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Leveraging Resource Management and Duality Theories to Strengthen Circular Economy Practices in the Waste-to-Energy Industry

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ABSTRACT

With the immediate actions required to address environmental issues posed by waste generation and the growing interest in the circular economy, anaerobic digestion (AD) offers a promising solution. As a major component of waste-to-energy, AD plays a dual role by processing waste and generating renewable energy at the same time, thus contributing to the success of closed-loop systems. However, the success of AD as a business remains uncertain due to the high costs of material handling. Through a systematic literature review (SLR), this study reveals AD-specific key barriers in feedstock exchanges and typical strategies applied to address them. The dual role of AD and the involvement of different stakeholders in the upstream processes further complicate these challenges, thus necessitating a more holistic approach to strategy formulation—an aspect not fully covered in the current literature. These gaps present opportunities to theorise the unique operations of AD businesses and the dynamics of multi-stakeholders in complex feedstock supply processes. This study integrates resource management theories and duality theory, proposing a theoretical framework to enhance the sustainability and circularity of AD ventures. The proposed framework views AD from a resource-oriented perspective and thus reinforces its pivotal role in fostering a truly closed-loop system within the circular economy.

1 | Introduction

As the transition to a circular economy gains momentum, anaerobic digestion (AD) is becoming a pivotal element in sustainable waste management, giving biowaste and wastewater a second life by converting them into valuable resources such as biogas and bio-fertiliser (Kumar and Samadder 2020). Compared to other waste management methods, such as in-vessel composting and incineration, AD demonstrates superior resource and energy recovery performance (Eriksson et al. 2015; Schott et al. 2016; Slorach et al. 2020; Tian et al. 2021). As part of waste-to-energy initiatives, this technology not only closes the loop on resource use (Tian et al. 2021), but also reinforces renewable energy practices and energy security (O'Connor et al. 2021).

Environmental consciousness (Angouria-Tsorochidou et al. 2023; Körner and Visvanathan 2013) and regulatory shifts towards renewable energy (Gregson et al. 2015) have catalysed the interest and investment in AD. Governments worldwide, recognising AD's potential to convert waste into energy, are increasingly embracing AD facilities to foster circular economies and mitigate environmental degradation

caused by waste generation (Lever and Sonnino 2022). Notably, in the United Kingdom (UK), initiatives such as the Private Finance Initiative (PFI) (Gregson et al. 2015), Green Gas Support Scheme (GGSS) (DESNZ 2023), and long-term contracts (Kumar and Samadder 2020; Slorach et al. 2020) have supported the development of large-scale AD facilities, highlighting the intersection of environmental policy and business opportunity in this sector.

Research on the feasibility of AD for valorising various waste types, including co-digestion, which combines biowaste to optimise biogas generation (Liu et al. 2021; Matthew and Spataru 2023; Yang et al. 2022), has reinforced the business case for this technology on both large (Kassem et al. 2020) and small scales (O'Connor et al. 2021). However, in some other cases, the viability of AD as a business venture remains contentious (Bruno et al. 2023; González-Arias et al. 2021). Various factors can hamper AD business's ability to remain economically viable. For instance, AD operations heavily rely on governmental subsidies and incentives (Usack et al. 2018), often making the businesses focus on serving the government and overlook other potential markets (Abdurakhmonov et al. 2021). Another barrier to the economic success of AD ventures is material and material handling costs, which constitute about 80% of the total processing costs (Martínez-Ruano et al. 2019). Input materials' variability (Le Pera et al. 2023), contamination (Kumar and Samadder 2020), seasonal fluctuations (Trujillo-Reyes et al. 2022), and logistical complexities (Iakovou et al. 2010) profoundly contribute to the costs of procuring and pre-processing feedstock. These input materials' characteristics hinder consistent energy production (Kumar and Samadder 2020; Slorach et al. 2020), which further affects business revenues.

The nature of AD operations within the waste management sector requires engagement with various waste producers, such as farmers (Assandri et al. 2022; de Jesus et al. 2021), the food service and hospitality industries (Brás et al. 2022; Pavan et al. 2021), distilleries (Matthew and Spataru 2023; Reynolds et al. 2022), and governments as households' representatives (Angeli et al. 2020; Lo and Woon 2016). The involvement of multiple actors with respect to various material types further ramifies the operations of AD as commercial entities, leading to additional transaction costs (Ketokivi and Choi 2014). The quantity and quality of organic waste depend on the waste collection systems provided by the waste producer (Lang et al. 2006), thus necessitating AD businesses to develop effective partnership selection strategies for stable and high-quality inputs. These issues are often neglected when AD is merely viewed as a waste treatment technology instead of producing high-quality products (Vögeli et al. 2014).

The predominant literature on AD, which focuses on waste valorisation from an environmental standpoint, often overshadows the competitive benefits of AD as a business venture (McDougall et al. 2022). Moreover, the diverse implementations of AD technology make it difficult to pinpoint specific issues hindering AD ventures from striving. Nonetheless, there is a strong indication that problems on the main process and downstream side of AD are often associated with the upstream side. Different biowaste sources determine the organic content of biowaste (Brás et al. 2022), which affects the energy production potential (Pereira and Silva 2023). Contaminants in the input materials, such as non-biodegradable or toxic substances such as plastics, chemicals, heavy metals, or pharmaceuticals (Cazaudehore et al. 2022), make direct digestate disposal into the soil or aquatic environment costly (Dalke et al. 2021; Lamolinara et al. 2022). These instances collectively show that AD's commercial viability is intricately linked to the characteristics of input materials (Le Pera et al. 2023) and highlight the importance of input management systems and supply strategy.

The viability and sustainability of AD businesses rely equally on technological prowess and effective management (Jensen et al. 2024). While technological innovations (Kassem et al. 2020; Kumar and Samadder 2020; Miramontes-Martínez et al. 2022) have been intensively studied, there is a notable lack of business and management perspectives in AD discourse. Literature providing a comprehensive framework for managing diverse feedstock sources and inconsistent results in economic feasibility studies on AD is currently underdeveloped. Hence, to bridge this gap, this study aims to explore how businesses operating in AD can effectively manage their feedstock supply to ensure their sustainable viability in producing green energy and truly closing the resources cycle. To achieve this, the following literature research questions guide the conduction of this study.

RQ1: What business and managerial challenges do AD businesses encounter in securing and managing feedstock supply to ensure their sustainability?

RQ2: What procurement management strategies are commonly employed by AD businesses to maximise resource recovery?

RQ3: To what extent can inter-organisational theories be applied to leverage circularity in AD's feedstock supply management?

This study employs a systematic literature review (SLR) to delve into various facets of feedstock supply management in the AD sector to better understand the business challenges, management strategies, and inter-organisational practices that enhance it. An SLR is a suitable method for gathering insights by thoroughly analysing and synthesising key evidence from existing research (Snyder 2019). Prior investigations using an SLR have been devoted to AD's technological facets and its role in energy recovery (Ampese et al. 2022; Wang et al. 2013), notably through biogas and biohydrogen production (Khawer et al. 2022), from wastewater (dos Santos et al. 2022) and organic waste, including food waste (Assis and Gonçalves 2022; Ren et al. 2018). Despite their significant contributions to the AD industry, they imply the need for an investigation from a business and management perspective to complete the puzzle, which results in a proposed framework.

The framework uses the theoretical triple lens of resource dependency, resource orchestration, and duality theories to explain the dynamics of feedstock supply and offer strategic guidance for AD ventures, balancing their roles in waste management and renewable energy production. Ultimately, this study aims to advance both academic and practical knowledge, providing valuable insights into the complex relationship between business, technology, and sustainability within AD operations and the broader waste-to-energy sector.

TABLE 1 | Inclusion criteria for retrieval and screening process.

Sample retrieval criteria	Title and abstract screening	Full-text assessment criteria
• Contains the following words in the title, abstract, and keywords: ('anaerobic digest*' OR 'co-digest*' OR 'biodigest*' OR 'bio-digest*' OR 'anaerobiosis') AND ('energ*' OR 'biogas' OR 'fertili*er' OR 'methane' OR 'biofuel' OR 'electric*' OR 'biomass' OR 'waste' OR 'manure' OR 'sludge' OR 'food') AND ('business model*' OR 'revenue' OR 'valori*ation' OR 'techno-econom*' OR 'market' OR 'profit' OR 'supply chain'). • Document type: article. • Source type: journal. • Language: English. • Publication year: 2000 to 2023.	• Relevant to answer research questions. • Cover words '*supply chain*' OR '*management*' AND the main aims are NOT biochemical processes. • Techno-economical studies that include supply management as variables or scenarios in the analysis.	• Can be fully accessed. • Focuses on the following information: business, management, or organisational challenges and barriers in the feedstock procurement process; procurement and supply strategy; management system improvement.

The remainder of this paper is structured as follows. Section 2 describes the research design, including data collection and methods to conduct analysis. Section 3 outlines the descriptive analysis of the articles reviewed and the thematic findings. The thematic findings cover entities running AD technology, challenges in feedstock supply, and typical procurement strategies. Section 4 elaborates on the implications of the findings, covering evidence characterising the interactions beyond organisational boundaries and the distinct nature of AD ventures. The section concludes by theorising the idiosyncrasies and inter-organisational interactions. The last section summarises the contributions and limitations of the study and outlines the prospective developments.

