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Waste Cooking Oil Recycling and the Potential Use of Blockchain Technology in the UK

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Abstract: This study explores the recycling of Waste Cooking Oil (WCO) in the UK, analysing the recycling models and practices, and investigating the application of blockchain technology (BCT) from Z company's Southern European project to UK's WCO recycling. Employing a multi-method qualitative approach, including unstructured and semi-structured interviews, the research delves into the experiences of current WCO recycling methods in the UK and Z company's project. Through thematic analysis of both primary data and archival data, the study identifies seven distinct recycling models in the UK and assesses the implementation of BCT using the Technology, Organization, and Environment (TOE) framework. The research underscores the current state of WCO recycling in the UK, highlighting the industry's challenges and providing recommendations for future implementation. Its significance lies in addressing the academic gap in WCO recycling studies and offering insights into recycling models and BCT application, potentially guiding future commercial endeavours.

Keywords: waste cooking oil; recycling models; blockchain technology; multi-method qualitative study; TOE framework

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1. Introduction

The escalation in global population and urbanization has altered food consumption patterns, leading to an increase in waste production, particularly waste cooking oil (WCO). Recognized for its potential in mitigating pollution and fostering sustainable energy [1], WCO originates from diverse sources: restaurants (47%), food processing industries (37%), households (18%), and other sources (3%) [2]. The efficient recycling of WCO is thus a crucial objective [1].

Internationally, several countries have established WCO recycling programs. The EU's RecOil project examines WCO recycling in high olive-oil-consuming nations like Spain and Italy. China has initiated recycling projects in 33 cities with government funding [3]. In the USA, California's CalFOG campaign aims to promote WCO recycling and mitigate sewer overflows [4], while Japan has launched nationwide collection efforts [3].

In the UK, local councils start to conduct the collection activities, such as the Shropshire Household Waste Recycling Centre (HWRC), which has been actively involved in the collection and conversion of WCO. Among UK restaurants, fast food outlets are the largest producers of WCO, particularly in Greater London, the North West and the South East [5,6]. And reports show that there are four main types of collectors in the UK, including Suppliers and Collectors, Waste Collectors, Specialist Commercial Collectors, and Closed-loop Collectors, with the latter focusing on converting WCO into biodiesel for their transport fleets or energy production [5,7].

Despite these efforts, the improper disposal of WCO is a global concern, particularly in backflow to the food supply chain (SC) and improper discharge. Instances in China and

India highlight the severity of this issue [4,8,9], with health risks associated with the reuse of heated WCO [3,10]. Improper discharge of WCO leads to significant environmental hazards, such as soil and water pollution [11,12], and causes severe sewer blockages in different countries [13]. In the UK, WCO-related issues like FOG and fatbergs necessitate costly and labour-intensive removal [14], placing a substantial burden on resources [15–17]. These blockages cost UK water companies around GBP 85 million annually [12], and USD 25 billion in the US [18]. Effective recycling and treatment of WCO can play a crucial role in mitigating these financial and environmental impacts, potentially reducing these significant expenses.

As mentioned above, the issue of improper disposal of WCO needs urgent attention. Recycling WCO not only helps to address environmental and public health issues, but also provides a solution to the global challenge of finding sustainable energy sources. One of the main applications of WCO is its conversion into biodiesel (see Figure 1), which is being increasingly adopted by countries around the world [7]. This trend is driven by the need to balance energy demands with reduced greenhouse gas (GHG) emissions, making biofuels a sustainable choice [3]. Moreover, the abundant and cost-effective availability of WCO eases the pressure on petroleum resources and food crops [19].

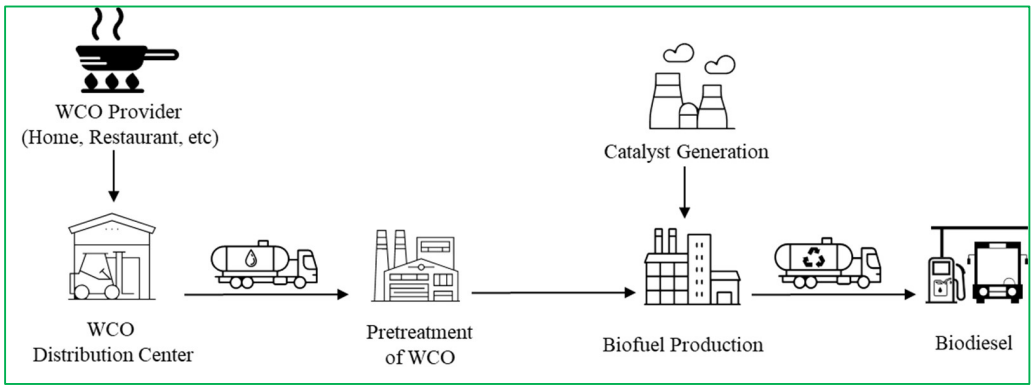

Figure 1. The recycling and processing of WCO (Source: Chung et al. [20]).

Indeed, countries such as Australia, China and the United States are actively engaged in biodiesel production from WCO [21]. In the UK, the transport sector, a significant carbon emitter, is increasingly turning to biodiesel as an alternative energy source [22]. For example, the conversion of the Whitechapel 'Fatberg' to biodiesel, which has powered hundreds of buses, is an example of this initiative's contribution to reducing overall carbon emissions [23,24].

Despite the rising demand for biodiesel, the current collection of WCO is insufficient to meet market needs. Estimates suggest that biodiesel produced from WCO could replace a small but significant portion of diesel consumption in the EU [25]. The UK government aims for a substantial increase in renewable fuel sources by 2032 [26]. However, the recycling rates remain low, with only a fraction of WCO being repurposed [12,27,28].

To enhance the recycling of WCO, legislative measures have been implemented in various regions. The EU, for instance, has prohibited the use of WCO in animal feed to prevent its re-entry into the food SC [29]. Post-'gutter oil' incident, China has tightened regulations surrounding WCO management [30]. The US has introduced several acts to promote waste management and resource recovery [3]. In the UK, laws and policies are focused on both the supply of WCO and the demand for biodiesel. Regulations such as the Water Industry Act 1991, the Food Safety Act 1990 and the Environmental Protection Act 1990 mandate proper WCO handling. Concurrently, initiatives like the Net Zero Strategy, Renewable Transport Fuel Obligation (RTFO) and Renewable Transport Fuel Certificates (RTFC) stimulate the demand for biodiesel.

To address concerns about WCO in food SC and biodiesel production verification, BCT is increasingly recommended for its ability to provide transparency and traceability [5,31,32].

This technology enhances the legitimacy and efficiency of the WCO recycling process and offers reliable biodiesel production verification, promoting sustainable development. BCT's effectiveness is evident in its use for recording carbon data in Sustainable Aviation Fuel and tracking biodiesel raw material production in Belgium [3,33]. In the WCO recycling sector, several blockchain firms, including Z company, are emerging as industry pioneers. Z company is a leading global technology company that is actively exploring the potential of BCT in real-world challenges. Currently, Z company is working with companies in Southern Europe to apply BCT to the WCO recycling chain (hereinafter referred to as the PROJECT). In some projects, they have designed an Internet of Things (IoT) system integrated with BCT and placed it in waste oil barrels. One of the functions of this IoT system is to measure the quality and quantity of the waste oil in real-time and upload this information to a terminal. With the underlying tracking capability of BCT, transparency and traceability will be ensured in the WCO recycling process.

