and sustainable practices to drive CaaS adoption.

In Internal Operations, "Maintenance" and "Technical Operations" enablers emphasise the significance of optimal service delivery, skilled training, and digitalisation. "Sales" highlights the role of successful pilot projects, client diversification, and loyalty systems in building trust and expanding the CaaS market. "Sourcing" underscores efficient technology procurement, range of services, and alignment with client needs.

Overall, the barriers and enablers provide a holistic perspective on the diverse elements that collectively shape the successful implementation of CaaS. They highlight the interdependence of cultural shifts, financial strategies, infrastructure development (which did not feature more as a barrier nor enabler lead), internal operational excellence, and supportive policy frameworks. The next sections provide more detail on what emerged as key barrier and enabling practices and contexts for implementing CaaS.

#### 4.1.1. Cultural

Several Cultural barriers contribute to the preference for an ownership BM among clients in the cooling industry. Appendix A shows the most cited ones and some of their example quotes. Firstly, clients, particularly government entities with tight budgets and short-term contracts, tend to opt for buying cooling equipment rather than embracing the as-a-service model. This choice stems from the belief that service-based models require higher budgets, which may not align with their financial limitations [Quote 1]. Additionally, both clients and providers exhibit high risk aversion, aiming to close deals quickly without assuming extensive risks and liabilities. While some countries mandate extended warranties to mitigate risks, many businesses prefer to sell products and avoid carrying over any potential liabilities [Quote 2]. Furthermore, the cultural mindset of clients being locked into the idea of purchasing cooling units perpetuates the belief that buying cooling equipment is the only viable option, separate from electricity and maintenance costs [Quote 3]. This locked-in mindset poses a challenge when attempting to shift from a product selling model to a service-oriented one [Quote 4]. Finally, the trusted nature of the ownership BM, established over time, makes it difficult for clients to embrace change and explore alternative options [Quote 5]. Another significant barrier is the lack of awareness and urgency to adopt more sustainable BMs. Some clients fail to perceive the incentives for transitioning to sustainable cooling practices, emphasizing the need for education on the financial benefits of sustainable cooling technologies [Quote 6]. Moreover, low education in sustainability topics contributes to resistance in adopting new BMs, as it takes time for clients to embrace innovative technologies and practices [Quote 7]. This directly also implies companies doing the ownership BM do not want to take risks and not get involved in changing [Quote 8]. On the Enablers side, it is necessary to assure clients that CaaS is the best environmental option (for Net-Zero cooling) and the lowest-cost [Quote 9], and embrace media coverage to raise awareness of new BMs in order to help show the efforts in the early stages of the food supply chain [Quote 10].

#### 4.1.2. Finance

Finance barriers and enablers play a pivotal role in shaping the landscape of CaaS initiatives, as exemplified by the details in Appendix B. On the barrier front, the struggle to access concessional funds is palpable due to the bureaucratic labyrinth that engulfs the application process. The intricate web of red tape and the staggering 1.5-year timeline for approvals divert valuable company resources from core operations [Quote 11]. Moreover, the financing challenge is exacerbated

by the geographical diversity of seasonal demand. The dynamic nature of cooling needs across different regions necessitates a deep understanding of local markets to ensure that funds are available when and where they are most needed [Quote 12]. Adding to the complexity are the high upfront costs that loom as a significant financial hurdle. The perceived elevated risks and limited financing options contribute to the daunting nature of these costs [Quote 13], while the prospect of recouping investments in District Cooling systems over an extended 8 to 10-year period further underscores the intricacies of financial decision-making in the CaaS landscape [Quote 14].

Conversely, CaaS also benefits from noteworthy finance enablers that hold the potential to reshape the industry. Notably, the alignment of CaaS with international development initiatives, particularly in sub-Saharan Africa, opens avenues to attract capital from global organisations focused on aid and sustainable development [Quote 15]. Standardisation emerges as a key strategy in addressing financial intricacies, with short-term contracts and fixed base fees simplifying the BM for customers [Quotes 16–17]. However, a fundamental enabler that stands out is the provision of secure and timely credit. This lifeline ensures the survival of CaaS enterprises by facilitating access to necessary funds and enabling efficient payment collections [Quote 18]. The intricate interplay of finance barriers and enablers delineates the path that CaaS endeavours navigate, underscoring the need for a balanced approach to financial decision-making.

#### 4.1.3. Infrastructure

The intricacies of infrastructure present both barriers and enablers of CaaS, as depicted Appendix C. As of barriers, the challenge of energy availability becomes prominent. The electricity grids in developing countries often struggle to meet the demands imposed by CaaS operations. The limitations within the electric utility industry can hinder the effective delivery of cooling services, posing a potential roadblock to widespread CaaS adoption [Quote 19]. Similarly, deficiencies in the existing cooling infrastructure form another barrier. The lack of appropriate design for district cooling systems, coupled with the inadequate selection of insulating materials, can undermine the efficiency and effectiveness of cooling services [Quote 20]. Furthermore, the absence of interaction between CaaS providers and construction designers during the building phase results in missed opportunities to incorporate CaaS-friendly features. The disconnect between infrastructure and CaaS design complicates retrofitting and adaptation efforts for systems that have already been established [Quote 21].

Conversely, infrastructure also offers avenues for enabling the success of CaaS initiatives. In terms of energy availability, the prospect of increasing renewable energy generation emerges as a significant enabler. Particularly in Africa, the cost-effectiveness and feasibility of generating renewable energy sources present an opportunity to power CaaS operations sustainably [Quote 22]. Furthermore, the relationship between land, location, and infrastructure is pivotal. When clients own and operate the buildings, there is an inherent incentive for cooperation with CaaS providers. This alignment reduces bureaucracy from the end-user perspective and facilitates smoother integration [Quote 23]. The high adaptability of CaaS to diverse geographical locations stands as another enabler. The ability of CaaS to conform to local legal systems and markets minimises complexities associated with expansion into various regions [Quote 24]. The dynamic interaction of infrastructure challenges and facilitators creates a multifaceted scenario that highlights the central significance of infrastructure in moulding the course of CaaS initiatives.

#### 4.1.4. Internal operations

The intricate interplay of internal operations barriers and enablers underscores the pivotal role of operational dynamics in shaping the trajectory of CaaS development as shown on Appendix D. Among the barriers within internal operations, maintenance emerges as a significant challenge. Meeting clients' demands for timely repairs becomes arduous, especially when the equipment is under lease, impeding quick responses to repair requests [Quote 25]. Similarly, sourcing appropriate technology providers becomes a hurdle due to the lack of interest sparked by CaaS offerings, complicating the alignment of partnerships [Quote 26]. The complexity of logistics and processes within technical operations presents further barriers, particularly in the procurement of suitable cooling transportation units [Quote 27]. The prevalence of outdated and inefficiently installed equipment poses yet another internal operations barrier, given the high costs associated with their replacement [Quote 28].