2 | Research Method

A SLR was undertaken to comprehensively retrieve, examine, and synthesise all available empirical evidence in the body of literature (Snyder 2019) on the supply management of AD. This methodology, originally developed in the medical field, has been adapted for social science applications (Davis et al. 2014) by utilising qualitative approaches (Greenhalgh et al. 2004). A meticulous process of gathering articles through systematic search criteria is applied (Snyder 2019), followed by a qualitative assessment of the articles' content to assess the quality and robustness of findings across diverse study designs. This helps to facilitate comparative analysis (Greenhalgh et al. 2004). This approach was particularly suited to the multidisciplinary and extensive body of literature on AD, ensuring a comprehensive understanding of the topic.

In this study, a systematic review aimed to identify all empirical evidence that met the pre-specified inclusion criteria to answer the research questions outlined in Table 1. The process commenced with sample retrieval through a systematic query from the research article database. The search strings used were purposely more general than upstream terms to ensure comprehensive coverage of both technical and business and managerial aspects relevant to AD operations and justify whether the majority of the problems were linked to procurement and supply chain management. Moreover, to address *RQ1*, which examines business and managerial challenges, we included terms such as 'business model', 'market', 'profit', and 'supply chain' to capture literature that explores the dynamics of AD within business contexts. *RQ2*, focused on procurement and resource recovery strategies, guided the inclusion of terms such as 'revenue', 'valori*ation', and 'techno-econom*' to identify studies centred on economic viability, supply chain efficiencies, and resource management in AD. For *RQ3*, which investigates the application of inter-organisational theories in AD's supply management, we employed a broad selection of terms—'supply chain', 'business model', 'market', and 'profit'—to ensure that relevant studies discussing collaborative frameworks, strategic alliances, and inter-firm cooperation were captured. Additionally, technical terms such as 'anaerobic digest*', 'biogas', 'biofuel', 'biomass', 'methane', 'fertiliser', 'waste', 'manure', 'sludge', and 'food' were incorporated across the RQs to ensure coverage of both the input and output processes central to AD. This study used the Scopus database, a leading multidisciplinary academic database (Qazi and Appolloni 2022), to retrieve the sample. The meta-data of

the articles within the sample were extracted into a comma-separated value (CSV) file for the screening process and eligibility assessment through a spreadsheet. Figure 1 represents the number of articles included and excluded at each stage.

From an initial sample of 2041 articles, 49 research articles were finally included for analysis, comprising descriptive and thematic analysis. The descriptive analysis involved examining the distribution of articles by publication year, journal outlets, and the focus of research, while the thematic analysis categorised key contexts of AD implementation, challenges, strategies, and inter-firm interactions within AD supply management based on pre-determined themes. The purpose of conducting these analyses was to comprehend the state-of-the-art AD supply management literature, identify the gaps in the literature related to this field, and ultimately answer the research questions. This study used predetermined themes (Table 2) presented as a codebook to analyse the sample of articles. The codes were further developed organically through the coding process using NVivo 1.5, and their relationships were analysed. By using explicit and systematic methods in retrieving and reviewing articles and all available evidence, bias can be minimised, thus providing reliable findings from which a theoretical framework can be drawn, and recommendations can be proposed.

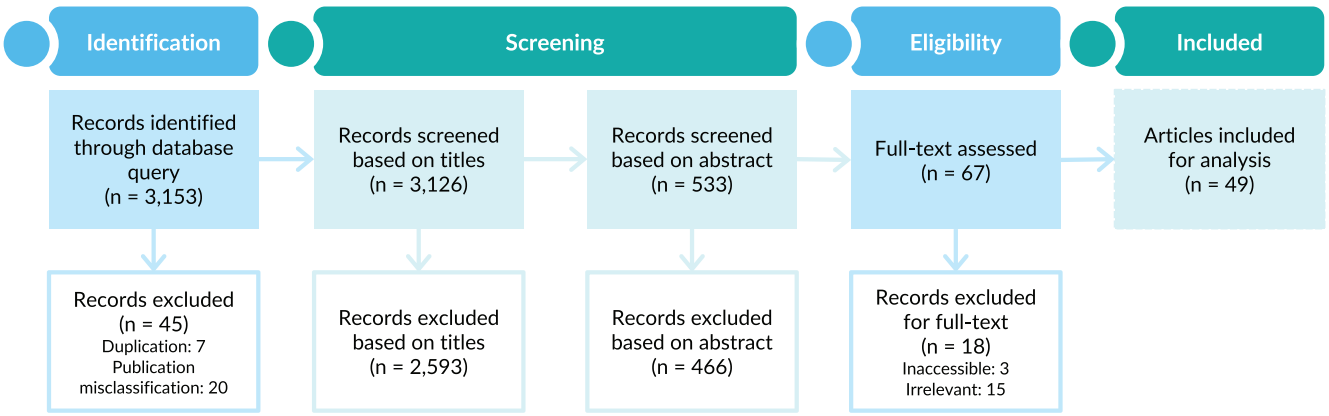

FIGURE 1 | Systematic assessment process (based on PRISMA flow diagram (Liberati et al. 2009)).

TABLE 2 | Predetermined themes for thematic analysis.

Code group	Main theme
• Geographical area • Industry/sector (e.g. agriculture, food processing, distilleries, retail, municipal solid waste (MSW), wastewater treatment) • Scale (lab-scale, small-scale, medium-scale, large-scale) • Feedstock types (e.g. food waste, farm waste, crop residue, energy crops)	• Context of AD implementation
• Quality • Cost • Availability • Logistics and transport • Stakeholder characteristics • External forces	• Challenges in the upstream process
• Feedstock diversification • Multiple sourcing • Public procurement • Supply network optimisation • Vertical and asset integration • Strategic alliance and joint venture	• Implemented strategies
• Alignment and collaboration • Competition • Interdependence • Information and knowledge sharing • Imbalance power • Motivation and interest • Autonomous behaviour	• Inter-firm interaction indications

3 | Findings

3.1 | Descriptive Analysis

Figure 2 illustrates the distribution of articles published annually and pertinent articles included in the analysis according to their respective publication years. Regardless of downward indices towards 2023, the general uptrend pattern highlights the contemporary nature of the topic and its alignment with the latest developments in the field. It underscores more research embracing the business and management sides of this technology. Notably, out of the 49 selected articles, the peak occurred in 2020, recording the highest incidence with eight articles. The sample articles are distributed across 31 journal outlets.

The *Journal of Cleaner Production* and *Applied Energy* have the highest incidence of recorded articles, with nine and eight articles, respectively. It is foreseeable that the *Journal of Cleaner Production* predominates in the number of articles within the final dataset, given the alignment of the journal scope, which emphasises cleaner industrial production, environmental, sustainability research, and practices. Similarly, *Applied Energy* is a peer-reviewed journal for innovation, research, and development in the area of energy. This journal makes the second-highest contribution, given the critical role of AD as a waste-to-energy technology. *Waste Management*, *Renewable Energy*, and *Energies* each contribute two articles. Given the distribution of publications across these outlets, it is evident that AD is a fundamental component of sustainable practices and highlights its significant role in the evolving energy landscape.

3.2 | Thematic Analysis

Guided by the predetermined themes in Table 2, this section outlines the review results encompassing entities running AD technologies, operational structure and decision scope in running AD as a business, feedstock supply challenges, and common procurement strategies. The first two sub-sections establish the landscape and operational context of AD businesses: Section 3.2.1 summarises the entities running AD businesses, while Section 3.2.2 synthesises the AD business's operational structure and decision scope.

Sections 3.2.3 and 3.2.4 then directly address the research questions (RQs) through nine key findings. Section 3.2.3 responds to *RQ1* by detailing the main business and managerial challenges AD businesses face in securing sustainable feedstock. Key issues include variability in feedstock quality (e.g. contamination, seasonal changes), logistical and transport costs (e.g. high expenses, quality degradation), specific operational requirements (e.g. additional sorting processes), and external factors, such as the impact of waste producers on feedstock accessibility. Section 3.2.4 addresses *RQ2* by outlining procurement strategies that enhance resource recovery. This includes optimising facility locations and transport routes, diversifying feedstock sources through partnerships with local authorities, and forming strategic alliances with stakeholders, such as farmers, to ensure a stable, high-quality feedstock supply.

This study, through Findings 4 and 9, also identifies key gaps in the literature. Finding 4 underscores that the behavioural aspect of stakeholders involved in the AD upstream process is yet to be explored. Finding 9 underscores that inter-organisational theories have yet to be systematically applied to AD operations within circular economy frameworks. These observations address *RQ3* and highlights an important area for further research.