This study aims to understand the overall picture of the UK WCO recycling market, the WCO recycling chain models and the potential possibilities of applying BCT in WCO recycling in the UK region. Based on the current cases, as well as the existing market conditions and available literature on potential research, we have formulated the following research questions in three key areas: market research, recycling practices, and future recommendations.

(1) What is the current WCO recycling situation in the UK?
(2) What are the current WCO recycling practices? What are the potential challenges for applying BCT in this process?
(3) What are the insights from the PROJECT? and what are the recommendations to the BCT for further deployment in the UK?

In order to thoroughly investigate the current situation of the WCO recycling chain in the UK and the potential application of BCT in this area, this study adopts a mixed research methodology of applying both unstructured and semi-structured interviews combining both primary and secondary data. Our research offers significant contributions both theoretically and practically:

Theoretically, it addresses the under-researched area of WCO recycling in the UK. Despite the increasing focus on global energy crises, climate change, and carbon reduction initiatives, studies specific to the UK's WCO recycling are scarce. This research aims to bridge this gap, laying a foundation for future studies and highlighting the unique aspects and opportunities within the UK WCO recycling market.

Practically, WCO recycling is vital in waste management, and its enhancement through innovation can offer fresh insights and improvements in waste recycling processes. While initial research exists, many aspects of BCT application in WCO management and recycling remain unexplored. Z company's active implementation of BCT in their WCO recycling project exemplifies its practical effectiveness. This study aims to explore the UK's WCO recycling models and the potential integration of BCT, offering insights and strategic guidance for the UK market, informed by the practical experiences and lessons learned from Z company's practices.

The rest of this paper is structured as follows: Section 2 compiles a literature review on WCO recycling and BCT, establishing the theoretical framework and identifying research gaps. Section 3 details the research methodology, including methods, data sources, and analytical techniques. Section 4 presents findings, covering the current state of the recycling market, the challenges in applying BCT, and insights from the PROJECT. Section 5 delves into a discussion of the recycling models and difficulties in implementing BCT in the UK's WCO recycling, along with strategic insights for future applications. Finally, Section 6 concludes the paper, summarizing key findings, discussing implications and limitations, and suggesting future research directions.

2. Literature Review

This chapter presents a comprehensive review of WCO literature, covering its background, global statistics, and potential as a recyclable resource with economic value. It delves into current recycling practices, associated challenges, and motivating factors. The chapter also explores the role of BCT in improving waste management and concludes by outlining the theoretical framework and reviewing relevant prior studies, laying a solid foundation for our research.

2.1. The Basic Background of WCO

WCO, primarily sourced from restaurants, food services, and the food processing industry, is unsuitable for human consumption due to health and legal reasons and thus requires recovery and management [34]. Estimating its volume accurately remains a challenge [35], but numerous studies offer insights into global WCO production. For instance, Wang [36] estimated Australia's annual WCO production at 50,000 tonnes, exploring its biodiesel potential. Chhetri et al. [37] assessed Canada's annual WCO output at 135,000 tonnes. In Europe, BioDieNet [7] reported the 27 EU countries produce 3,550,000 tonnes of WCO. Notably, as early as 2010, China's production of WCO surpassed that of the EU, the United States, and Canada combined by a factor of 2.73 [38], making it a significant production region for WCO.

In the UK, precise WCO statistics are scarce [7,12,39]. Carter and Halle [39] initially estimated UK's WCO production at around 200,000 tonnes (approximately 219 million litres). The UK Sustainable Biodiesel Alliance [40] later updated this to 250 million litres annually, and ECOFYS [7] suggested an annual range of 264 to 409 million litres.

WCO is a versatile resource with multiple applications and significant added value. It serves as a fermenting agent for biobutanol production in biofuels [41], and is used to produce high-value green chemicals like lubricants and bio-based materials [42]. However, its primary use is in biodiesel production, a key alternative to fossil fuels in addressing rising GHG emissions and promoting sustainable energy use [2,3,43,44].

WCO biodiesel reduces emissions and has a lower environmental footprint compared to petrochemical diesel, with a low technological adaptability [45,46] and high conversion rate often exceeding 80% [47]. In the UK, WCO is a principal biodiesel feedstock, with 52% of renewable fuels in 2021 being biodiesel derived from WCO. Despite this, the UK heavily relies on imports, particularly from China, which accounted for about 31% of its total imports in 2022 [27,48].

Moreover, WCO's recovery and transformation align with circular economy principles, emphasizing resource reuse and circularity [49,50]. This is because the WCO business model achieves a closed-loop system, resulting in cost-effectiveness and economic benefits [51]. For example, projects like RecOil in Europe demonstrate the economic and environmental benefits of this model [52]. Efficient WCO management aligns with sustainable development goals and offers business opportunities [53].

Numerous articles on WCO have revealed its potential quantity and unique commercial value. However, few studies have focused on the recycling efforts of WCO. Our research will concentrate on this aspect, exploring the recycling practices of WCO in the UK.

2.2. WCO's Management and Recycling Practices

Currently, several researchers have conducted research on the recycling status and models of WCO in different regions. For example, Loizides et al. [54] examined Cyprus's InnovOleum system, combining WCO collection with social causes for sustainable operations. Belgium's Valorfrit system, involving 99 entities, coordinates national WCO collection and reporting [12]. In the Netherlands, a nationwide system with 2000 collection points encourages resident participation in WCO recycling [12].

In the research for WCO recycling models, Zhang et al. [19] identified two primary models: Third-Party Take-back (TPT) and Biodiesel Enterprise Take-back (BET), prevalent in China, USA, and Japan, offering insights into efficient WCO recycling. The driving

mechanism behind them is also different. In China, TPT benefits from policy support and environmental awareness, while BET is popular in the USA and Japan due to market demand and sustainable development focus. Other drivers for WCO recycling include social inclusion and low-cost labour in developing countries [11,55]. Studies by Yang et al. [45] and Tsoutsos et al. [56] highlight the role of regulations, employment opportunities, and environmental awareness in promoting WCO recycling.

In the UK, changing market prices of WCO, driven by renewable energy demand, offer economic recycling incentives. The RTFO scheme also supports biofuel use, enhancing WCO recycling efforts [7]. However, challenges remain, including low recycling rates and the need for collective stakeholder action [2,11]. WCO theft causes significant industry losses [7,57,58], and the biofuel market faces transparency and accountability issues in documentation and regulatory compliance [34,59]. Moreover, the UK government requires traceable information to verify the origin of WCO to better comply with RTFO regulations [5]. However, current information along the recycling chain is difficult to validate, hampering efforts to recycle WCO [35,60]. Establishing a reliable tracking system is crucial for ensuring legitimate and environmentally compliant WCO sources.

There is a growing global interest among scholars in the study of WCO. However, research specifically targeting WCO in the UK remains scarce. What are the recycling models for WCO in the UK? What drives the recycling of WCO? These are the questions this paper aims to investigate.

2.3. The Application of BCT and Market Demand

BCT, recognized for its decentralized, immutable, and transparent data processing capabilities, offers significant potential in enhancing SC efficiency and recycling processes [61,62]. Its ability to securely record and verify transactions without a central authority makes it particularly suitable for complex recycling chains, ensuring data integrity and credibility [63].