Conversely, internal operations also offer pathways for enabling successful CaaS implementations. Diversification of the client portfolio across geographical regions with partial cooling needs, whether during specific times of the year or particular periods of the day, emerges as an enabler [Quote 29]. This strategic approach not only enhances the financial stability of providers but also mitigates risks during disruptive events like the COVID-19 pandemic [Quote 30]. Furthermore, embracing digitalisation within technical operations proves to be an essential enabler. The implementation of smart metering and other digital solutions fosters confidence in the system's functionality and bolsters overall operational efficiency [Quote 31].

#### 4.1.5. Policy

The last category is Policy-related barriers and enablers which also play a pivotal role of regulatory and strategic dynamics in shaping the trajectory of CaaS success. Within the realm of policy as depicted in Appendix E, issues arise in the realm of processes due to unclear and non-existent regulations that hinder CaaS progress. The lack of support for adopting low-Global Warming Potential (GWP) refrigerants and efficient technologies within regulatory frameworks impedes optimal CaaS implementation [Quote 32]. Additionally, the absence of well-defined distinctions in cooling appliance regulations creates missed growth opportunities. Strategies further compound policy barriers, as unclear contract specifications blur the line between service and lease arrangements, thwarting proper structuring for CaaS agreements. This lack of clarity poses challenges in distinguishing between a service-focused contract and a capital lease, influencing client decisions on equipment acquisition [Quote 33].

On the other hand, Policy enablers pave the way for successful CaaS adoption. The establishment of service provider ratings, analogous to energy efficiency ratings (A*-F), emerges as a key enabler to gauge CaaS offerings and refrigerants. Likewise, certifications specific to CaaS bolster trust and confidence in this BM, ensuring higher levels of assurance among stakeholders [Quote 34]. The implementation of gradual regulatory improvements represents another enabling approach. Rather than abrupt regulatory shifts, incremental changes over time instil investor confidence and minimise uncertainty linked to changing regulations. This approach becomes especially valuable in uncertain legal landscapes, allowing for short-term CaaS solutions in periods when the direction of future laws is unclear. Moreover, policy enablers emphasise the importance of balanced government interventions encompassing both regulatory adjustments and financial incentives, fostering a supportive environment for CaaS development [Quote 35].

### 4.2. Sector analysis

In this section, a sector analysis is performed. The transition towards CaaS represents a paradigm shift in the cooling industry, promising increased energy efficiency, reduced environmental impact, and enhanced access to cooling technologies. However, this transformation is not without its challenges. Firstly in Fig. 4, we delve into the nuanced barriers that impede the adoption of CaaS across distinct sectors, offering a deeper understanding of the multifaceted obstacles encountered.

The Industrial sector, encompassing segments like the concrete

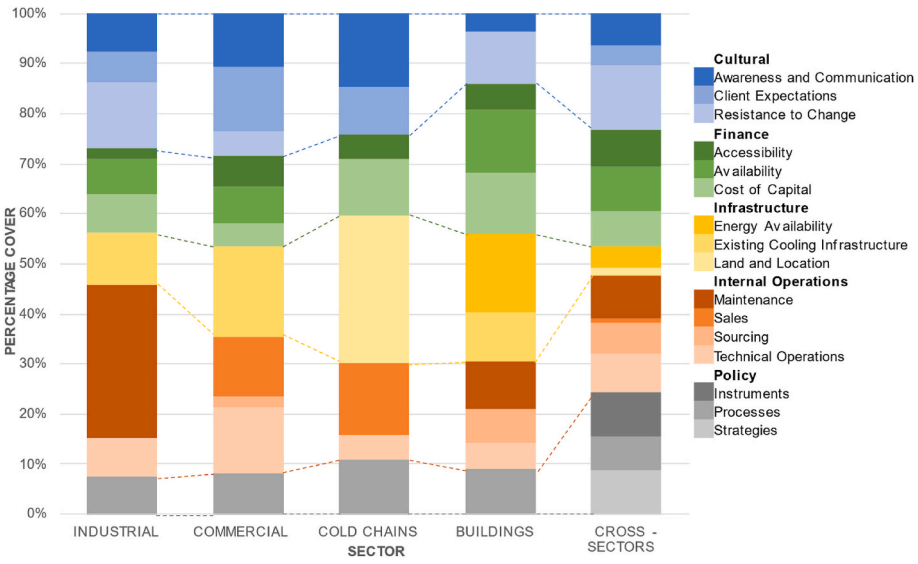



**Fig. 4.** Barriers coding by sector.

industry, grapples with intricate barriers that stem from both operational and cultural dimensions. Maintenance barriers loom large, with issues related to restarting idle technology echoing a common refrain. Extended periods of inactivity necessitate complex and costly procedures to reinstate equipment functionality, posing economic and logistical challenges. This is exacerbated by idle equipment, which results from the sector's sensitivity to weather and geographical conditions. Rapid response to repairs becomes paramount in a CaaS model, yet the need to meet client demands for immediate repairs while adhering to leasing agreements introduces practical complexities. The Industrial sector's resistance to change, entrenched in cultural norms, is another formidable barrier. Clients' historical preference for ownership models reflects a longstanding trust in conventional business structures. This inertia presents a challenge in persuading stakeholders to embrace the novel CaaS approach. Incentives, policy frameworks, and transformative education efforts are necessary to break this impasse and pave the way for the adoption of service-oriented cooling solutions.

The Commercial sector exhibits a delicate balance of barriers, with each representing a distinct facet of the adoption challenge. Internal operational challenges are pronounced, notably within sales differentiation and tenant engagement. The complex nature of CaaS and its potential similarity to utility models introduces challenges in sales presentations. Convincing individual tenants in diverse commercial and housing environments to collectively opt for CaaS requires intricate negotiation and change management strategies. Technical operations complexities encompass reporting and risk management. The multitude of transactions and interconnections in a CaaS framework requires meticulous impact reporting, a task fraught with intricacies. Sourcing barriers surface due to difficulties in identifying technology providers aligned with the CaaS philosophy. Moreover, establishing credibility through reference projects poses a substantial challenge. The need to present successful case studies that validate CaaS's viability in real-world scenarios is critical, yet such projects might be limited due to factors like client confidentiality and emerging BMs. Furthermore, the risk associated with technology performance recovery requires proactive strategies, thereby emphasizing the sector's need for robust risk assessment and mitigation measures.

The Cold Chains sector unveils unique barriers related to infrastructure, shaped by geographical and contextual factors. The scarcity of cooling facilities outside urban areas impairs accessibility, especially in rural and remote regions. Limited land availability exacerbates this challenge, obstructing the establishment of cooling installations. Paradoxically, the absence of cultural barriers in this context might be linked to the sector's nascent state in certain regions. The lack of entrenched cooling practices provides an opportunity for the adoption of innovative and sustainable solutions without resistance to change.

Within the Buildings sector (space cooling), barriers are intertwined with energy infrastructure and technological accessibility. Energy availability, primarily derived from electricity grids, poses significant hurdles, particularly in regions where grid connectivity is limited. The reliance on traditional energy sources further compounds environmental concerns. Additionally, acquiring advanced technology to monitor cooling system performance demands substantial investment, further complicating the CaaS adoption process.