3.2.1 | Entities Running AD Technologies

When investigating business challenges encountered by entities operating in AD technology, it is essential to define the nature of these entities and their operational environments. Although the entities capable of running AD technology are rarely explicitly mentioned, the literature highlights diverse settings where AD technology is deployed, encompassing food processing enterprises (Krungkaew et al. 2023; Valenti et al. 2023), renewable

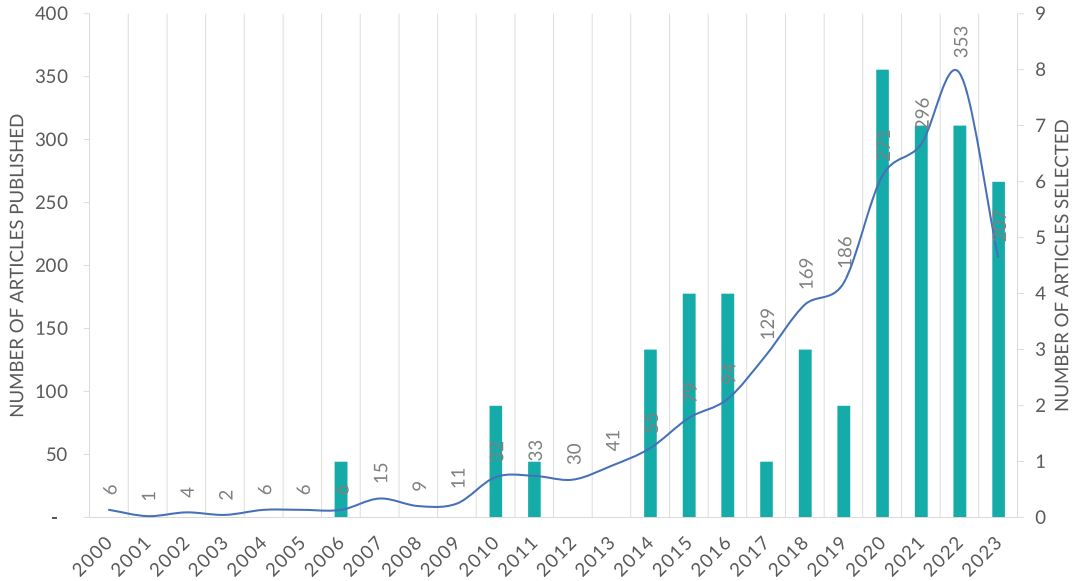

FIGURE 2 | Number of relevant articles based on publication year.

energy production (Mahjoub et al. 2020), waste management (Hussain et al. 2020; Lang et al. 2006), and communities such as in agricultural sectors (Swindal et al. 2010) and public facilities in rural areas (Sime 2020). Each setting involves distinct entities with unique motivations for using AD.

In agriculture and food processing, AD is primarily adopted to manage waste from core activities. It is also indicated that both farmers (Swindal et al. 2010) and food producers (Krungkaew et al. 2023) are capable of running and embedding AD systems in their operations. Their motivation stems from a desire to reduce additional costs associated with waste disposal compliance (Assandri et al. 2022). They opt for in-house waste management using AD to save on disposal fees and, in some cases, to get additional revenues or cost savings through energy generation (O'Connor et al. 2021).

Public community digesters in residential settings also focus on waste disposal (Angeli et al. 2020) but with nuanced differences from agricultural settings. For farmers, energy production from AD is a secondary benefit, while in residential areas, AD serves a dual purpose as a waste management system and a decentralised energy system (Sime 2020). It is the perception of usefulness that distinguishes households-based and farmers-based AD. Despite the primary objectives of community-based AD being stated, the literature does not clearly specify whether these community digesters are operated by the community itself or managed by another entity.

AD is also integral to the renewable energy and waste management sectors. Studies on renewable energy supply commonly include terms such as 'plant managers' (Manzone et al. 2020; Mertens et al. 2016) or 'biogas plant operators' (Mertens et al. 2016; O'Connor et al. 2021), or 'operators of storage and conversion facilities' (De Meyer et al. 2016) to refer to entities operating in AD as biogas or bioenergy producers. In waste management literature, entities responsible for operating AD facilities are referred to as 'plant operators' (Reynolds et al. 2022) or 'AD plant operators' (Valenti and Toscano 2021) or 'technology operators' (Robles et al. 2020) or 'materials recovery facility operators' (Gregson et al. 2015). These instances elucidate the existence of dedicated business entities whose core competence and revenue generation lie in operating AD technology.

Given the variability of potential implementations of AD and the entities running AD systems, the urgencies and challenges in obtaining feedstock are contingent upon the operational landscape. As discussed, the primary goal of AD adoption for farmers and food producers is to manage residues from their main operation. This is somewhat different from dedicated AD operators in the energy or waste-to-energy sectors whose primary motivation for operating AD is revenue generation. This study will mainly focus on, but is not limited to, investigating challenges in feedstock procurement for green energy generation experienced by dedicated AD operators.

3.2.2 | Operational Structure and Decision Scope in Running AD as a Business

Literature on AD that includes business and managerial terms is commonly multidisciplinary studies. Therefore, to identify the business-specific challenges that AD ventures face, it is crucial to understand their operational structure and the decision-making processes involved. Figure 3 outlines how various activities and decisions are coordinated to achieve organisational goals. Four operational layers essential for running AD technology as a business were synthesised from the 49 selected articles. Each layer

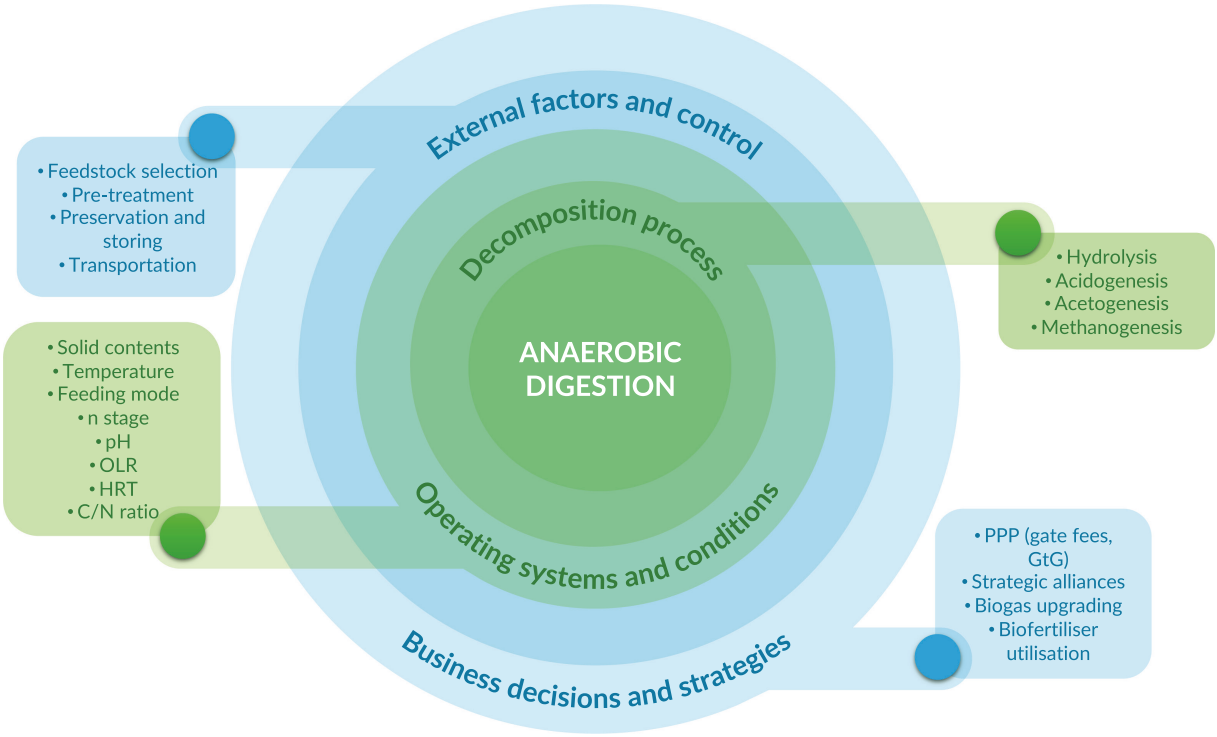

FIGURE 3 | Four operational layers in running AD technology as a business.

interacts with the others. At the core, AD operations involve the main decomposition processes. These processes determine how organic materials are converted into renewable energy and biofertilisers (Pereira and Silva 2023), which are influenced by operating conditions such as the number of stages (n stage) of AD systems, organic loading rate (OLR), hydraulic retention time (HRT), and carbon/nitrogen ratio. Studies in the biochemical field often analyse and configure these conditions to optimise the core process and energy generation.

The next layer covers factors partially under the control of AD operators while significantly impacting the operating conditions. It covers decisions involving external variables or parties, such as feedstock selection, pre-treatment, preservation and storage, and logistics. Further out, there are factors influencing the commercial aspect of AD operations. It covers business decisions and strategies, such as the decision to be involved in public-private partnerships or whether the business plan upgrades the existing product and expands the markets.

A clear understanding of this operational structure and its respective decision scope helps this study and researchers in the business and management field identify their potential contributions to the AD industry. While the core of AD operation and operating conditions are closely related to biochemical processes and technology developments, the two outermost layers are directly associated with business and managerial challenges. This classification has also guided this study in identifying business-related challenges and strategies implemented by AD ventures, as presented in the following sections.

3.2.3 | Challenges in Feedstock Supply

As part of the green energy sector, AD is valued for its ability to produce biomethane, which can be upgraded to biogas, biofuel, and electricity. Ranjbari et al. (2022) provide a taxonomy that classifies biofuels based on their feedstock types and sources: first generation (1G) from edible crops, second generation (2G) from non-edible crops and biowaste (e.g. food waste, agricultural residues, and animal manure), third generation (3G) from algae, and fourth generation (4G) from genetically modified crops and algae. While recent studies have initiated the exploration of algae (3G) (Bussa et al. 2020; Mahjoub et al. 2020), the current research focus predominantly remains on the second-generation (2G), utilising energy crops and biowaste as primary feedstock sources (Mahjoub et al. 2020; Ranjbari et al. 2022; Van Dael et al. 2014).