Academic interest in BCT's application to waste management is growing. Taylor et al. [64] highlight BCT's role in enhancing information clarity and risk management. Gong et al. [65] found that BCT improves efficiency and transparency in marine plastic waste management. Similarly, França et al. [66] demonstrated its benefits in financial management and social inclusiveness in Brazil's waste management sector. BCT also plays a crucial role in waste management and reverse logistics, offering long-term data support and simplifying financing processes [67]. Gong et al. [68] confirms its advantages in recycling, including environmental protection and transparent recycling chains. In the circular economy, BCT can optimize operations, enhance transaction security, and improve overall performance [69,70]. The integration of BCT with Internet of Things (IoT) further facilitates stakeholder cooperation and efficiency [71].

In addition, the potential of BCT in WCO management is increasingly recognized. The UK requires source verification of feedstock for biodiesel to provide RTFC [5,60], a traceability requirement prevalent in today's WCO recycling processes within the EU [35]. Spain's legislation mandating digital source signatures for biofuels further underscores BCT's applicability [34]. Saurabh and Majumdar [72] advocate for BCT's inclusion in WCO management to improve recycling chain efficiency.

Despite its potential, research and applications combining WCO and BCT are limited. This gap indicates the need for further exploration of BCT in WCO management for more efficient, environmentally friendly, and sustainable solutions.

2.4. The TOE Framework

Tornatzky and Fleischer [73] introduced the Technology, Organization, and Environment (TOE) framework, emphasizing its role in influencing firms' technology adoption and performance [74]. This framework is particularly relevant to the adoption of new information technologies at the organizational level [75,76], which guides the investigation of BCT adoption in this study.

Research leveraging the TOE framework has explored various factors impacting BCT adoption. Malik et al. [77] highlighted Australian organizations' perceived benefits of BCT, especially in enhancing transparency and security. Ganguly [75] identified 40 challenging factors for Indian logistics firms, while Xu et al. [76] noted BCT's potential to improve efficiency in the German automotive SC. However, recognition from stakeholders emerges as one of the main challenges to the adoption of BCT, such as Clohessy and Acton [78] emphasized the importance of top management support and organizational readiness in Irish companies. In contrast, Dehghani et al. [79] focused on technological aspects affecting organizational decisions on BCT. Other studies like Kamble et al. [80,81] and Gökalp et al. [82] explored factors influencing BCT adoption in SCs, with the latter underscoring environmental determinants. Kouhizadeh et al. [83] and Xie et al. [63], respectively, discussed the feasibility limitations of adopting BCT in sustainable SC and recycling chains.

These studies have expanded understanding of BCT adoption factors within the TOE framework, providing a theoretical basis for this study. However, most research concentrates on daily business operations and SC management, with less focus on recycling chains and sustainable SC, particularly in the context of WCO recycling. This study aims to address this gap, exploring WCO recycling chain-specific factors influencing BCT adoption.

3. Research Methodology

3.1. Methodological Choice

This study employed a multi-method qualitative approach for an in-depth understanding of the topic [84]. Interviews with Company Z and restaurants yielded primary data, offering contextual insights [85], while secondary data from public databases and corporate websites helped understand the UK's WCO recycling market and its potential models. This approach ensured that our findings were grounded in practical realities [84].

3.2. Data Collection

3.2.1. Primary Data Collection

For the primary data collection, we employed both unstructured and semi-structured interviews, they guarantee data pertinence to the research's central theme, and the queries discussed through interviewing are usually regarded as factual in various aspects [84,86].

To comprehend Z company's practices, we conducted two comprehensive interviews with Z company to ensure meticulous data analysis. For examining the UK's WCO recycling practices, we opted for semi-structured interviews. This approach centres on pre-defined themes, ensuring a deeper grasp of the topic without being overly subjective [84]. The interview follows a set theme list. Consequently, we prepared a detailed interview protocol in advance (see Appendix A), encompassing study themes and interview guidance [86].

We used a purposive non-probability sampling method for restaurant interviews to gather unbiased, comprehensive data [87]. It allows for selecting samples with vital expertise, especially for lesser-researched topics [88]. Restaurants were chosen based on four criteria: (1) their role in the sector, (2) involvement in WCO recycling, (3) variety in main offerings, (4) operations familiarity in Southampton. Additionally, we used snowball sampling: initial participants suggested other relevant stakeholders for the study [87]. These recommended stakeholders were approached for potential interviews.

We approached several targeted participants through both email and face-to-face invitations, including representatives from Z company. Among them, two in-depth discussions (Int-01, Int-04) from the manager of Z company's PROJECT ensured the authenticity and specificity of the data collected. The remaining four participants hailed from various restaurants (Int-02, Int-03, Int-05, Int-06). This diversity guaranteed a comprehensive data set, preventing an over-representation of any single restaurant category. These four participants shared their operational perspectives and experiences. The ensuing Table 1 presents detailed information regarding these interviews.

Table 1. Interviews details.

ID	Date	Length	Organization	Position	Location
Int-01	22 June 2023	33 min	Z company	Project Manager	London
Int-02	3 July 2023	23 min	Small Chinese Restaurant	Owner	Southampton
Int-03	4 July 2023	26 min	Fried Chicken Takeaway	Staff	Southampton
Int-04	11 July 2023	39 min	Z company	Project Manager	Oxford
Int-05	14 July 2023	30 min	Large Chinese Restaurant	Owner (1), Manager (2)	Southampton
Int-06	5 August 2023	28 min	Fish and Chips Takeaway	Owner (1), Staff (2)	Southampton

Participants were given study materials prior to the interviews, such as an email summarizing the setting, goals, and potential contributions of the research. For the sake of transparency, a cover letter was included [84]. And to transcribe the recorded audio, we used iFLYREC (https://www.iflyrec.com (accessed on 5 July 2023)). This voice recognition platform has been extensively used in several research studies [89,90] and is believed to be more reliable than other platforms [91]. After transcription, we checked for errors and discrepancies multiple times manually and asked the participants to clarify and confirm key statements when necessary [92].

In-person interviews were conducted to ensure dependability and authenticity [84], with voice recognition technology enhancing transcription accuracy. Post-interview checks ensured the precision of key statements, maintaining objectivity. The study's exploratory nature and limited geographic scope may affect its applicability, and the diversity in follow-up questions for different organizations could impact its universality. However, the credibility and validity were upheld through the use of unstructured and semi-structured interviews [84].

3.2.2. Secondary Data Collection

In our study, secondary data was crucial for understanding UK's WCO recycling. This data, originally collected for different purposes, offers new insights into our research questions [93,94]. Given our limited prior knowledge, this data was invaluable. During the study, we sourced secondary data from public databases, company websites, and documents until reaching data saturation. This approach provided a thorough understanding of the UK's WCO recycling market. Table 2 below lists some of the most representative secondary data sources we use, combining these data with primary research, we gained deep insights into our research topic, leading to detailed descriptions and theoretical advancements [84].

3.3. Data Analysis

Aligning with Lester et al. [95], the data analysis aimed to address the research question with appropriate techniques for reliable insights [96]. Thematic analysis was chosen due to its suitability for the qualitative data from interviews, documents, and websites. This method involves coding to identify relevant themes for in-depth analysis, offering a structured approach for qualitative data interpretation [84]. The four-step thematic analysis proposed by Saunders et al. [84] was followed:

Table 2. Key Secondary Data Sources.