Cross-sector insights underscore the intricate interplay of barriers across different contexts. Notably, policy-related challenges emerge as a recurrent theme. Unclear contract specifications pose a critical hurdle, as the shift from ownership-based models to service-based CaaS introduces novel contractual intricacies. The lack of standardised contracts and policies amplifies uncertainty and increases reluctance among stakeholders, hindering progress.

Furthermore, the absence of risk assessment and support from financial institutions underscores the need for collaborative efforts to establish clear risk evaluation frameworks. The exclusion of cutting-edge technologies from national development plans hampers the incentive landscape for innovative CaaS models. Bridging this gap requires aligning policy frameworks with technological advancements and promoting a conducive environment for emerging companies.

In sum, the barriers to CaaS implementation within diverse sectors reflect a complex amalgamation of operational, cultural, and policy challenges. Addressing these barriers needs a holistic approach that combines technological innovation, policy reform, and stakeholder engagement. By navigating these obstacles collectively, a sustainable path towards widespread adoption of CaaS can be forged, ushering in a new era of efficient and environmentally conscious cooling solutions.

The realisation of CaaS holds significant potential for revolutionising cooling solutions across various sectors. However, the journey toward comprehensive CaaS adoption requires identifying and harnessing key enablers. Fig. 5 delves into the pivotal enablers within each sector, focusing on the policy, finance, infrastructure, cultural, and internal operational dimensions that contribute to overcoming barriers and facilitating the integration of CaaS.

The Industrial sector, characterised by its complex operations, identifies a synergy between infrastructure and policy enablers that catalyse CaaS adoption. The concept of designing for reduced cooling demand emerges as a pivotal infrastructure enabler. By integrating

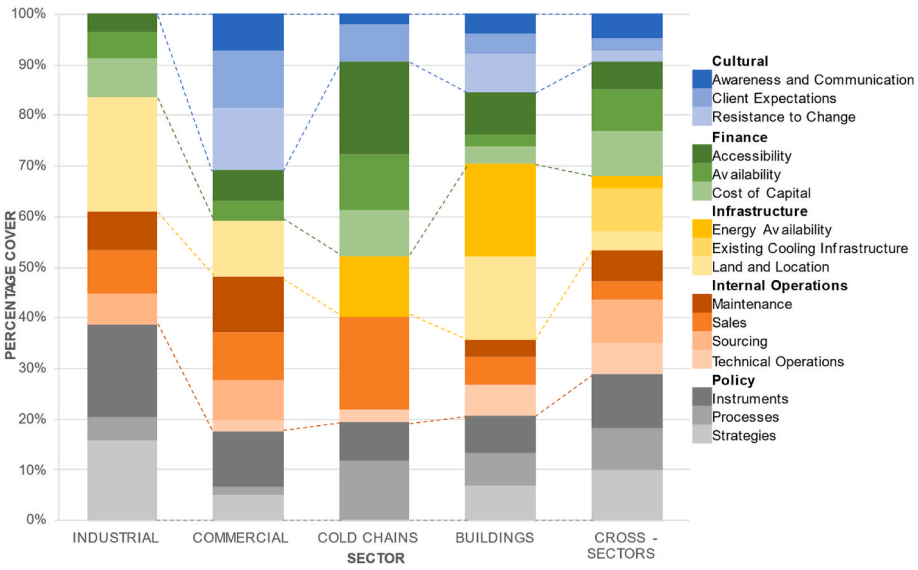



**Fig. 5.** Enablers coding by sector.

passive cooling measures into facility design, active cooling demand is curtailed, resulting in increased equipment efficiency and operational stability. This underscores a shift from reactive maintenance to proactive efficiency enhancement, aligning with the principles of circularity for CaaS. Policy processes and strategies play an instrumental role in propelling CaaS forward in the Industrial sector. Sustainable cooling roadmaps, when effectively implemented, expedite the integration of impactful policies that drive the adoption of energy-efficient cooling solutions. Expert consultations and industry recommendations further crystallise these strategies, setting the stage for sector-specific temperature thresholds. The involvement of industry associations and committees in standard-setting fosters alignment with sustainable cooling practices.

For the Commercial sector, cultural enablers emerge as linchpins in journey toward CaaS integration. A comprehensive awareness and communication strategy assumes paramount importance, educating clients about the multi-faceted benefits of CaaS. Demonstrative projects serve as living examples, illustrating the feasibility and functionality of CaaS, and raising stakeholders' awareness and confidence. The sector also recognizes the significance of stakeholders' shared commitment to sustainability, a catalyst that transforms the mindset from conventional to environmentally conscious practices. Client expectations and competition, both intertwined with cultural aspects, emerge as pivotal enablers. Rising demand from end-users creates a pull factor that propels the adoption of CaaS, rendering it a market necessity. Competitive forces incentivise growth and learning, sparking innovation and driving service excellence. Building trust among stakeholders fosters cooperation, a fundamental tenet in the CaaS model. Furthermore, a gradual transition from cooling-selling companies to servitization will enhance sustainability and align with circular economy principles.

For the Cold Chains sector, finance and infrastructure enablers converge, forging a path toward efficient and sustainable cooling solutions. Accessibility of finance is propelled by subsidies for sustainable components, rendering high-quality technology affordable and accessible. Partnerships with international development organisations streamline capital inflow, aligning CaaS initiatives with broader aid efforts. Price caps will introduce a fair competitive landscape, while diversification of component suppliers works in synergy with cost-reducing initiatives. Energy availability and infrastructure also assume critical roles in Cold Chains. The imperative to increase renewable energy generation aligns with the sector's unique position in sub-Saharan Africa, where renewable alternatives emerge as cost-effective and readily accessible solutions. Embracing this transition not only addresses energy crises but also underpins sustainable cold chain operations.

The Buildings sector (space cooling), instrumental in achieving cooling efficiency, highlights the role of finance enablers in the CaaS ecosystem. Establishing a track record of performance stands as a precursor to attracting investors, a prerequisite for concessional funding access. Drawing lessons from successful servitization models will underscore the viability of transitioning to CaaS, lending credence to the business case. Price caps, while fostering fair competition, empower clients with economic control and confidence in their financial commitments. The availability and cost of capital enablers are pivotal in tailoring investment structures. Balancing risk through nuanced financial mechanisms stimulates investment, safeguarding against uncertainties and bolstering confidence. Infrastructure enablers also come to the fore, with adaptable CaaS solutions being positioned to thrive in diverse geographical locations. A symbiotic relationship emerges between CaaS and building design, as early involvement facilitates the seamless incorporation of passive cooling measures.