Predominant research on waste valorisation underscores that AD is an effective alternative disposal pathway to landfilling (Angeli et al. 2020; Gregson et al. 2015; Taifouris and Martín 2018) that addresses adverse environmental impacts from waste generation. While the considerable amount of organic content in waste generated creates opportunities for businesses and various entities to implement AD (Lo and Woon 2016), challenges persist concerning its usability (Pavan et al. 2021), which is associated with its quality and accessibility. Biowaste presents variations in the organic composition (Assandri et al. 2022; Escalante et al. 2016; Mohammadi et al. 2023), which manifests in the feedstock quality. It is also acknowledged that waste, even after the sorting and segregation process, retains contaminants (Gregson et al. 2015) that can disrupt AD operations (Hussain et al. 2020). Moreover, seasonal variations could affect the volume and quality of biowaste (Angeli et al. 2020; Gregson et al. 2015; Iakovou et al. 2010; Lang et al. 2006; Liu et al. 2021). These collectively influence the effectiveness of biowaste that can be converted into energy. Consequently, businesses operating in AD with energy production as their core service face difficulty in obtaining stable and reliable feedstock from waste.

Finding 1: While biomass from waste is abundant and has great potential, there are ongoing issues with its quality, like contamination and inconsistent production volume and organic content, making it difficult to use this type of biomass effectively as a source of green energy.

While AD operators who rely solely on energy crops may experience fewer contamination issues, they are also not immune to inconsistent feedstock supply. Seasonality of biomass production (Balaman and Selim 2014b, 2015; De Meyer et al. 2016; Pavan et al. 2021) hinders AD operators from reliably producing and serving renewable energy to the market. It emphasises that AD operators constantly struggle with access to effective feedstock despite the feedstock types used. Moreover, the geographical dispersion of feedstock sources (Tanguy et al. 2017) and associated logistics complicate AD plant managers' access to feedstock, significantly impacting procurement. The more spread out the feedstock source locations are, the higher the transportation costs (Krungkaew et al. 2023; Kwon and Han 2021; Robles et al. 2020).

Not only burdening AD operators with non-value-added expenses, but feedstock transportation also introduces technical challenges (Matthew and Spataru 2023) due to the bulky nature of feedstock deliveries (Iakovou et al. 2010; Valenti et al. 2023) using specific vehicles (Angeli et al. 2020; Lo and Woon 2016). Feedstock quality may also decline during transport (Assandri et al. 2022; Manzone et al. 2020), leading to potential opportunity losses. The level of impurities is believed to be superior in road collection if there is a lack of adequate control over the vehicle used (Brás et al. 2022). Consequently, optimising facility locations and transportation processes to minimise costs and prevent quality degradation remains an essential area of research.

Finding 2: Multiple supplier locations and the requirement for specialised vehicles, along with potential quality loss during transportation, will incur non-value-added costs that, in turn, affect the AD business viability in generating green energy.

Challenges associated with cost during the procurement process extend beyond transportation. AD operators can procure feedstock from energy crops directly from farmers or biomass markets. However, securing affordable and stable biomass prices often proves difficult (Mertens et al. 2016), and operators may face competition from other businesses (Ranjbari et al. 2022). Interestingly, procuring feedstock from biowaste presents unique scenarios. Instead of incurring costs, AD operators may receive payment for accepting waste through gate fee schemes (a government incentive mechanism for waste management) (Gregson et al. 2015; Lyng et al. 2018; Reynolds et al. 2022).

Alternatively, they may also adopt a scenario in which farmers make direct payments for waste management services (Mayerle and Neiva de Figueiredo 2016).

In the latter cases, AD operators function as waste managers, thus often handling diverse biowaste conditions (Pereira and Silva 2023), which leads to additional activities, such as sorting and segregating biowaste from other waste streams and contaminants. Some AD operators decide to self-conduct these activities (Brás et al. 2022; Lyng et al. 2018; Matthew and Spataru 2023), while others prefer to work with external entities (e.g. households through local authorities) responsible for separated waste collection (Ankathi et al. 2021; Brás et al. 2022) for lesser feedstock variability. Each approach entails its own additional operations expenses (Liu et al. 2021; Matthew and Spataru 2023; Yang et al. 2022). Importantly, not all biowaste procurement is cost-free. In some cases, AD operators may need to pay, as supplying an AD plant may not be the most cost-effective or beneficial option for waste producers (Reynolds et al. 2022).

Finding 3: As part of waste-to-energy, AD businesses receive waste as a revenue stream and as their feedstock. This idiosyncrasy forces AD businesses to deal with low-quality feedstock and carry out extra processes to improve its quality, a dilemma not experienced by businesses that exclusively operate in waste management or green energy generation sectors.

Referring to the technological function of AD, the core competency of AD operators resides in transforming biomass and biowaste into energy. Biowaste's sorting and separation process constitutes ancillary activities. Like in other business settings, non-core activities can be outsourced. For instance, responsibility for separate municipal solid waste (MSW) collection may rest with the inhabitants at waste sources, the local authority in charge of waste management, or other entities. Lang et al. (2006) suggest that waste collection systems provided by municipalities determine the variation in the volume and quality of feedstock collected. Notably, household participation in food waste collection is a primary driver of waste collection volume, and yet the collection rate has proven to be varied (Matthew and Spataru 2023). Brás et al. (2022) highlight that shortcomings in the selective disposal practices by inhabitants lead to an inherent risk of biowaste deviating from expected collected amounts or quality. Despite the sensitisation efforts to alter the behaviour of residents, achieving definitive outcomes remains uncertain (Angeli et al. 2020).

In agriculture and industrial sectors, organisational behaviours similarly impact the total mass and quality of feedstock (Lang et al. 2006). Farmers as waste producers may reject the use of concrete floors due to its negative impact on their production and operation costs (Caruana 2019), despite the potential improvement of manure collection for AD. Resistance to changing established practices can hinder effective biomass collection (Caruana 2019), and internal management practices, such as livestock feeding, can lead to fluctuations in manure composition (Bussa et al. 2020).

Although material flows of feedstock and their influencing mechanisms can be identified (Krungkaew et al. 2023; Lang et al. 2006) and optimised (Mahjoub et al. 2020), suppliers hold the power to decide to whom they want to sell the feedstock or use it for other purposes (Krungkaew et al. 2023; Mertens et al. 2016). Consequently, the quantity and quality of biowaste entering AD facilities are determined by individuals and organisational behaviours of the respective stakeholders.

Finding 4: The accessibility and quality of feedstock are intricately affected by the behaviours of waste producers, creating dependencies for AD operators. However, these phenomena remain underexplored in the body of literature.

3.2.4 | Common Procurement Strategies

As the barriers and challenges in AD feedstock procurement become more apparent, this section elaborates on the prevalent strategies to address the respective challenges. Given that accessibility issues dominate AD operations, selecting optimal facility locations is one of the predominant strategies being studied as it can reduce transportation costs (Ankathi et al. 2021; Thiriet et al. 2020) while maximise the benefits (Balaman and Selim 2014b; Balaman and Selim 2014a; Van Meerbeek et al. 2015) and environmental impacts (Ankathi et al. 2021; Mohammadi et al. 2023). Optimising facility locations often consider proximity to feedstock sources, waste generation centres, and end-users of the AD by-products (Kwon et al. 2022; Kwon and Han 2021). Additionally, the scale and capacity of AD facilities need careful planning to align with the local feedstock availability. Implementations of such strategy include strategic placement of AD facilities near urban areas (Robles et al. 2020; Thiriet et al. 2020; Yang et al. 2022), agricultural regions (de Jesus et al. 2021; Mayerle and Neiva de Figueiredo 2016), or industrial hubs (Brás et al. 2022; Valenti et al. 2023) to optimise the collection and processing of biowaste.

Once the locations are determined, optimising transportation routes becomes crucial, particularly considering moving feedstock requires specialised trucks. This process involves identifying the most efficient routes for collecting biowaste and delivering it to AD facilities (Matthew and Spataru 2023; Mayerle and Neiva de Figueiredo 2016; Valenti et al. 2023; Yang et al. 2022) to reduce transportation costs, fuel consumption, and greenhouse gas emissions. This strategy not only enhances the economic viability of feedstock supply but also aligns with sustainability goals by minimising the environmental footprint.

To develop such strategies, optimisation methods such as mixed-integer linear programming (MILP) are frequently applied (Ankathi et al. 2021; Balaman and Selim 2014b; Balaman and Selim 2014a; Kwon et al. 2022; Kwon and Han 2021; Liu et al. 2021; Mohammadi et al. 2023; Thiriet et al. 2020). There is also an increasing use of Geographic Information Systems (GIS) to improve the optimisation models and methods (Ankathi et al. 2021; de Jesus et al. 2021; Valenti et al. 2023; Valenti and Toscano 2021). Research within this domain has aided the decision-making process by accommodating various factors and conditions. The advancements in technology have also improved the methods of formulating these strategies. Nonetheless, determining facility location and capacity is limitedly applied in the strategic planning process and is only relevant in establishing new facilities but does not apply to existing ones.

Finding 5: While greenfield AD plants reduce feedstock procurement costs through better facility locations and capacity planning, brownfield AD plants can only rely on transportation route optimisation.