Category	Source	Target
Law and Policy	Department for Transport, Food Standards Agency, GOV.UK, etc.	To identify the relevant laws and policies that have been used to provide support for the development and regulatory aspects.
Company and Practice	McDonalds, Olleco, BioUKFuels, etc.	To investigate current WCO recycling practices and analyse the recycling chain models in the UK market.
Data and Report	Public Health England, ECOFYS, GREENEA, etc.	To gather valuable data for analysis, elucidating market conditions and bolstering research findings.

Data Familiarization. Accurate transcription of interview sessions and detailed examination of transcripts and secondary data from websites and databases were conducted. This step involved an initial understanding of data structure and potential themes.

Data Coding. Employing an abductive approach, open coding was applied to both interview and archival data to explore implicit meanings. A coding framework, adjusted as needed, ensured a thorough and theoretically informed analysis.

Theme Identification and Relationship Analysis. This step involved searching for themes and identifying relationships by regularly updating research memos and notes. The abductive method was used to evaluate themes against theories, analysing connections between codes.

Refining Themes and Testing Propositions. Themes were refined to establish a cohesive framework. Patterns within data were analysed to discern relationships between themes and construct testable propositions. Reflexivity was emphasized, considering all possible interpretations, including contradictory data, to ensure comprehensive analysis [97].

Overall, this systematic approach aimed for a genuine, objective reflection on the subject, enhancing understanding of the data.

4. Research Findings

4.1. The Recycling of WCO in the UK

4.1.1. Overall Situation

Similar to many other countries, in the UK, the primary use of WCO is as feedstock for bioenergy production [48,60]. As mentioned above, the WCO is collected by four categories of collectors and then transported to biofuel refineries for further processing.

Regarding the supply side, the UK's domestic WCO mainly comes from food manufacturers and restaurants, with a significant portion being collected in the England region [7,60]. Among these, fast-food outlets are considered to be the largest contributors. Therefore, the number of fast-food outlets in a region can likely influence the WCO output in that area [5]. According to data from Public Health England [6], Greater London (8662), North West (7533), and South East (6092) have the highest number of fast-food outlets in England. Furthermore, Birmingham (1058), Leeds (966), and Manchester (752) are the top three cities with the most fast-food outlets, resulting in a higher concentration of WCO in these regions, as shown in Figure 2, where darker colours represent more fast-food outlets in the area.

4.1.2. Relevant Legislation

The current UK regulations are somewhat vague, as they predominantly encourage the recycling of WCO from the supply and demand standpoints and mandate effective waste storage and processing, yet lack specificity and lucidity, as shown in Figure 3.

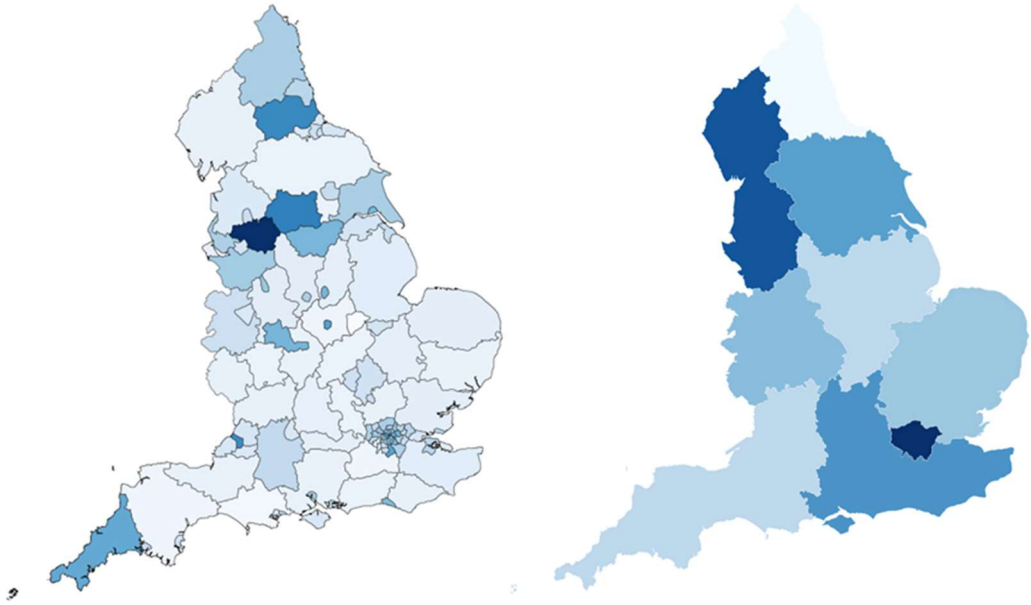

Figure 2. Fast Food outlets in England (Source: Public Health England [6]; Office for National Statistics [98]).

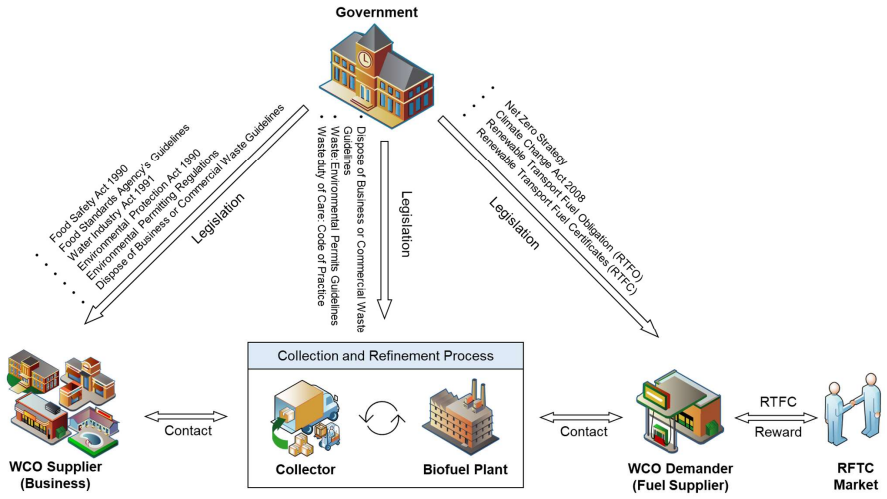

Figure 3. Relevant legal framework.

Figure 3 illustrates that the WCO supply side is mainly governed by six documents. The Food Safety Act of 1990 authorizes government investigations into FOG-related issues, with possible fines or operational cessation orders for non-compliance. Food Standards Agency's (FSA) guidelines mandate safe WCO storage and collection by licensed carriers. The Water Industry Act 1991 and Environmental Permitting Regulations prohibits unauthorized discharge into public sewers, and the Environmental Protection Act 1990 requires businesses to prevent environmental pollution from waste. Additionally, it is imperative for businesses to adhere to the Dispose of Business or Commercial Waste Guidelines, which include storing waste safely and securely, signing the waste transfer note, and ensuring that waste collectors are registered for proper disposal, among other requirements.

On the demand side, the Net Zero Strategy and the Climate Change Act set a target for industry carbon emissions to reach zero by 2050. To support this, the UK's RTFO requires fuel suppliers to include a minimum percentage of sustainable content, aiming for a 14.6% renewable fuel content by 2032. RTFO incentivizes suppliers through RTFC, offering double credits for fuels from waste sources like WCO. Suppliers failing to meet RTFO standards can purchase RTFCs in the RTFC market to fulfil their obligations.