Cross-sector insights unveil a tapestry of enablers. In the realm of cultural facilitation, education plays a central role. Effective communication strategies educate clients about the co-benefits of CaaS, fostering understanding and commitment. Acknowledging the roles of all stakeholders, from providers to end-users, in the CaaS journey, builds trust and reinforces the sustainability narrative. The transition from ownership to servitization is driven by entrepreneurship and institution-supported businesses, paving the way for innovative service models. In the financial landscape, access to capital emerges as a primary enabler. Easier capital funding access, driven by subsidies, diverse funding sources, and innovative financing structures, reinforces sustainable projects. Standardised contracts and financing vehicles simplify engagements, while guarantees and insurance mitigate investment risks. Availability of transparent accounting practices ensures accurate asset valuation, facilitating balanced financial decision-making. Internal Operations will include the optimisation of service provision, underpinned by proactive maintenance strategies and accountability, ensures efficiency, reliability, and customer satisfaction. Sales strategies benefit from diversifying client portfolios, enhancing adaptability to seasonal variations and disruptions. Embracing digitalisation, including smart metering and equipment connectivity, streamlines operations, optimising energy usage, and bolstering sustainability. Infrastructure and Policy also contribute significantly to CaaS adoption. Robust digitalisation, connectivity between equipment, and designing for reduced cooling demand streamline operations. Regulatory improvements, public sector

procurement, and certification mechanisms provide clarity and confidence to stakeholders. These enablers collectively cultivate an environment conducive to CaaS expansion.

## 5. Discussion

The findings highlight a range of obstacles and opportunities that must be addressed to facilitate the transition to CaaS. These challenges include awareness gaps, financial and technical barriers, and the need for aligned policies. To unlock CaaS transformative potential, collaboration among policymakers, financial institutions, technology providers, and end-users is crucial to achieving sustainable cooling solutions.

Finance and Infrastructure involve internal and external elements that influence Policy, which, in turn, shapes Culture dynamics (e.g., procurement cultures). Key enablers for CaaS, such as Infrastructure, Policy, Cultural, and Financial factors, drive the sector's shift toward sustainability, echoing the roles of policy and cultural enablers (Gillham et al., 2023). Internal Operations are most manageable for CaaS providers. Together, they support the adoption of efficient, sustainable, and eco-conscious cooling solutions.

Our analysis reveals a critical gap in the literature: the role of cultural dynamics in shaping CaaS adoption. Most of the existing research overlooks these cultural factors, either by focusing on narrow applications (Nain and Bhasin, 2022) or exhibiting a geographical bias (Kindström and Ottosson, 2016).Cultural barriers to CaaS adoption emerge as the main barrier, alongside Finance and Policy challenges. Cultural barriers, such as ingrained perceptions and lack of knowledge sharing between providers, hinder acceptance of circular economy principles (Kanatlı and Karaer, 2022). The scarcity of CaaS knowledge exchange between providers, owing to limited competition, mirrors the external challenges (Britton et al., 2021; Fell, 2021). CaaS can face resistance where cultural contexts shape energy consumption behaviour (Lafuente et al., 2019). Financial barriers also persist, particularly in creating a viable investment space with appropriate investment frameworks and risk analysis, continue to hinder CaaS, as previously mentioned in discussions on financing in energy transitions (Suganda and Gabriel, 2021).

Geographical variations in CaaS awareness and adoption are significant. In the UK, scepticism was high among academic consultants who viewed the model to be inapplicable and irrelevant for the UK context. In contrast, emerging economies like India and Mexico are still exploring its potential. In Nigeria, the priority was client education on CaaS's benefits, while Singapore's diverse client portfolio provided resilience in the face of global disruptions. These regional differences reflect CaaS adoption across geographies, depending on economic development, infrastructure availability, and cultural norms (Pavanello et al., 2021).

A disconnect between practitioners and policymakers regarding CaaS opportunities was also identified. While policy-level discussions occur, practitioners perceive a lack of support and alignment with financial institutions and regulatory bodies. This highlights the need for improved communication and collaboration to bridge the gap and create an enabling environment for CaaS initiatives (Gillham et al., 2023; Kanatlı and Karaer, 2022). The feeling of isolation among CaaS providers during the transition process emphasises the lack of competition and knowledge-sharing opportunities. They also quoted local contextual challenges, such as resistance from governments to transition to renewables, as hindrances to their efforts. This can enhance the risk of servitization entrenching existing levels of demand rather than helping reduce it (Morley, 2018).

Providers noted sector-specific challenges: retrofitting CaaS into existing infrastructure (such as buildings) is easier than adapting new construction projects. Delivering the service to newly constructed facilities entail different engineering requirements. These sectoral differences reinforce the need for tailored approaches to each market, aligning with varying cooling requirements (Gillham et al., 2023). The weak communication between CaaS providers and manufacturers further complicates adoption, with providers hesitant to rely on a single manufacturer. This echoes the case of Lighting-as-a-Service where the manufacturers themselves were the driving force behind the servitization BM. As such, large cooling manufacturers could be in an advantageous position to develop the CaaS model.

CaaS providers also face challenges in addressing end-of-life management for cooling equipment, a key aspect of the circular economy. There is only one known case of a manufacturer offering end-to-end CaaS services in Africa, with their European franchise focusing on product distribution rather than full-service provision. This suggests that the availability and accessibility of comprehensive CaaS offerings may vary across different regions and markets (Nolden et al., 2016).

Finally, there is a lack of understanding about the value networks and collaborations required within the CaaS ecosystem. Service providers report uncertainty about the support they need, and policymakers are unclear on how to effectively support CaaS efforts. This highlights the importance of further research and stakeholder engagement to establish effective partnerships and collaborations that can facilitate the growth and development of CaaS. Although policy is not seen as crucial for the current progression of CaaS, there is a recognition that it will be essential to prevent power imbalances from arising among major CaaS providers in the future.

## 6. Conclusions

This study examined the barriers and enablers to adopting CaaS and explored its potential as a systemic intervention for sustainable cooling. As one of the first peer-reviewed articles to focus on servitization in cooling, the findings the complex interactions between enablers, such as internal operations, finance, infrastructure, data, technology, and market conditions, and their influence on CaaS uptake. Cultural factors, more than finance and policy, emerged as the main barrier to the acceptance of circularity principles.

Geographical differences were noted, with varying levels of CaaS adoption across regions. Tailoring the CaaS model to sector-specific needs and improving communication between providers and manufacturers were found to be essential for successful implementation. Furthermore, a gap between practitioners, policymakers, and regulatory bodies, points to the need for better stakeholder alignment and collaboration.

Local barriers, such as government resistance toward renewables, further hinder the adoption of CaaS. There is a knowledge gap in understanding necessary collaborations within the CaaS ecosystem. Service providers struggle with the support required, while policymakers are unclear about how to promote CaaS initiatives. Enhanced stakeholder engagement and research are needed to establish effective partnerships and support growth.

The study highlights sector-specific variations, the importance of better communication between CaaS providers and manufacturers, and the need to improve equipment and end-of-life management. Regional disparities in CaaS availability and the lack of effective value networks are also key areas for improvement. These findings offer a foundation for further research and strategies to optimise CaaS implementation across sectors and regions.

This study highlights key barriers and enablers to adopting the CaaS BM but has certain limitations. It primarily relies on qualitative interviews, which may limit the generalisability of findings across such diverse contexts. Future research should incorporate quantitative methods for a more robust analysis and expand to include a broader range of regions and stakeholders to capture diverse perspectives. Additionally, the study focuses largely on the views of CaaS providers, so incorporating more insights from clients and end-users would offer a more holistic understanding of the challenges and opportunities in CaaS adoption.