Although not explicitly stated in previous studies, multiple sourcing and public procurement are other significant strategies for AD procurement management. Co-digestion or feedstock mix, which manifests feedstock diversification, has proven to be an effective way to mitigate quality issues due to inconsistent organic contents (Mohammadi et al. 2023) and more cost-competitive (Liu et al. 2021; Matthew and Spataru 2023) when feedstock availability and accessibility are not the central issue (Yang et al. 2022). Using diverse organic materials, such as MSW, agricultural residues, and industrial by-products to the feedstock mix (Brás et al. 2022; Lyng et al. 2018; Mahjoub et al. 2020; Mayerle and Neiva de Figueiredo 2016; Taifouris and Martín 2018; Thiriet et al. 2020; Yang et al. 2022) is indicative of a multiple-sourcing strategy. By engaging with multiple suppliers, AD operators can reduce their dependence on a single source, thereby mitigating the risks associated with potential disruptions (Mohammadi et al. 2023), fluctuations in supply, or changes in waste composition (Iakovou et al. 2010). This approach fosters resilience, stability, and adaptability in facing dynamic waste availability and market conditions.

Collaboration with public entities is also crucial, as evidenced by the inclusion of municipal solid waste in feedstock mixes. Public procurement initiatives involve partnering with municipalities, local governments, or waste management authorities. These entities play crucial roles in waste collection and segregation (Lang et al. 2006), making them valuable partners in securing a steady supply of municipal waste and other organic materials, such as green waste from landscaping (Boscaro et al. 2018; Van Meerbeek et al. 2015) and wastewater management (Kwon et al. 2022; Valenti and Toscano 2021). By engaging in public procurement, AD businesses can support the governments in achieving environmental sustainability goals and the circular economy by diverting biowaste from landfills.

Finding 6: Feedstock diversification derived from multiple origins and active engagement with local authorities in providing waste management services will enhance AD operators' business adaptability. However, how these strategies should be formulated within AD businesses remains under-researched.

Reflecting the multiple-sourcing strategy and diverse contexts in which AD can be implemented, various possible configurations of AD supply networks are evident in the literature (e.g. Balaman and Selim 2014b, 2015; De Meyer et al. 2016; Kwon and Han 2021; Mahjoub et al. 2020; Robles et al. 2020; Tanguy et al. 2017; Van Meerbeek et al. 2015). The underlying reason for this research concentration is that AD businesses, specifically as green energy producers, must strategically plan and optimise these networks to ensure a reliable and cost-effective feedstock supply. Nonetheless, prior studies commonly construct the supply networks based on activities, often lacking representation of specific business entities executing these actions (limited to the work by Krungkaew et al. 2023; Lyng et al. 2018; Mohammadi et al. 2023; Pavan et al. 2021), let alone their interactions. This oversight is caused by the predominant focus on optimising the supply networks instead of emphasising the coordination of interaction among the stakeholders, hindering optimal management in the implementation. Understanding who is clearly involved in supply network activities and managing relationships with them are crucial for the success of the focal entity operating in AD. After all, the challenges to developing a sustainable bioenergy industry lie in the role of each actor within the supply network and the interrelated decisions within the network (De Meyer et al. 2016).

Finding 7: Diverse feedstock types and acquisition methods result in varied supply network configurations. However, specific stakeholders' engagement, and how they coordinate, within the supply network are often overlooked.

Effective sourcing strategies often require collaborative initiatives through the formation of strategic alliances, such as partnerships with farmers (de Jesus et al. 2021) or institutions generating biowaste, including catering businesses, professional gardeners, and food processing companies (Brás et al. 2022). Likewise, vertical integration can optimise feedstock supply chains, particularly in agro-industries, where waste management is closely linked to AD (Krungkaew et al. 2023). In these cases, agribusinesses typically drive forward integration rather than dedicated AD operators. In the context of dedicated businesses operating in AD, this strategy is rarely implemented, except, perhaps, by those who source their feedstock from cultivated biomass.

While these procurement strategies offer significant benefits through synergy creation, they come with their own set of challenges. Coordinating with multiple alliances requires effective communication and logistics management. Public procurement entails navigating bureaucratic processes and aligning with waste management policies. AD businesses must carefully balance these considerations to optimise their sourcing strategies for a reliable and sustainable feedstock supply. It is striking that despite the practical relevance of these challenges, research explicitly addressing them, in the context of AD, is rarely found. This gap can be routed back to the lack of specification of stakeholders involved in AD supply networks. Managing such challenges cannot be done without clearly understanding the actors influencing feedstock supply success.

Finding 8: Vertical integration and formation of alliances have helped AD operators secure feedstock. However, the details on how their implementation can eventually address feedstock supply management problems are not apparent.

Building on these findings, securing high-quality feedstock for green energy production remains a significant challenge for AD businesses regardless of the abundant availability of biowaste. This challenge stems from accessibility and quality issues. Feedstock from waste, to date, presents variability in nutrient contents and contamination levels, making it challenging to achieve optimal energy generation. Accessibility is crippled by the scattered locations of suppliers and specific transportation requirements, which also affect the quality of the feedstock. The diversity in waste acceptance scenarios further complicates AD business operations.

Decision-making support systems for facility locations (including co-locations), capacities, and transportation routes have been proposed to address such issues. Nonetheless, in a more complex business landscape, little progress has been made since 2010 in terms of managing AD as business entities, with studies on biomass-to-energy still primarily focusing on production technologies (Iakovou et al. 2010) rather than supply chain management. Though some studies hint at potential collaborators with whom AD plant managers can make alliances, the absence of studies delving into frameworks to create and manage alliances within the supply network potentially hampers the successful execution of deliberately designed networks.

Finding 9: There is an apparent paucity of theoretical perspectives that take into account the idiosyncrasies of AD operations as waste-derived green energy producers.

This finding particularly underscores the significant gap in the literature in understanding and addressing the unique challenges of AD operations. There is a critical need for theoretical perspectives that account for the specific characteristics of AD ventures, particularly in forming and managing strategic alliances within the supply network for efficient and sustainable AD businesses. This research gap offers an opportunity for further studies to explore innovative solutions for managing the tensions within AD business operations as waste-derived green energy producers. Addressing these challenges could significantly improve AD technology's commercial viability and environmental impact, contributing to the advancement of circular economy practices and renewable energy production.

4 | Discussion and Synthesis

4.1 | Evidence of Inter-Organisational Interactions in AD Supply Management Practices

Derived from the findings, there is an absence of explicit discussions on inter-organisational theories and practices within the context of AD feedstock supply management. This underscores that the existing literature cannot fully address *RQ3*. Nonetheless, some indications that such theories could potentially complete the expansive technical studies (Dunmade 2019) were found. Constructs such as competition, uncertainty, interdependence, collaboration, and power dynamics emerge as critical factors influencing AD operators' interactions with other parties. Through this collection of constructs, this study seeks to highlight how inter-organisational theories and practices potentially contribute to understanding and addressing challenges in AD feedstock supply management.

4.1.1 | Competition and Uncertainty

Competition is part of the business nature. Despite global efforts to support the renewable energy transition, this sector, including AD, struggles with cost-competitiveness when compared to conventional energy sources due to high capital expenses (Timilsina 2021). A central challenge for AD plant managers operating in the renewable energy sector lies in the procurement of feedstock that does not compromise the food supply (De Meyer et al. 2016; Mahjoub et al. 2020) nor is uncertain in terms of quality (Matthew and Spataru 2023; Yang et al. 2022). This dilemma encapsulates the broader struggle to balance environmental sustainability with the economic viability of AD operations.

For AD businesses that are exclusively reliant on cultivated biomass or energy crops, procurement is often hindered by competition with land use (Boscaro et al. 2018; De Meyer et al. 2016) and with animal feeds (Ranjbari et al. 2022). This circumstance posits AD operators in competition with other companies and sectors demanding biomass. When sourcing feedstock from waste, the competitive landscape may be less transparent. Various waste valorisation technologies, including composting, incineration, and recycling facilities (e.g. for animal feed production), may target similar biowaste for different purposes (Tanguy et al. 2017), setting the stage for a dynamic interplay between them and AD operators in obtaining the appropriate amount and quality of feedstock. Taken together, competitions in feedstock procurement create uncertainty for AD plant managers in green energy production, especially knowing accessibility to feedstock determines the viability of an AD business. Subsequently, the presence of competition exacerbates access to feedstock, thus leaving the future of AD ventures hanging by a thread.

4.1.2 | Interdependence and Dynamics of Power

Interdependence among organisations exists whenever an organisation cannot fully control all conditions for achieving desired outcomes and requires resources from other organisations (Pfeffer and Salancik 1979). In the AD literature, interdependence is often implied rather than directly discussed. Waste management systems comprise all interacting socioeconomic aspects, including physical (materials) flows and agents as decision-makers of the systems (Lang et al. 2006). To operate and produce green energy, AD plant managers need efficient feedstock process flows reaching their facilities' gates, necessitating a solid network of feedstock collection, storage, and pretreatment processes (Angeli et al. 2020). The interrelated agents' decisions within the network in succeeding in the transition towards renewable energy (De Meyer et al. 2016) underscore interdependence among agents.

Although biowaste is reportedly abundant and underutilised (Sime 2020), issues of accessibility and quality create AD dependencies on stakeholders who control the allocation, access, and use of biowaste within the waste-to-energy supply chain. Nevertheless, this dependency is mutual. For example, farmers are obliged to dispose of manure properly, and the AD system can provide a solution for doing this in the most efficient way and offer a green energy supply for farming operations (Caruana 2019).