For the collection and refinement process, the current findings focus on operational aspects. Waste holders should adhere to the requirements outlined in the Dispose of Business or Commercial Waste Guidelines and Waste: Environmental Permits Guidelines to ensure proper registration and disposal of waste. Additionally, statutory guidance provided by the Environment Agency, such as the Waste Duty of Care: Code of Practice, mandates that waste holders manage waste appropriately to maintain robust management practices.

As blending biofuel with conventional fuels, such as petrol and diesel, is a straightforward process [99], the following discussion on the recycling chain will primarily focus on WCO collection.

4.2. The Recycling Chain Models

This research identified seven types of WCO recycling models, including Supplier and Collector-BET, Supplier and Collector-TPT, Waste Collector-TPT (I), Waste Collector-TPT (II), Specialist Commercial Collector-TPT, Specialist Commercial Collector-BET and Closed-Loop Collector-TPT. As a groundbreaking finding of this study, this section provides a comprehensive analysis of these seven recycling models, revealing their structures and explaining how they operate.

4.2.1. Supplier and Collector

1. Supplier and Collector-BET;

Company A is a nationwide company in the UK, supplying virgin oil and recycling the WCO. It operates the largest biorefinery in the UK, specializing in the conversion and sale of biodiesel. As a supplier and collector, its recycling model is shown in Figure 4. With its own logistics fleet and biofuel plant, Company A operates under the BET model. Under this model, Company A provides businesses with rewards based on the amount of WCO they provide. If a business also chooses to purchase virgin oil from Company A, these incentives can be used to offset the cost. The collected WCO is sent to the plant to be converted into biofuel.

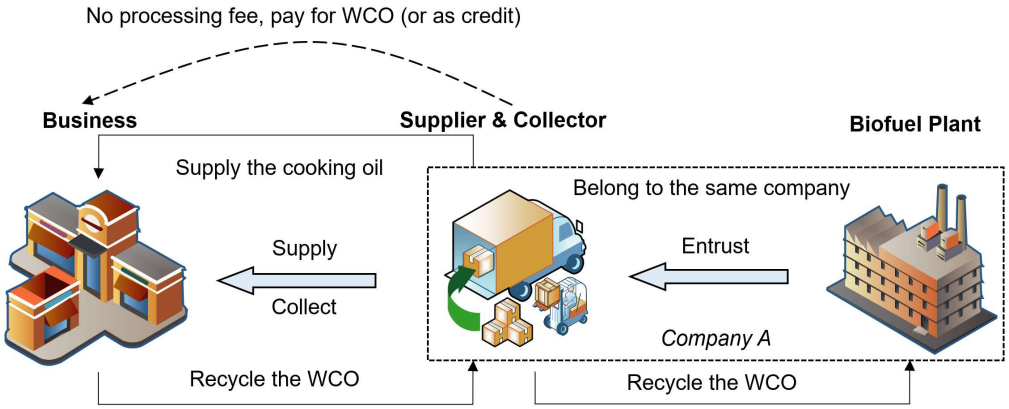

Figure 4. Supplier and Collector-BET.

2. Supplier and Collector-TPT;

Company B is a family-run business serving mainly the England area. As a supplier and collector, its recycling model is shown in Figure 5. Acting as an intermediary between businesses and biofuel plants, Company B adopts the TPT model, a commonly utilized model in the UK. Company B purifies the WCO before sending it to a third-party biofuel plant.

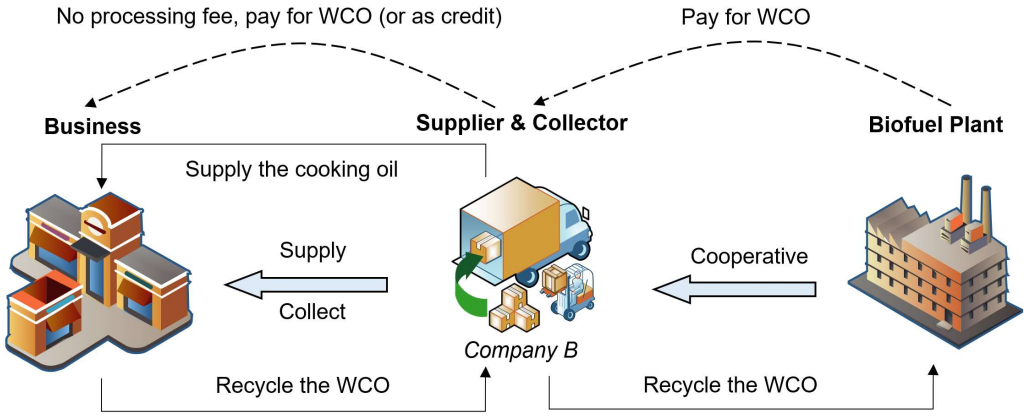

Figure 5. Supplier and Collector-TPT.

4.2.2. Waste Collector

1. Waste Collector-TPT (I);

Company C is a leading global waste management company with extensive operations in the UK, especially as a service provider for local HWRC. As a collector of WCO, its process is illustrated in Figure 6. Although the UK has not mandated household WCO recycling, guidelines are provided. In some HWRC managed by Company C, local authorities encourage residents to deposit the household WCO in designated containers. Company C is responsible for processing all waste from the HWRC and transporting WCO to biofuel plants.

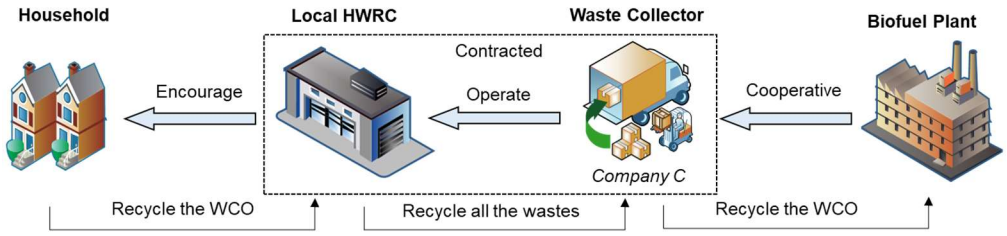

Figure 6. Waste Collector-TPT (I).

2. Waste Collector-TPT (II);

Company D is a waste management company serving over 25,000 UK businesses, offering more than 20 types of commercial waste recycling services, including WCO recycling. As a waste collector, its recycling process is shown in Figure 7. Businesses use Company D's dedicated containers to store and collect WCO. As an integrated waste management company, it can recycle multiple types of waste at once and sends the WCO to biofuel plants. In this model, Company D acts solely as a WCO collector, adopting the TPT model.

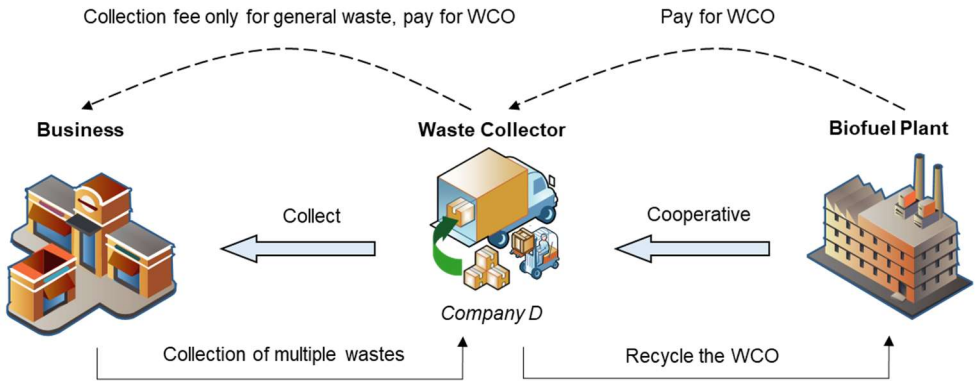

Figure 7. Waste Collector-TPT (II).