Key recommendations for future research include addressing cultural barriers, exploring CaaS dynamics across different regions, and

improving collaboration frameworks between providers and manufacturers. Policymakers should also focus on creating regulatory frameworks that encourage CaaS adoption while preventing potential power concentration among providers.

In hindsight, the most likely successful way forward is to combine enablers that address multiple barriers, such as increasing finance and investment vehicles with appropriate policies and raising awareness campaigns. By incorporating the insights gained from this study, organisations and nations can make informed decisions and leverage CaaS to optimise their systems, reduce energy consumption, and contribute to sustainable cooling.

## CRediT authorship contribution statement

**P.G. Palafox-Alcantar:** Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **C. McElroy:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **P. Trotter:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **A. Thomas:** Writing – original draft, Formal analysis, Data curation. **R. Karutz:** Formal analysis, Data curation, Conceptualization, Writing – review & editing, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

The authors gratefully acknowledge the support provided by the Future of Cooling Programme at the Oxford Martin School, University of Oxford. Philipp Trotter received funding from the Climate Compatible Growth programme of the UK government. The views expressed here do not necessarily reflect the UK government's official policies. The authors also would like to sincerely thank Aaron Guo for the invaluable support in the coding steps during the thematic analysis.

## Appendix A. Example quotes of the duality of Cultural barriers and enablers.

| Category and sub-category | Description | Source | Example Quote |
|---|---|---|---|
| Cultural Barrier-Client Expectations | Clients' preference for an ownership business model | A7 | [Quote 1]: "The customer need, of course is changing a lot. Governments especially, they do that for all kinds of operations they have, do you see that on an annual basis their budget will drop? And typically, that kind of service buying model require more budgets. So that's one of the barriers that the buying behaviour is buying." |
| Cultural Barrier-Resistance to Change | High risk aversion from both clients and providers | A7 | [Quote 2]: "Really invest on it because having a contract with an end user also include some risk and liabilities. And those risk and liabilities is not always welcomed by many businesses. Because they won't really using a risk adverse manner, just want to sell the product, close the deal and not carryover of any risk and liability." |
| | Locked-in mindset from clients to buy cool unit | A11 | [Quote 3]: "It's the cultural agenda. The idea that people have it in their minds that buying cool for people. The idea of buying cool in the same way as you would buy electricity and moving away from the idea of an AC isn't something you had to buy. That's the real cultural change." |
| | | A27 | [Quote 4]: "I think the biggest barrier we see as advisors is on the selling side. selling a service is very different than serving selling you a product. For most large industrial players, that shift is massive. It's a very small business to start with." |
| | | C12 | [Quote 5]: "We've always done it this way. It's going to stay that way now. That refers on the one hand to the cool method, there will be newer much more efficient and filling method units. But we have always done it this way now. We're going to stay with it […], but on the other hand also we have always bought us a cooling unit. We continue to buy us a cooling unit." |
| Cultural Barrier-Awareness and Communication | Lack of awareness on the urgency to change | C13 | [Quote 6]: "But I believe that the will is there with some, and certainly not yet with others. They just don't see it as necessary yet." |
| | | C9 | [Quote 7]: "So, there is no education on sustainability. In the sense that we actually educate them on the value of cooling on their financial gain […]. So, we actually had that challenge of adoption. It takes time for them to invite new technology, new practices." |
| | Lack of awareness on the urgency to change/High risk aversion | A10 | [Quote 8]: "A barrier in the sense that currently many technologies are not built to serve they are built to sell. So that means that with the current technologies […] companies that have been doing this for many, many years, they do not have a direct incentive in wanting to shift to the model, because they prefer to not take any financial risk […] while smaller companies might be more agile." |
| Cultural Enabler-Awareness and Communication | Educate clients about the co-benefits of CaaS | C4 | [Quote 9]: "Everyone buys into a mission of cooling the world sustainably or moving to Net-Zero cooling. So, for us it's part of our DNA and what we want to achieve, who we hire and how we deliver it. But like I said, even if you couldn't care less about the planet and you just want to make cash, CaaS is still the best model." |
| | | C9 | [Quote 10]: "But on the whole work done and international media coverage has given us incredible publicity and awareness, but we still need to educate in this country who rely on the food coming from our customers […]." |

## Appendix B. Example quotes of the duality of Finance barriers and enablers.

| Category and sub-category | Description | Source | Example Quote |
|---|---|---|---|
| Finance Barrier-Accessibility | Difficulty to access concessional funds | C2 | [Quote 11]: "There's so much concessional finance, this capital available and coming to India for energy efficiency. But it's not properly channelled. It's not coming into this at all. […] There was an international source in fact it was the French government […] but you know it's a fairly lengthy application process, like 1 1/2 years of application and you have to submit the application in French and it is so cumbersome that we gave up in the middle even though we were progressing well […] So it's not worth it at some point." |
| Finance Barrier-Availability | Variation of seasonal demand across geographies | C1 | [Quote 12]: "It's also vary depending on the state you're in, for example, right now I'm in Durango, and in all of the 18 years that I lived here, not one single house had in an AC unit because we don't need it here. No one here has an AC unit, but while studying in Monterrey, if you don't have one, it's not possible to live there in the summer." |
| Finance Barrier-Cost of Capital | High upfront costs | A24 | [Quote 13]: "So however, these SMEs face brand barriers, so the potential remains largely untapped. Like some of the barriers include high upfront costs, higher risk perception, uncertain returns and other barriers, investments, and limited finance." |
| | | C6 | [Quote 14]: "But the challenge is, you know, companies which offer AC services or which have been traditionally doing manufacturing. […] But it all comes down to high initial costs for the projects to take off." |
| Finance Enabler-Accessibility | Attract capital from international development organisations | C9 | [Quote 15]: "On the financing we're a little bit fortunate because of the momentum by the sustainability movement. The energy transition movement which has been in place over the past decades. […] We were also able to demonstrate multiple impacts and attract money like productive use of energy in cooling and a reduction in food spoilage and increase in the income of smallholder farmers, […] sustainability has become something that most our governments and foundations and organisations are interested in." |
| Finance Enabler-Availability | Standardised contract and finance vehicles | C17 | [Quote 16]: "I guess large companies are also more willing to adopt a more standardised contract rental model. It means the customer starts to rent for half a year and the short-term contract allows to get to know the business model." |
| | | C31 | [Quote 17]: "So, the way we found out that we could go around recovering investment is that you have a standard portion that helps you ensure a certain return on investment within a timeframe. And the variable brings you to the final objective that you have in recovery of your investment. So, it's a combination, but we of course we learned that as we were built the contract and we start working with the building." |
| Finance Enabler-Cost of Capital | Secure and timely credit | C3 | [Quote 18]: "We secured payments guaranteed payments. I think that's key for any business to continue […] To collect payments on time and to make sure there is access to credit when needed, otherwise the businesses are not sustainable." |