AD operators are also interdependent with intermediaries (Pavan et al. 2021), such as storage facilities managers, transporters, or even government agencies. In a high dispersion of urban waste producers in the context, local governments facilitate periodical biowaste collection through specialised bags or containers (Brás et al. 2022). Even the feedstock storage activities require external sources to perform as transfer stations

before the feedstock is shipped in high-volume trucks to AD facilities (Brás et al. 2022), this includes local governments as food waste collection points (Ankathi et al. 2021). Although not explicitly mentioned who performs the transportation activity, Valenti et al. (2023) underscore that such entities are critical in waste-to-energy systems. AD operators will likely rely on them as they will determine the feedstock quality received at AD facilities' gates.

The nature of interdependence introduces dynamics in the power of exchanging resources interfirm (Hillman et al. 2009; Pfeffer and Salancik 1979). Resource allocation in interfirm exchanges is a selective process that creates unequal opportunities for the exchanging parties (Pulles et al. 2023). Actors with greater needed competencies and resources hold the higher power and have control over collective actions. In the AD context, waste producers determine the quantity and quality of biowaste received by AD operators. For instance, as waste producers, farmers may resist implementing effective biomass collection due to its impacts on established practices (Caruana 2019). In the context of feedstock from MSW, AD operators gain power from the capability of providing waste removal services (Mayerle and Neiva de Figueiredo 2016), and yet, they cannot control feedstock quality to generate optimum green energy. AD operators cannot demand the public to provide separate waste streams, but local authorities can, as they have the upper hand from a legitimate position as regulatory bodies. Furthermore, governments control the tipping fee schemes, be they volume-based or energetic value-based (Reynolds et al. 2022), determining AD revenues.

4.1.3 | Collaborative Actions and Complexities

High interdependence and power dynamics among exchanging parties intensify the competitive uncertainty as organisations' operations rely on other parties' ability to provide the required resources willingly. Consequently, firms enter alliances with other entities to gain power over resources (Xia et al. 2018). To have access and control over segregated biowaste from the sources, AD operators establish trade associations (e.g. ADBA), form alliances with farmers, participate in public procurement or engage in government contracts.

Collaborative agreements between public (e.g. municipalities) and private agents serve as an essential driving force in establishing secure waste disposal (Lang et al. 2006), particularly for food waste (Angeli et al. 2020). For instance, Lo and Woon (2016) introduced a technologically assisted waste separation process involving optic bags for food waste. Once transferred to the refuse stations, a sensor will automatically separate these bags from other MSW, facilitating their subsequent recycling into value-added products. To implement this proposed solution, collaboration among various stakeholders, encompassing optic bag producers, the public, governments, AD operators as recycling and recovery facilities, and power companies, is obligatory (Lo and Woon 2016). Brás et al. (2022) also emphasise that the success of food waste recovery requires collective efforts. Municipalities' participation is essential to educate waste producers on separate disposal (Brás et al. 2022) and provide containers for selective door-to-door waste collection (Angeli et al. 2020; Brás et al. 2022). Therefore, collaborations with public authorities and other supporting private agents for segregated waste can facilitate AD operators to secure feedstock with better quality. Furthermore, government contracts provide revenue stability (e.g. through a gate fee scheme) and limit uncertainty, given that governments are unlikely to evade payments (Abdurakhmonov et al. 2021).

Collaboration with the agricultural sector also offers broader benefits. Addressing environmental bottlenecks, such as manure disposal, can enhance agribusiness production (Mayerle and Neiva de Figueiredo 2016). Society's welfare can be maximised when a biomass supply network for energy generation is designed appropriately. For example, Nugroho et al. (2022) design pathways for synthesising methanol from biomass, offering economic, environmental, and social benefits. Such pathways necessitate the participation of farmers, transporters, AD plant managers as methanol producers, and methanol retailers. However, designing the network alone will not suffice. Successful execution requires stakeholders within the supply network to work together effectively. de Jesus et al. (2021) suggested establishing strategic partnerships with agro-industry to secure the required feedstock supply to centralised AD facilities for biogas production. However, the study simply stated the potential amount of feedstock that can be supplied and estimated transportation cost reduction by forming strategic alliances with two or three clusters of farmers without further elaborating on establishing such partnerships.

Despite these benefits, managing the integration between recovery facilities and the MSW management systems remains challenging (Tanguy et al. 2017). For instance, despite the claims of government support towards AD deployment for food waste valorisation in the UK, comingled waste collection is still implemented (Gregson et al. 2015). Weak functional alignment among the national programmes, regulatory bodies, agribusinesses, and households in implementing decentralised biogas is evident in the work by Sime (2020). In agriculture, integration between the agricultural sector and AD as waste recovery is intended to close the loop in which waste from agriculture is recovered by AD, and the resulting digestate as a substitute for fertiliser is sent back to farmers (Lyng et al. 2018). But this loop is crippled by the reluctance of farmers to accept and utilise the digestate, resulting in AD plant's difficulties in finding willing recipients for the digestate (Swindal et al. 2010).

AD operators must navigate complexities arising from the involvement of multiple stakeholders, each with its own set of competencies, capabilities, interests, and priorities. Balancing the goals of different entities within the collaborative framework becomes an intricate task. Hence, understanding the relationship between interdependence and collaboration becomes fundamental. Specifying resources that AD operators should have in order to provide and satisfy the needs of network stakeholders becomes critical to balancing out the dependencies.

4.2 | The Idiosyncrasies of AD Ventures

The management of input materials has always been critical for a business to create value (Porter 1985). For AD operations,

organic materials, whether classified as 1G to 4G (Ranjbari et al. 2022), serve as essential input or feedstock for renewable energy production. Feedstock from crops (1G or 2G) is the most reliable feedstock due to their volume and quality controllability to some extent (Balaman and Selim 2015), providing promising stable energy production to fulfil green energy demands. Unfortunately, bioenergy derived from this feedstock type is no longer viable as it has received many critiques and poses social (Assandri et al. 2022; Mahjoub et al. 2020) and ethical problems (De Meyer et al. 2016). This circumstance has compelled AD businesses to find alternative feedstock sources. With the pressing environmental issues, biowaste (e.g. food waste, animal manure, and crop residue) has emerged as a potential feedstock alternative. The problem with this feedstock is extracting the organic matter from waste, positioning AD to operate beyond the renewable energy sector.

Depending on the operational settings, AD can be part of the waste management, resource recovery, or waste-to-energy sectors. The primary responsibility of waste management is receiving waste and ensuring its fate (Vögeli et al. 2014). Moving further, resource recovery business activities involve sorting waste into different streams and developing technologies to extract resources from each waste stream. To date, technologies to extract resources from waste in efficient manners are still growing while posing various technical barriers (Matthew and Spataru 2023; Van Dael et al. 2014). Companies within this sector strive to find better ways to extract and convert waste into more valuable products.

Unlike other waste management businesses, AD has an embedded role: adding value to the extracted resource that determines its next life cycle. AD transforms organic matter extracted resources from waste into biomethane as valuable renewable energy, positioning AD as part of the waste-to-energy system or resource recovery sector. This situation, however, necessitates AD to operate in an ambidextrous manner. When functioning as a waste management system, AD operators undoubtedly need to receive waste regardless of its organic content and quality and, in turn, constantly work with inconsistent feedstock conditions for energy generation. In other words, as renewable energy producers, feedstock quality will constantly challenge the operation and expenses not merely for energy conversion but also for sorting and extracting resources from waste.

The roles of 'double-edged' ventures result in intricate situations for AD operators in managing their business. For instance, the relationship between buyers and suppliers typically involves an exchange of resources or services for income (Pulles et al. 2023). However, during waste transactions in the waste-to-energy sector, these exchanging activities are dissolved. Waste producers, especially governments, function as AD energy production direct suppliers, but concurrently, they are AD waste management service users. As green energy producers, AD plant managers expect to obtain high-quality feedstock, but as waste managers, they cannot impose their counterparts to only dispose of biowaste with high-nutrient and energy contents, meaning AD operators will accept any conditions of waste. On the other hand, governments need to comply with a global commitment to properly choose efficient disposal trajectories of biowaste and transition towards renewable energy sources; hence, they also need AD to achieve it. These perplexing situations create high interdependency with institutional bodies (Abdurakhmonov et al. 2021). The high ratio of AD operators' total income from government incentives corroborates the significant interactions between AD operators and governments (Usack et al. 2018).

Having contracts with government agencies subsequently tends to make the firms focus more on satisfying the needs of the governments (Abdurakhmonov et al. 2021). This situation potentially makes AD operators overlook other opportunities and puts their continued existence solely in the hands of the governments. When highly dependent on a single party, an organisation will take action to reduce the dependence on external parties and gain control over critical resources to reduce uncertainties (Xia et al. 2018). To mitigate this dependency, AD operators often diversify their feedstock sources, forming alliances with other waste producers, such as farmers. This formation of alliances reduces reliance on a single source (Pfeffer and Salancik 1979) and allows AD operators to better adapt to waste availability and quality fluctuations.

Although forming alliances with parties other than governments eventually shifts the existing interdependence patterns, synchronising resources in waste-to-energy is difficult owing to the number of actors, companies, exchanges, and regulations involved (Pavan et al. 2021). This is compounded by the fact that the viability of waste-to-energy plants is highly determined by the synergy among relevant sectors (e.g. local businesses, farmers, households, waste collectors, and governments) (Matthew and Spataru 2023). Therefore, a comprehensive approach and sophisticated strategies are indispensable.