4.2.3. Specialist Commercial Collector

1. Specialist Commercial Collector-TPT;

Company E collects WCO in Southampton, as well as in the northern and southern parts of England. As a professional commercial collector, its recycling process is shown in Figure 8. Company E collects WCO from businesses and transports it to biofuel plants. In this model, they pay businesses for the WCO, while biofuel plants purchase WCO from Company E, positioning them as an intermediary.

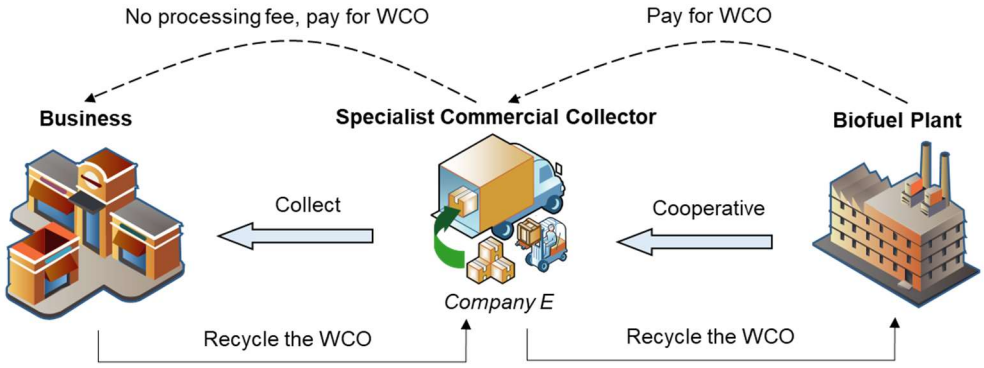

Figure 8. Specialist Commercial Collector-TPT.

2. Specialist Commercial Collector-BET;

Company F provides biofuel in the regions of England and Wales and is also engaged in the WCO collection business. As a specialist commercial collector, its recycling model is shown in Figure 9. During the WCO collection process, when the collected WCO exceeds 100 L, Company F compensates a certain fee, subsequently transporting the WCO to the biofuel plant using its own fleet.

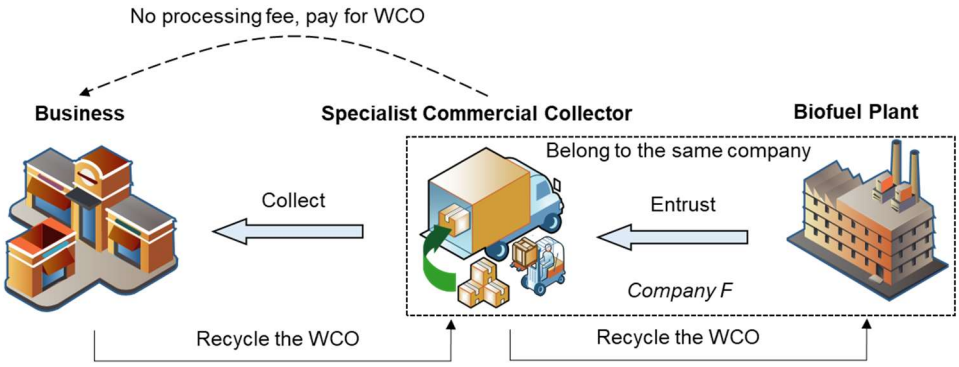

Figure 9. Specialist Commercial Collector-BET.

4.2.4. Closed-Loop Collector

1. Closed-Loop Collector-TPT;

Company G, a globally renowned fast-food chain, collaborates with Company H, a leading global logistics service provider, and Company A, who own the UK's largest biorefinery, for the recycling, processing, and utilization of WCO. Their specific collaboration model is illustrated in Figure 10. The three parties implement a closed-loop recycling system: Company H supplies Company G with goods and collects Company G's WCO on its return trip. This WCO is then handed over to Company A for conversion into biofuel, which fuels Company H's transport fleet, thus being reused for transporting goods.

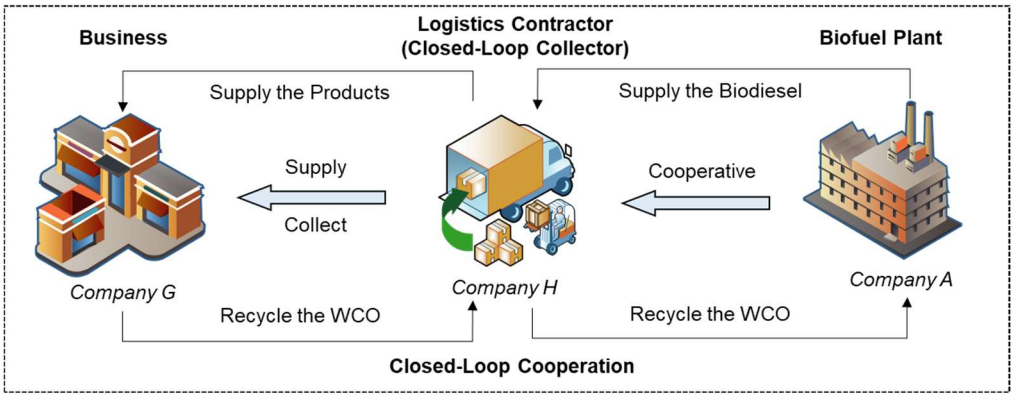

Figure 10. Closed-Loop Collector-TPT.

4.3. WCO Recycling Practices in the UK

4.3.1. Recycling Practices

All four interviewed restaurants confirmed that they benefit from free WCO recycling and receive rewards for it. Specifically, Int-05 follows the Supplier and Collector-BET model, while the others (Int-02, Int-03, and Int-06) use the more common Specialist Commercial Collector-TPT model in Southampton. Restaurants have the flexibility to decide the frequency of recycling, with collectors performing regular pickups based on demand. Further details are provided in Table 3.

Table 3. The collection of WCO from restaurants.

ID	Model	Output/Week	Price/£	Collection Frequency	Storage Method	Price of the Virgin Oil/(20 L)/£
Int-02	Specialist Commercial Collector-TPT	20 L	8	Weekly	Used oil drums	30~35
Int-03	Specialist Commercial Collector-TPT	60 L	40	Fortnightly	Barrels provided by collectors	37
Int-05	Supplier and Collectors-BET	60 L	18	Weekly	Used oil drums	37
Int-06	Specialist Commercial Collector-TPT	40 L	20	Monthly	Barrels provided by collectors	38

4.3.2. Recycling Drivers

The drivers for restaurants to collect the WCO are mainly: (1) the convenience of the recycling process, as well as (2) economic drivers.

First, all four restaurants indicated that they were very satisfied with the current recycling process for WCO, and that the convenience of the WCO recycling process was the main driver for restaurants to collect WCO.