## Appendix C. Example quotes of the duality of Infrastructure barriers and enablers.

| Category and sub-category | Description | Source | Example Quote |
|---|---|---|---|
| Infrastructure Barrier-Energy Availability | Electricity grid unable to cope with demand of CaaS | A26 | [Quote 19]: "The biggest problem in developing countries, as I see it, is that the electric utility industry is not capable to cope with demand. And because it's not capable of growth, electricity rates have gone way up, because you still have to pay the same amount of money to maintain the grid. But the growth in the underlying kilowatt hour sales is very low, 2–4% per year. While CapEx costs are increasing by 10% annually." |
| Infrastructure Barrier-Existing Cooling Infrastructure | Lack of appropriate design for district cooling | C6 | [Quote 20]: "There is no common practice on designing right, choosing the right material, and then doing the construction, or implementing the design, and also the preventive maintenance and operations. So, all these are relatively new and there were one or two pilot projects which started in India and this is about a decade ago." |
| Infrastructure Barrier-Existing Cooling Infrastructure | Lack of interaction with construction designers | C2 | [Quote 21]: "Oftentimes what happens is that it's too late to make big design changes […] The building structure is already built. The contractor, the scope of work, the bill of quantity everything is already selected and the work is already started. So, in this case it is difficult to make major changes into the basic engineering concept that we're going to do. Structure cooling or radiant cooling or exercise at cooling and we're going to reduce the compressor-based cooling, right? Those opportunities are gone OK. […] But the structural changes, it's too late now." |
| Infrastructure Enabler-Energy Availability | Increase renewable energy generation | C3 | [Quote 22]: "If there's a way, we can make it happen that all income generating activities would be from the sound or from renewable natural resources […] But rather them going through that hurdle. We help them. Bridge that gap and you can pay for a monthly service fee for whatever service they require, what it's cooling, whether it relates electricity from renewable sources." |
| Infrastructure Enabler-Land and Location | Buildings owned and operated by clients incentivise cooperation with providers | C2 | [Quote 23]: "Typically, the easiest sectors to work with are the sectors where the infrastructure of cooling is traditionally owned and operated by the same entity that uses the building. […] Because the benefits are directly or through into you." |
| Infrastructure Enabler-Land and Location | High adaptability of CaaS to various geographical locations | A21 | [Quote 24]: "So, coming back to the question, is that CaaS is adaptable to various parts of the world by all means of infrastructure and operations, one just needs to respect the various legal systems." |

## Appendix D. Example quotes of the duality of Internal Operations barriers and enablers.

| Category and sub-category | Description | Source | Example Quote |
|---|---|---|---|
| Operations Barrier-Maintenance | Difficulties in repairing in time | C17 | [Quote 25]: "It is difficult to find repairs on-time, but customers who still have their own repair departments, then perhaps not so much. Yes, we have the people anyway. Most ready-mix concrete plants have a lock and electrician somewhere." |
| Operations Barrier-Sourcing | Difficulty in finding right tech providers | A8 | [Quote 26]: "I think what I've observed from the outside is that you know the real maker right, that have just been really hard to predict in the lab context is having the technology providers who are interested in implementing CaaS." |
| Operations Barrier-Technical Operations | Complexity in logistics and processes | C23 | [Quote 27]: "And the ability to scale that up to be able to deliver to very remote places where there's a transport challenge logistics but roads are bad." |
| | Unfit for purpose installed equipment | A27 | [Quote 28]: "The big challenge is existing assets; we should probably actually transform those. And I think as the example, was indicating that the only way I think, that we need will be service or products to make them fit for purpose." |
| Operations Enabler-Sales | Diversify client portfolio in geographies where cooling is needed for only a part of the year-day | C2 | [Quote 29]: "The longer is the operating time, the better it is right? So? Educational institutes are only going to run for 9 h and there will be two months of break, right? So, then the economics are not as good. Because the benefits that you bring into the table are only working for 12 h a day and nine months of the year? So, where if you if you have continuously operational assets? Obviously, it's much more feasible financially and much more attractive financially for the end user." |
| | | A10 | [Quote 30]: "And by having a diversified portfolio they can cope with, for example, the pandemic, because some customers like libraries or hospitals might still need cooling even during a pandemic, while other companies might not." |
| Operations Enabler-Technical Operations | Digitalisation of operations | C30 | [Quote 31]: "A system that we can verify its performance and also for our clients to have a smart metering and to be able to know their exact consumption and the air quality that they're getting gives them a lot more confidence in our systems and to all to verify the system efficiency and equipment status and overall analytics allows us to provide a highly efficient CaaS model." |

## Appendix E. Example quotes of the duality of Policy barriers and enablers.

| Category and sub-category | Description | Source | Example Quote |
|---|---|---|---|
| Policy Barrier-Processes | Unclear and inexistent regulation to support CaaS | C23 | [Quote 32]: "Then the third aspect would be around the restrictions and regulations that are available are unclear and some are not widely available and not having the lowest GWP possible and the best efficiency possible for cooling appliance usage." |
| Policy Barrier-Strategies | Contract specifications remain unclear | A25 | [Quote 33]: "In the contract it's really relevant that the wording is made correctly to make sure that it isn't a service agreement that one service agreement rather than a leasing agreement operating or financial lease. This is also a challenge in the built environment as a service industry." |
| Policy Enabler-Instruments | Ratings for service providers | A27 | [Quote 34]: "Certification and a way of rating CaaS providers for these business models is really interesting because it can be a really big contributor to this integrated energy approach." |
| Policy Enabler-Processes | Gradual regulatory improvements | A26 | [Quote 35]: "The main thing is remembered that I think government also plays a big role. And governments have a responsibility to make sure that the building sector decarbonises at speed and scale that required my country and so part of this is marriage between government regulation and finance […] And so I do think that slow and gradual regulation improvement will guarantee the services success, and without it the uptake of CaaS will be quite slow." |

## Data availability

The data that has been used is confidential.

## References


Adwek, G., Boxiong, S., Ndolo, P.O., Siagi, Z.O., Chepsaigutt, C., Kemunto, C.M., Arowo, M., Shimmon, J., Simiyu, P., Yabo, A.C., 2020. The solar energy access in Kenya: a review focusing on Pay-As-You-Go solar home system. Environ. Dev. Sustain. 22, 3897–3938.

Ahlgren, P., Jarneving, B., Rousseau, R., 2003. Requirements for a cocitation similarity measure, with special reference to Pearson's correlation coefficient. J. Am. Soc. Inf. Sci. Technol. 54, 550–560. https://doi.org/10.1002/ASI.10242.

Baines, T., Ziaee, A., Oscar, B., Bustinza, F., Shi, V.G., Baldwin, J., Ridgway, K., Ziaee Bigdeli, A., Bustinza, O.F., 2017. Servitization: revisiting the state-of-the-art and research priorities. Int. J. Oper. Prod. Manag. 37, 256–278. https://doi.org/10.1108/IJOPM-06-2015-0312.

Batidzirai, B., Trotter, P.A., Brophy, A., Stritzke, S., Moyo, A., Twesigye, P., Puranasamriddhi, A., Madhlopa, A., 2021. Towards people-private-public partnerships: an integrated community engagement model for capturing energy access needs. Energy Res. Social Sci. 74, 101975.