4.3 | Proposed Theoretical Framework

It is evident that AD businesses transact with multiple stakeholders to procure feedstock for green energy production. Biomass and biowaste producers have control over the feedstock that serves as resources for AD businesses. Thus, to survive and thrive, AD businesses contribute to their environment by providing waste solutions and green energy, which can also be seen as resources needed amidst global pressure to implement sustainability practices. These circumstances create interdependence between AD facility managers and other actors within the waste management and bioenergy sectors. Balancing this interdependence of resources, thus, becomes critical for AD business to remain relevant. Strategies such as public procurement and forming alliances (Hillman et al. 2009; Xia et al. 2018) have been proposed as solutions to address challenges encountered by organisations operating in AD in managing their feedstock supply.

The inter-organisational interactions between AD operators and their external entities in ensuring feedstock supply invoke theoretical explanations. Considering the explained phenomena collectively, resource dependence theory (RDT) (Hillman et al. 2009; Pfeffer and Salancik 1979) can serve as a reference theory to comprehend AD businesses better and eventually assist AD businesses in gaining a competitive advantage. This study seeks to extend RDT by applying and modifying the constructs and relationships and reevaluating the boundary conditions

based on the contextual idiosyncrasies of the resource recovery sector. Through the findings, researchers constantly, back and forth, reaffirm the theory (Ketokivi and Choi 2014). This includes an attempt to check the applicability of constructs and relationships of the theory with context and respecify the elements of the theory. The results were synthesised as follows.

In order to produce reliable renewable energy, AD operators require a constant feedstock supply, which cultivated biomass can offer. As opposed to feedstock from waste, this type of feedstock exhibits less variability in terms of quality, which increases the value of this resource. Nonetheless, because of the social and ethical problems posed by this type of feedstock, this resource becomes limitedly produced. Consequently, asymmetric power in the feedstock exchange is created (Pfeffer and Salancik 1979), as indicated in the previous section, in which farmers have control over the access and usability of this feedstock. In turn, AD operators, as exchange participants with less power, become more dependent. Align with RDT, the scarcer the critical resource, the higher the dependence of the focal firm towards the resource (Pfeffer and Salancik 1979). This illustration leads to the following proposition.

Proposition 1. Resource munificence negatively influences an AD operator's dependence on other organisations.

Pfeffer and Salancik (1979) argue that dependent organisations seek to manage and reduce external dependence through various actions, encompassing operating as part of coalitions. Forging strategic partnerships with farmers or clusters of farmers is an illustration of how AD operators navigate resource dependence. Another example of circumventing dependence is participating in public procurement. Firms tend to create linkages with the government to have the best ability to manage dependence (Hillman et al. 2009). It is also evident that AD operators try to diversify their feedstock supply from multiple sources. Aligned with RDT, diversification is motivated by a desire to avoid dependence. Other dependence-reducing strategies that can be pursued are vertical integration and association formation. Although the sample of academic literature in the present study does not indicate the implementation of these strategies, there is evidence of them in practice. Previous studies illustrate that bioenergy companies may have their own feedstock plantation to reduce dependence towards resources as a form of backward integration (Epplin et al. 2007; Yang et al. 2016). Additionally, the existence of the Anaerobic Digestion and Bioresources Association (ADBA) exemplifies AD firms' endeavours to gain more power. Taken together, firms will try to circumvent external dependencies through the orchestration of their supply network, thus:

Proposition 2. High dependence intensifies the need for an AD operator to orchestrate its supply network.

In a situation where AD operators function as waste managers, they need to develop their competencies in extracting resources from waste received, which in turn results in more energy produced. Research and practices on developing AD technology, such as co-digestion pre-treatment technology advancements and integration with other technologies, can be perceived as attempts to gain capabilities, providing solutions for waste producers and, at the same time, acquiring resources for renewable energy production. Notably, this phenomenon resonates with resource orchestration theory, where organisations focus on developing internal resources and capabilities to gain competitive advantage by creating values (Sirmon et al. 2007, 2011; Sirmon and Hitt 2009). This theory emphasises the configuration of resources and capabilities, which involve structuring, bundling, and leveraging actions. Therefore, when operating as waste managers, AD operators may focus on developing their own competitive advantage in order to leverage existing supply networks (Skipworth et al. 2023). This study views that, as a response to external dependencies, firms need to perpetually navigate both external and internal resources, each of which involves developing resource portfolios (structuring), combining resources to create and adjust organisation capabilities (bundling), and ultimately, leveraging organisation advantage through the application of the capabilities. Taken together, the following proposition can be postulated.

Proposition 3. Internal resource orchestration mediates the relationship between an AD operator's dependence and supply network orchestration.

In response to external dependence, it is evident (as discussed in Section 4.1.4) that AD operators manage the interactions with their suppliers to secure sustainable feedstock supply for generating green energy. At the same time, AD operators are actively developing their internal resources and capabilities through technology advancements to process waste effectively. Aligned with resource orchestration theory, the purpose of orchestrating resources, both internal and external (Skipworth et al. 2023), is to create values (Sirmon et al. 2007) so the venture will remain relevant and viable. In the context of this research, providing solutions for waste disposal problems and concurrently producing valuable products (green energy and bio-fertilisers) profitably and sustainably, are the values that AD businesses strive to create and deliver. It is also known that value generation in the context of a circular economy is contingent upon the engagement of supply chain actors (Jensen et al. 2024), highlighting the importance of supply network orchestration in value creation. Moreover, continuous innovation is needed to enhance values captured from waste as a second resource (Nogueira et al. 2023). Hence, it leads to the following proposition.

Proposition 4. Supply network orchestration (a) and internal resource orchestration (b) allow a focal firm to create circular business values.

As highlighted before (in Section 4.2), as a waste-to-energy sector, AD operators face conflicting goals in receiving waste. On one side, AD operators operate as waste management systems accountable for ensuring the proper end-of-life of biowaste. On the other hand, as business entities in the renewable energy sector, they also seek profitability to remain viable, which is hindered by inconsistent feedstock quality from received waste. Acknowledging such interconnectedness is a starting point of the duality theory (Graetz and Smith 2009). The theory emphasises that to strive in a complex and increasingly global environment, an organisation needs to embrace the presence of opposite properties in managing business, known as dualities (Graetz and Smith 2009), tensions (Figelj and Biloslavo 2015) or

paradoxes (Farrukh and Sajjad 2024), but perceive them as complementary rather than contradictory, also known as a dualities-aware perspective (Graetz and Smith 2009). An increase in complexity in the AD business landscape drives a concurrent need to nurture innovation alongside maintaining stability in organisational systems, which in this context can be achieved by establishing good relationships with external parties owning the critical resources. Although it is not an easy task, effectively managing conflicting goals in receiving waste potentially accelerates AD operators' capability through the orchestration of both supply networks and internal resources in creating value and enhancing their competitiveness. It has been proven that creatively managing tensions within organisations can lead to value creation (Pattinson et al. 2023). Given this, the following proposition is developed.

Proposition 5. The AD operator's capability in managing dualities facilitates its resource orchestration in creating circular business values.

Given these points, this study proposes a theoretical framework (Figure 4) that conjuncts resource dependence theory, resource orchestration theory and duality theory to develop strategic procurement for AD ventures. As suggested by Hillman et al. (2009), despite the movement toward multiple resource dependency relationships, research has rarely considered multiple simultaneous strategies for reducing interdependencies. Integrating RDT with other theories focusing on how organisations specify resource needs internally may offer comprehensive insights. A synthesised approach potentially provides an understanding of how different strategies, managing external dependence through collaborative actions with social actors and orchestrating internal resources, may interact and influence one another, especially by taking the dualities in business operations into account.

This proposed framework underscores the significance of a dualities-aware perspective in aiding the understanding of how AD ventures can navigate the complex interplay between waste management and energy production roles. This perspective is characterised by five attributes that enable the investigation and management of the competing forces: (1) simultaneity, (2) relational, (3) minimal thresholds, (4) dynamism, and (5) improvisation (Graetz and Smith 2008, 2009). It is apparent that, on the one hand, AD operators act as waste management systems accountable for ensuring the proper end-of-life processing of organic waste, leaving them no choice but to accept waste materials (Slorach et al. 2020; Vögeli et al. 2014). On the other hand, as business entities in the renewable energy sector, they seek reliable, cost-efficient input materials to achieve profitability (Liu et al. 2021; Pereira and Silva 2023), which is difficult to acquire given the inherent characteristics of waste, such as its inconsistency in quality and quantity (Angeli et al. 2020; Gregson et al. 2015; Liu et al. 2021). This dual role demonstrates the attribute of simultaneity: the co-existence of opposing drivers (Smith et al. 2017). It creates tension between the necessity of accepting waste, which entails extra costs for material pre-processing, and the desire to procure more consistent, reliable, and cost-efficient feedstocks for energy production. These seemingly mutually exclusive decisions are, in fact, interconnected and complementary. Given that the AD technology itself is designed to transform organic waste into green energy, it is impossible to dichotomise these two roles and their consequences. Acknowledging interconnectedness between these tensions represents the second attribute of a dualities-aware perspective: its relational characteristics.