Int-03 stated that the convenience of the recycling process allows him to not have to worry too much about the work, and that he only needs to storage the WCO, many collectors even come to the restaurant to find the potential cooperation. Int-02 also stated that the convenience of recycling is the main reason that motivates him to work with collectors.

Restaurant manager Int-05(2) was even more positive about this and felt that the process had never created concerns.

> *'Actually, the process is really convenient because we wouldn't have to pour the oil or do anymore [. . .]. Because he comes and delivers it and then takes it away and we don't have any concerns. There is no need to actually touch him in this process, just put the new oil here and then the used oil is picked up [. . .]. They are conveniently disposed of.'*

Going further, restaurant staff Int-06(2) summarized feelings about the whole process, which is very representative of the interviews with the four restaurants.

> *'The price and process is affordable, the overall process is convenient and there is nothing we need to be concerned about.'*

Additionally, the fact that WCO recycling generates some monetary reward despite the fact that restaurants consider WCO to be worthless waste is the second reason why restaurants collect WCO, and a total of three restaurants (Int-02, Int-03, Int-06) expressed this willingness.

Restaurant owner Int-02 stated that the reward offered by collector drove his own collection of WCO:

> *'Personally, I don't pay attention to WCO [. . .]. He came and then said he would pay money after collecting, so I agreed to give them the WCO because for one thing, the WCO is not much use, and the other thing is that I will also be paid.'*

Restaurant staff Int-03 expressed the same view and when pressed further on the reason for this response, he noted:

> *'Well, it's easy, you don't need much motivation to do it, I mean it's kind of waste, you won't use it anymore, they come and take it away and I get paid for it.'*

In addition, Int-06(2), a restaurant staff, considered the collection of WCO as more of a 'surprise', which was driven by the fact that not only did he not have to pay for disposal but he was also able to get paid for it.

> *'We didn't even think about paying us, but you know in the UK it costs money and effort to dump any waste, and the fact that he can come and collect the WCO for you and then pay you for it, and you don't have to do anything for him to dispose of the WCO for you, that's a very good arrangement for us.'*

4.3.3. Potential Problems with the Recycling Process

Currently, the WCO recycling process faces two major problems (1) neglect of the recycling process and (2) inaccuracy of WCO measurements.

First, all four restaurants interviewed reported that they had no in-depth knowledge of the use of WCO and the recycling process, and never cared about the specifics of recycling.

Second, when WCO is recycled, collectors 'empirically' assess the quantity and quality to determine the price to pay. Although this method lacks precision, the collectors' estimation is recognized because the restaurant does not care much about it. For example, restaurant staff Int-02 mentioned:

> *'They operate with experience and their estimation is relatively accurate due to their experience. Even though they estimate it based on about 60 litres, it doesn't matter to me how much it is, I only need to dump the WCO and its actual amount, we don't care.'*

Staff Int-06(2) expressed a similar view:

> *'The exact amount of how much oil we don't mind because it's something of no value to me not to be concerned about, it's good enough for him to collect my oil normally and pay me for it.'*

4.4. Challenges of Applying BCT

There are a total of six serious challenges to the current use of BCT in UK restaurants by applying the TEO framework, as shown in Figure 11.

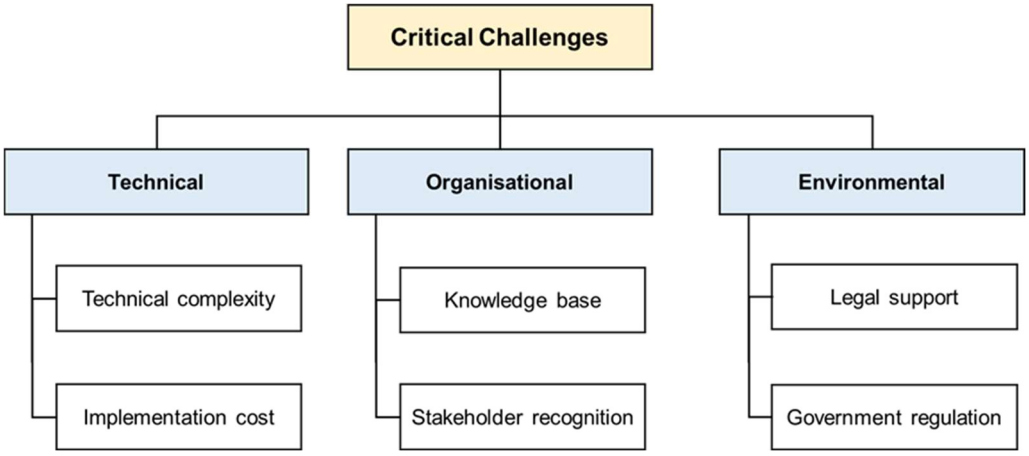

Figure 11. Challenges for adopting BCT.

4.4.1. Technological Challenges

The technical challenges of implementing BCT are (1) complexity and (2) implementation costs.

Manager Int-05(2) explicitly stated that this technology would enhance the current WCO recycle operations and boost operational efficiency. However, upon further inquiry about the considerations of applying the technology, Int-05(2) voiced her reservations about its use:

> *'We take into account the ease of the technology. It should be something the employees can handle. If the process adds additional workload for the staff, we won't opt for it [. . .]. We also won't consider it if the implementation costs are too high.'*

4.4.2. Organizational Challenges

The adoption of BCT technology depends on the specific circumstances of the organization. In this domain, we've identified subthemes, namely (1) knowledge base and (2) stakeholder recognition.

Firstly, the interviewed restaurants have inadequate knowledge about BCT. After a detailed presentation of the current applications of BCT and IoT in the field of WCO recycling, three restaurants (Int-02, Int-03, Int-04) indicated that they were unfamiliar with this technology. Only the manager of Int-05 responded and inquired further, but potentially perceived BCT as a virtual technology that is hard to integrate with practical operations.

Additionally, among the four restaurants, only the larger restaurant (Int-05) expressed willingness to adopt this technology. Restaurant owner Int-06(1) felt it was not relevant to his primary business and denied the potential benefits of the technology:

> *'To put it simply, it doesn't do much for us. The compensation for such a large barrel of oil is minimal, and it's not my core business, so there's no need for that technology [. . .]. It doesn't offer much helps.'*

Restaurant owner Int-02 felt that the shift was unnecessary, manifesting direct disapproval of the BCT application:

> *'My operations here aren't that sophisticated, and on a daily basis, we won't delve into such high-tech stuff [. . .]. I personally don't pay attention to this process [. . .]. This process for me doesn't need to be too technical, it's convenient as it is.'*

4.4.3. Environmental Challenges

Regarding WCO recycling, there is (1) a lack of explicit legislative support in the UK, and (2) insufficient governmental regulation. This reduces attention on WCO recycling and the likelihood of BCT application.

Currently, there are no explicit legal provisions mandating a specific level of WCO recycling in the UK. The guidelines provided by the FSA and the Environment Agency emphasize the importance of efficient storage, collection, and transportation of WCO. However, other relevant policies and documents predominantly focus on general waste management, with occasional mentions of WCO disposal. This lack of specificity in legal policies contributes to noticeable ambiguity, stemming from the absence of targeted legislation and enforceable mandates. Consequently, regions in the UK intermittently have to grapple with the issue of 'fatbergs' resulting from indiscriminate dumping.