Bocken, N.M.P., Short, S.W., Rana, P., Evans, S., 2014. A literature and practice review to develop sustainable business model archetypes. J. Clean. Prod. 65, 42–56.

Bolton, R., Hannon, M., 2016. Governing sustainability transitions through business model innovation: towards a systems understanding. Res Policy 45, 1731–1742. https://doi.org/10.1016/J.RESPOL.2016.05.003.

Boons, F., Lüdeke-Freund, F., 2013. Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. J. Clean. Prod. 45, 9–19. https://doi.org/10.1016/J.JCLEPRO.2012.07.007.

Braun, V., Clarke, V., 2022. Thematic Analysis: A Practical Guide. SAGE.

Britton, J., Minas, A.M., Marques, A.C., Pourmirza, Z., 2021. Exploring the potential of heat as a service in decarbonization: evidence needs and research gaps. Energy Sources B Energy Econ. Plann. 16, 999–1015. https://doi.org/10.1080/15567249.2021.1873460.

Brown, D., Hall, S., Martiskainen, M., Davis, M.E., 2022. Conceptualising domestic energy service business models: a typology and policy recommendations. Energy Pol. 161. https://doi.org/10.1016/j.enpol.2021.112704.

Chesbrough, H., 2010. Business model innovation: opportunities and barriers. Long. Range Plan. 43, 354–363.

Chirumalla, K., Leoni, L., Oghazi, P., 2023. Moving from servitization to digital servitization: identifying the required dynamic capabilities and related microfoundations to facilitate the transition. J. Bus. Res. 158, 113668. https://doi.org/10.1016/J.JBUSRES.2023.113668.

Deng, J., Deng, Y., Cheong, K.H., 2021. Combining conflicting evidence based on Pearson correlation coefficient and weighted graph. Int. J. Intell. Syst. 36, 7443–7460. https://doi.org/10.1002/INT.22593.