Tension also exists in two orchestration areas outlined in the proposed framework. The limitations in technological capabilities for processing impure organic waste necessitate that AD businesses optimally orchestrate their supply networks for sustainable feedstock (Mohammadi et al. 2023). AD operators with effective supply network orchestration, such as possessing the power to negotiate with the suppliers for proper waste collection (Angeli et al. 2020; Brás et al. 2022), are more likely to acquire consistent, high-quality feedstock from waste for energy production. Hence, having strong supply networks associated with secure, steady feedstock supplies minimises the need for advanced pre-treatment technologies and costs for pre-processing materials. However, with higher technological capabilities to deal with various waste conditions, the need for intensive orchestration of the supply network is potentially reduced.

Harnessing these tensions requires the third attribute: minimum thresholds—just enough, but not too much structure

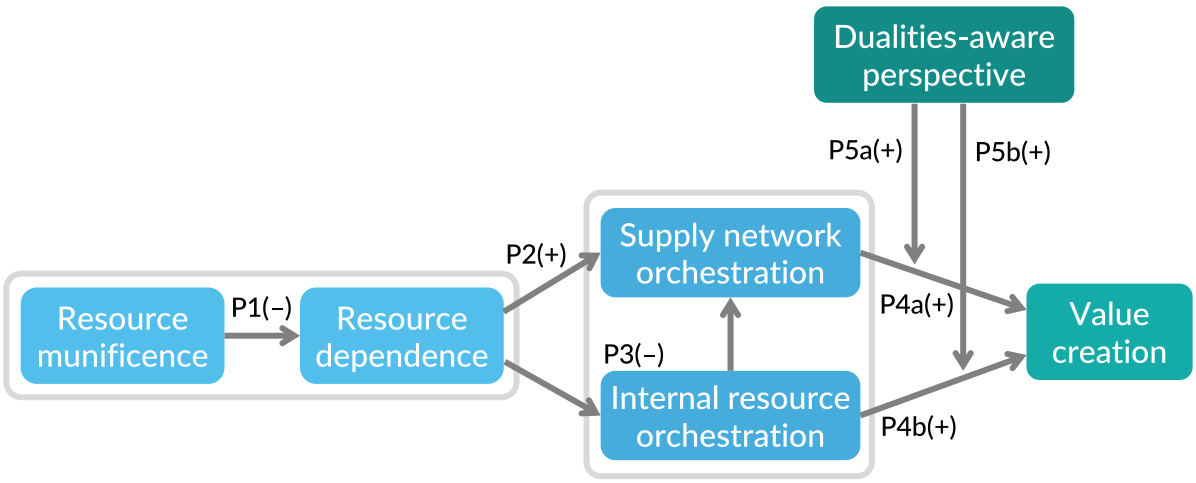

FIGURE 4 | Proposed theoretical framework: dualities-based resource management.

to maximise the push-pull tension (Graetz and Smith 2008). As an operational consequence, AD operators must formulate strategies and mechanisms to determine the extent to which supply network orchestration and internal resource orchestration are needed to achieve optimal results. Mutual adjustments between tensions or the flexibility to switch between management approaches (Pattinson et al. 2023), for instance, balancing the strengthening of technological advancements with enhancing supply network orchestration, represent the fourth attribute: dynamism. Lastly, to facilitate the interlinkages between previously mentioned attributes, improvisation is needed. Improvisation combines deliberation and spontaneity, involving the ability to recognise when to be flexible and to find the balance between opposing forces by considering their interactions and mediating their influences (Graetz and Smith 2009).

By recognising and managing organisational dualities, AD operators can better manage resource dependencies and optimise internal resource allocation, leading to more resilient and adaptable business strategies (Figelj and Biloslavo 2015). Addressing these challenges could significantly enhance the commercial viability and environmental impact of AD technology, thereby advancing circular economy practices. This integrated framework thus offers a robust approach for future research to explore innovative solutions for managing the tensions within AD business operations as waste-derived green energy producers.

5 | Conclusions

This review explored the intricacies of feedstock supply management in the AD sector, aiming to provide insights into how businesses operating in this domain can effectively manage their input to close the loop of resource flow while producing green energy. Through an extensive literature analysis, key findings emerged around challenges, strategies, and indications of inter-organisational interactions. The primary barriers in AD procurement management are typical, revolving around quality, accessibility, and costs. Beyond these common challenges, the study revealed the idiosyncrasies of AD ventures, particularly the challenges posed by the reliance on different feedstock types. While cultivated biomass offers stable energy production potential, its social and ethical implications limit availability, creating asymmetric power dynamics in the feedstock exchange. Conversely, feedstock derived from waste presents challenges in extraction and variability but aligns more closely with waste management objectives. AD businesses, therefore, operate within a dual role—waste managers and renewable energy producers—adding complexities to their functions.

A substantial body of literature primarily focuses on developing strategies to locate feedstock sources and designing optimal supply networks by determining AD facility location and respective capacity. Although such work has ultimately assisted the decision-making processes for establishing new plants, it lacks a detailed examination of entities operating in the supply networks and their interaction, limiting the applicability of such network designs. Consequently, no literature has thoroughly dissected the interplay beyond organisational boundaries. However, evidence of inter-organisational interactions in AD supply management practices can be found. Concepts such as competition, uncertainty, interdependence, power dynamics, and stakeholder collaborative actions underscore inter-organisational theories' relevance to AD business practices.

5.1 | Theoretical Contributions

This study contributes by eliciting research gaps from business perspectives, complementing the existing intensive technical and operational research within the AD and resource recovery domain. Through the lens of RDT (Pfeffer and Salancik 1979), this study sheds light on the interactions between AD operators and external stakeholders within the AD supply network. Nonetheless, given the idiosyncrasies of AD businesses, RDT alone does not fully explain these dynamics. Hence, a theoretical framework is proposed by incorporating resource orchestration (RO) theory (Sirmon et al. 2007, 2011; Sirmon and Hitt 2009). This study extends the boundary conditions of RDT by contextualising it to the unique interdependencies and resource dynamics in the waste-to-energy sector. This study provides a nuanced understanding of how AD operators navigate resource dependencies. It expands upon Pfeffer and Salancik's (1979) original model by illustrating how AD businesses respond to and manage dependency through strategic partnerships, diversification, and internal resource development, which bridges RDT with RO theory.

The framework highlights the interplay between external resource dependence and internal resource orchestration strategies to establish strategic procurement and business values, considering the complexities and the dualities (Graetz and Smith 2009) inherent in AD ventures. The integration of duality theory (Graetz and Smith 2009) highlights the dual roles of AD operators as waste managers and energy producers, emphasising the need to balance conflicting goals to achieve business sustainability. This dualities-aware perspective contributes to the theoretical understanding of how firms can effectively orchestrate resources and capabilities to create value in complex, interdependent environments. The proposed theoretical framework also offers valuable insights into effective AD resources management and business strategies.

5.2 | Implications for Practice

From a practical standpoint, this study provides actionable insights for AD operators and other stakeholders in the waste-to-energy sectors. The proposed framework offers strategic guidance on how AD ventures can effectively manage their external dependencies on feedstock suppliers through public procurement, strategic alliances, and diversification of feedstock sources. Additionally, it emphasises the importance of developing internal capabilities through technological advancements and resource orchestration to enhance operational efficiency and value creation.

It is apparent that AD ventures operate in a complex landscape arising from the dual roles of AD operators as both waste managers and energy producers. Understanding the dynamic tensions and challenges posed by these roles from a dualities-aware perspective is an important starting point for achieving

profitable and sustainable businesses that foster circular economy practices. A dualities-aware perspective has proven effective in enabling organisations to creatively manage tensions for value creation (Pattinson et al. 2023). Therefore, by adopting a dualities-aware perspective, AD ventures can better navigate the inherent tensions between waste management and energy production, resulting in more resilient and profitable business models. This dual-focus resource management insight can guide industry leaders and managers in designing and implementing strategies and practices that support the sustainable profitability of AD ventures, ultimately contributing to the broader goals of environmental sustainability and the circular economy.

5.3 | Limitations and Future Research

Despite its notable contribution to advancing knowledge in both academic and practical domains, this study has limitations. Due to the stringent search strings and filtering process in PRISMA (Liberati et al. 2009) and by focusing exclusively on peer-reviewed scientific journal articles, the SLR may overlook other valuable sources that could enhance understanding of the field. Additionally, the proposed theoretical framework requires further validation, as the propositions were based on the authors' interpretation of the text corpus. Further empirical research is therefore needed to refine and validate the proposed framework.

Operationalising the attributes of a dualities-aware perspective in the context of AD ventures can serve as a foundation for exploring the underlying intricacies, complexities, and mechanisms of coexisting, seemingly contradictory elements within this sector. Such pursuits require the involvement of key stakeholders, including AD operators, policymakers, and supply chain partners. Collaborative efforts among a diverse array of industry participants can help uncover tacit knowledge that remains untapped by the current literature. Moreover, such initiatives can yield deeper insights into the impact of evolving environmental, economic, and regulatory conditions on the framework's applicability in real-world contexts.

Author Contributions

Adhya Rare Tiara: conceptualisation, investigation, formal analysis, data curation, writing – original draft preparation, writing – review and editing, visualisation. **Benny Tjahjono:** conceptualisation, supervision, writing – review and editing, funding acquisition, resources. **Macarena Beltran:** conceptualisation, supervision, writing – review and editing, funding acquisition. **Francis Rayns:** supervision, validation, writing – review and editing. **Philip Longhurst:** validation, resources, writing – review and editing.

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