Doni, F., Corvino, A., Martini, S.B., 2019. Servitization and sustainability actions. Evidence from European manufacturing companies. J. Environ. Manag. 234, 367–378.
ESMAP, 2020. Compendium to the Primer for Space Cooling, 030/20. World Bank, Washington, DC.
Fell, M.J., 2021. The history of heat-as-a-service for promoting domestic demand-side flexibility: lessons from the case of budget warmth. Journal of Energy History 5.
Foss, N.J., Saebi, T., 2017. Fifteen years of research on business model innovation: how far have we come, and where should we go? J. Manag. 43, 200–227. https://doi.org/10.1177/0149206316675927.
Frades, I., Matthiesen, R., 2010. Overview on techniques in cluster analysis. In: Bioinformatics Methods in Clinical Research. Methods in Molecular Biology. Humana Press, pp. 81–107. https://doi.org/10.1007/978-1-60327-194-3_5.
Geissdoerfer, M., Morioka, S.N., de Carvalho, M.M., Evans, S., 2018a. Business models and supply chains for the circular economy. J. Clean. Prod. 190, 712–721. https://doi.org/10.1016/j.jclepro.2018.04.159.
Geissdoerfer, M., Vladimirova, D., Evans, S., 2018b. Sustainable business model innovation: a review. J. Clean. Prod. 198, 401–416. https://doi.org/10.1016/j.jclepro.2018.06.240.
Gillham, E., Nolden, C., Banks, N., Parrish, B., Moya Mose, T., Sugar, K., 2023. Facilitating application of the energy service concept: development of an analytical framework. Energy Pol. 178, 113584. https://doi.org/10.1016/J.ENPOL.2023.113584.
Guldmann, E., Huulgaard, R.D., 2020. Barriers to circular business model innovation: a multiple-case study. J. Clean. Prod. 243, 118160.
Guldmann, E., Remmen, A., 2018. Towards Circular Business Models: Experiences in Eight Companies.
Hennig, C., Meila, M., 2015. Cluster analysis: an overview. In: Handbook of Cluster Analysis. Chapman and Hall/CRC, pp. 22–41. https://doi.org/10.1201/B19706-4.
Hockerts, K., Weaver, N., 2002. Towards a theory of sustainable product service systems—what are the dependent and independent variables of S-PSS. In: Proceedings of the INSEADCMER Research Workshop “Sustainable Product Service Systems—Key Definitions and Concepts.
International Energy Agency (IEA), 2018. The Future of Cooling Opportunities for energy-efficient air conditioning.
International Renewable Energy Agency, 2019. Innovation Landscape Brief: Aggregators. Abu Dhabi, UAE.
Jon Chua, K., Al-Nini, A., Haji Ya, H., Al-Mahbashi, N., Hussin, H., 2023. A review on green cooling: exploring the benefits of sustainable energy-powered district cooling with thermal energy storage. Sustainability 15, 5433. https://doi.org/10.3390/SU15065433.
Kanatlı, M.A., Karaer, Ö., 2022. Servitization as an alternative business model and its implications on product durability, profitability & environmental impact. Eur. J. Oper. Res. 301, 546–560. https://doi.org/10.1016/J.EJOR.2021.10.052.
Khosla, R., Miranda, N.D., Trotter, P.A., Mazzone, A., Renaldi, R., Mcelroy, C., Cohen, F., Jani, A., Perera-salazar, R., Mcculloch, M., 2020. Cooling for sustainable development. Nat. Sustain. https://doi.org/10.1038/s41893-020-00627-w.
Khosla, R., Renaldi, R., Mazzone, A., McElroy, C., Palafox-Alcantar, G., 2022. Sustainable cooling in a warming world: technologies, cultures, and circularity. Annu. Rev. Environ. Resour. 47, 449–478. https://doi.org/10.1146/ANNUREV-ENVIRON-120420-085027.
Kindström, D., Ottosson, M., 2016. Local and regional energy companies offering energy services: key activities and implications for the business model. Appl. Energy 171, 491–500. https://doi.org/10.1016/J.APENERGY.2016.03.092.
Kizilcec, V., Parikh, P., 2020. Solar home systems: a comprehensive literature review for sub-saharan Africa. Energy for Sustainable Development 58, 78–89. https://doi.org/10.1016/j.esd.2020.07.010.
Knuckles, J., 2016. Business models for mini-grid electricity in base of the pyramid markets. Energy for Sustainable Development 31, 67–82.
Kühl, C., Bourlakis, M., Aktas, E., Skipworth, H., 2019. How does servitisation affect supply chain circularity? – a systematic literature review. J. Enterprise Inf. Manag. https://doi.org/10.1108/JEIM-01-2019-0024.
Lafuente, E., Vaillant, Y., Vendrell-Herrero, F., 2019. Territorial servitization and the manufacturing renaissance in knowledge-based economies. Reg. Stud. 53, 313–319. https://doi.org/10.1080/00343404.2018.1542670.
Martínez-Ruiz, Y., Manotas-Duque, D.F., Ramírez-Malule, H., 2023. Financial risk assessment of a district cooling system. Energy 278, 127879. https://doi.org/10.1016/J.ENERGY.2023.127879.
Miranda, N.D., Lizana, J., Sparrow, S.N., Zachau-Walker, M., Watson, P.A.G., Wallom, D. C.H., Khosla, R., McCulloch, M., 2023. Change in cooling degree days with global mean temperature increasing from 1.5° C to 2.0° C. Nat. Sustain. 1–5.
Morley, J., 2018. Rethinking energy services: the concept of ‘meta-service’ and implications for demand reduction and servicizing policy. Energy Pol. 122, 563–569. https://doi.org/10.1016/J.ENPOL.2018.07.056.
Mukoro, V., Sharmina, M., Gallego-Schmid, A., 2022. A review of business models for access to affordable and clean energy in Africa: do they deliver social, economic, and environmental value? Energy Res. Social Sci. 88, 102530.
Nain, A., Bhasin, S., 2022. Making Sustainable Cooling in India Affordable - A Study of Financing and Cooperation Models. Council on Energy, Environment and Water, New Delhi, India.
Nolden, C., Sorrell, S., Polzin, F., 2016. Catalysing the energy service market: the role of intermediaries. Energy Pol. 98, 420–430. https://doi.org/10.1016/J.ENPOL.2016.08.041.
Okkonen, L., Suhonen, N., 2010. Business models of heat entrepreneurship in Finland. Energy Pol. 38, 3443–3452.
Palafox-Alcantar, P.G., Khosla, R., McElroy, C., Miranda, N., 2022. Circular economy for cooling: a review to develop a systemic framework for production networks. J. Clean. Prod. 379, 134738. https://doi.org/10.1016/j.jclepro.2022.134738.
Palo, T., Åkesson, M., Löfberg, N., 2019. Servitization as business model contestation: a practice approach. J. Bus. Res. 104, 486–496. https://doi.org/10.1016/J.JBUSRES.2018.10.037.
Park, C., 2022. Expansion of servitization in the energy sector and its implications. Wiley Interdiscip Rev Energy Environ. https://doi.org/10.1002/WENE.434.
Pavanello, F., De Cian, E., Davide, M., Mistry, M., Cruz, T., Bezerra, P., Jagu, D., Renner, S., Schaeffer, R., Lucena, A.F.P., 2021. Air-conditioning and the adaptation cooling deficit in emerging economies. Nat. Commun. 12 (1 12), 1–11. https://doi.org/10.1038/s41467-021-26592-2, 2021.
Pelli, P., Lähtinen, K., 2020. Servitization and bioeconomy transitions: insights on prefabricated wooden elements supply networks. J. Clean. Prod. 244, 118711.
Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2019. Business model innovation for circular economy and sustainability: a review of approaches. J. Clean. Prod.
Pye, S., Bradley, S., Hughes, N., Price, J., Welsby, D., Ekins, P., 2020. An equitable redistribution of unburnable carbon. Nat. Commun. 11, 3968.
Raddats, C., Kowalkowski, C., Benedettini, O., Burton, J., Gebauer, H., 2019. Servitization: a contemporary thematic review of four major research streams. Ind. Market. Manag. 83, 207–223. https://doi.org/10.1016/j.indmarman.2019.03.015.
Richter, M., 2013. Business model innovation for sustainable energy: German utilities and renewable energy. Energy Pol. 62, 1226–1237.
Roome, N., Louche, C., 2016. Journeying toward business models for sustainability: a conceptual model found inside the black box of organisational transformation. Organ. Environ. 29, 11–35.
Sarancic, D., Pigosso, D.C.A., Pezzotta, G., Pirola, F., McAloone, T.C., 2023. Designing sustainable product-service systems: a generic process model for the early stages. Sustain. Prod. Consum. 36, 397–414. https://doi.org/10.1016/J.SPC.2023.01.020.
Schot, J., Steinmueller, W.E., 2018. Three frames for innovation policy: R& D, systems of innovation and transformative change. Res Policy 47, 1554–1567. https://doi.org/10.1016/J.RESPOL.2018.08.011.
Singh, M., Jiao, J., Klobasa, M., Frietsch, R., 2022. Servitization of energy sector: emerging service business models and startup’s participation. Energies 15, 2705.
Stahel, W.R., 2016. The circular economy. Nature 531 (7595 531), 435–438. https://doi.org/10.1038/531435a, 2016.
Stegehuis, X., von Raesfeld, A., Nieuwenhuis, L., 2023. Inter-organizational tensions in servitization: a dialectic process model. Ind. Market. Manag. 109, 204–220. https://doi.org/10.1016/J.INDMARMAN.2023.01.004.
Suganda, Y., Gabriel, D.S., 2021. Identifying critical success factors in implementing air conditioning servitization to encourage business model innovation. In: International Conference on Industrial Engineering and Operations Management, pp. 2651–2662. Sao Paulo, Brazil.
Sumarsono, N., Kasali, R., Balqiah, T.E., 2023. Circular business model, technology innovation and performance: a strategic-based theoretical framework in the Indonesian energy transition. Renewable Energy Focus 45, 259–270.
Tauqeer, M.A., Bang, K.E., 2018. Servitization: a model for the transformation of products into services through a utility-driven approach. Journal of Open Innovation: Technology, Market, and Complexity 4, 60.
Trotter, P.A., Brophy, A., 2022. Policy mixes for business model innovation: the case of off-grid energy for sustainable development in sub-Saharan Africa. Res Policy 51, 104528. https://doi.org/10.1016/J.RESPOL.2022.104528.
Trotter, P.A., Cooper, N.J., Wilson, P.R., 2019. A multi-criteria, long-term energy planning optimisation model with integrated on-grid and off-grid electrification – the case of Uganda. Appl. Energy 243. https://doi.org/10.1016/j.apenergy.2019.03.178.
Trotter, P.A., McManus, M.C., Maconachie, R., 2017. Electricity planning and implementation in sub-Saharan Africa: a systematic review. Renew. Sustain. Energy Rev. 74. https://doi.org/10.1016/j.rser.2017.03.001.
Wasserbaur, R., Schroeder, A., Beltagui, A., 2023. Heat-as-a-Service (HaaS): a complex adaptive systems perspective on servitization. Prod. Plann. Control. https://doi.org/10.1080/09537287.2023.2189639.
Welsby, D., Price, J., Pye, S., Ekins, P., 2021. Unextractable fossil fuels in a 1.5° C world. Nature 597, 230–234.
Wesseling, J.H., Bidmon, C., Bohnsack, R., 2020. Business model design spaces in socio-technical transitions: the case of electric driving in The Netherlands. Technol. Forecast. Soc. Change 154, 119950. https://doi.org/10.1016/J.TECHFORE.2020.119950.
Yang, M., Evans, S., 2019. Product-service system business model archetypes and sustainability. J. Clean. Prod. 220, 1156–1166.
Zhang, W., Banerji, S., 2017. Challenges of servitization: a systematic literature review. Ind. Market. Manag. 65, 217–227. https://doi.org/10.1016/J.INDMARMAN.2017.06.003.
Zott, C., Amit, R., Massa, L., 2011. The business model: recent developments and future research. J. Manag. 37, 1019–1042. https://doi.org/10.1177/0149206311406265.