On the regulatory front, a noteworthy discovery is that in recent years there has been a noticeable decrease in the rigour and standards of regulation. Int-02, a restaurant owner, noted that compared to the past, there was less supervision and routine checks seemed superficial:

> *'Things have changed a lot in recent years. Earlier, the inspections were more rigorous. Now, many staff members have been cut from their departments, resources are stretched thin, wages are lower, and maybe fewer people are willing to do the job. So the checks now seem like they're just ticking boxes [. . .]. Past inspections were very formal and strict [. . .]. Nowadays, there are too many restaurants, they can't possibly monitor them all.'*

Further, restaurant staff Int-03 pinpointed that the pandemic significantly impacted the effectiveness and efficiency of the regulation, resulting in the current lax state:

> *'The reason they aren't inspecting many restaurants is because of the 'corona time'. Before the COVID-19 outbreak, they had dedicated teams. They would scrutinize everything—inspecting your sink, room temperature, fridge, and so on, unlike now. The 'corona time' essentially disrupted their operations.'*

4.5. The Insights of Southern Europe Project of Z Company

There are a total of five practical insights that Z company has used to successfully advance the PROJECT in Southern Europe, as show in Figure 12.

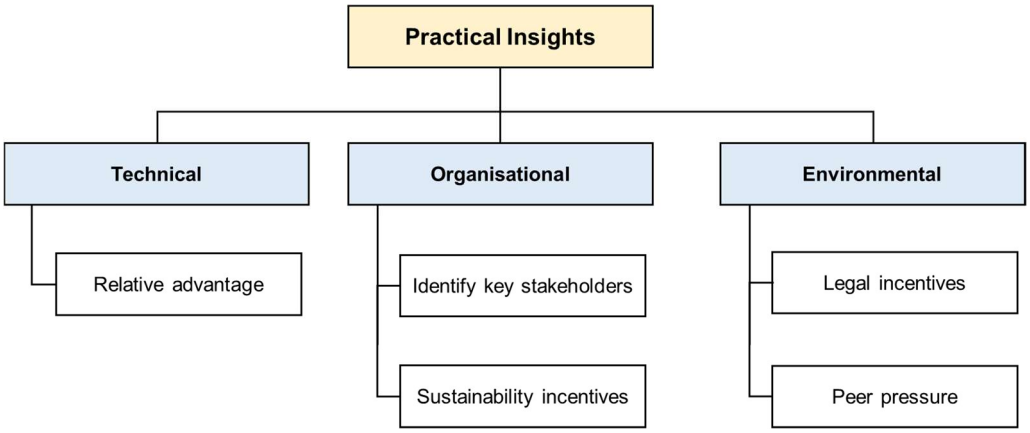

Figure 12. Insights for adopting BCT.

4.5.1. Technological Insights

Many hold misconceptions and resistance towards the adoption of new technologies. As Project Manager Int-01 highlighted:

> *'The technology is quite novel, while the industry is predominantly traditional [. . .]. Thus, people need the novelty to be superior, or they won't embrace change.'*

Therefore, unless the technology demonstrates distinct advantages, instigating change remains challenging. According to C. Gluesing [100] (p. 124), relative advantage refers to 'the degree to which an innovation is better than the idea or technology it could replace

or that came before it'. In our research context, this concept alludes to the enhanced transparency in the recycling chain facilitated by BCT, which aids corporate operation.

Currently, Europe's collection industry lacks transparency, grappling with significant issues of fraudulent collections and data discrepancies. Given Europe's ambitious quotas for WCO recycling coupled with its inefficient realization, there's a trend of introducing virgin oil as used oil. Nevertheless, Z company's integration of BCT + IoT serves dual purposes: ensuring oil authenticity and tracing oil throughout its lifecycle. Such measures not only diminish fraudulent activities and tax evasion but also, owing to Z company's low energy consumption BCT, become a marketing asset for partners. The presented advantages address numerous challenges in recycling, transforming WCO recycling into a unified, transparent, and traceable system.

4.5.2. Organizational Insights

(1) identify key stakeholders and (2) sustainability incentives are the two organizational factors that boost the PROJECT.

During the implementation of the PROJECT, one of Z company's pivotal strategies was to collaborate with WCO collection companies rather than liaising directly with restaurants. This strategy stems from a profound understanding of market behaviours and stakeholder attitudes, as described by the Project Manager in both Int-01 and Int-04:

> *'The most challenging part is identifying the right restaurants or participants [. . .]. For the primary user who's given oil, they don't really care about it, they just know they're gonna get paid for. They don't really care about the mechanism [. . .]. So what these guys have done is that they've targeted the collection companies because they're huge. So these companies, they are the ones who have led to the collection points and all that stuff. So, you kind of go that way, not to the restaurant first.'*

Sustainability incentives encourage stakeholders at every phase of the recycling chain to participate. Conventional collection methods often involve WCO being collected for free. Still, ownership of WCO should warrant compensation, with greater quantities fetching more rewards. The synergy of BCT and IoT ensures accurate data logging, facilitating precise compensation, thus motivating partners to embrace BCT. This also furnishes Z company with the opportunity to propel project execution, in interview Int-01:

> *'I like it as a sustainable project because it's profit along every step of the way, and everyone is incentivized to do that [. . .]. And you know for the restaurant, they have paid to buy this oil, and when they get rid of it, they don't get anything. So if they got some money, it still is something that I think they'd be willing to do.'*

4.5.3. Environmental Insights

Environmental factors, predominantly external, encompass two main pillars: (1) legal incentives and (2) peer pressure.

Legal impetus forms the bedrock for Z company's successful practice. Europe's stipulated net-zero objectives underscore the significance of WCO collection and conversion. The entire EU has mandated regional laws necessitating WCO and related data collection and documentation, bolstering Z company's project execution. As Project Manager Int-01 observed:

> *'I think that a key driver of this is government support, either financially and or with legislation [. . .]. Because this is something that potentially will help drive this project a lot, because you know people do get paid for this eventually but everyone needs a push from the government [. . .]. So we're really looking for government led legislation to encourage the collection of these waste products.'*

Moreover, peer pressure amplifies the PROJECT's adoption across organizations. Initial uncertainties surrounding BCT impede early-stage execution. However, as an increasing number of industry players join, it fosters wider acceptance:

'So the main players have already signed up. This could be attributed to a form of peer pressure [. . .]. It's possible that if a few companies were to sign up initially, it could trigger a snowball effect, encouraging more companies to follow suit.'

5. Discussion

5.1. Research Review

This study explores the UK's WCO recycling market and draws on the success of the PROJECT to enhance existing research. To address Research Question 1, we identify seven prevalent recycling chain models in the UK. Addressing Research Question 2, we investigate restaurant WCO recycling practices, and using the TOE framework to pinpoint challenges in adopting BCT. Insights from the PROJECT partially respond to Research Question 3. Next, the key concerns of this study are discussed below with a view to gaining deeper managerial insights, and answer the rest of the Research Question 3 by giving the recommendation for future application.

5.2. The Recycling Chain of WCO

In answering the first research question, our study identified seven distinct WCO recycling models in the UK, a novel finding in the field of UK WCO recycling. This diversity reflects the industry's complexity and various waste management strategies. Our research, building on the general overview by ECOFYS [7] and Smith et al. [5], and further provides a detailed understanding of how different collectors operationalize their strategies.

A notable trend is the preference for the Third-Party Take-back (TPT) model over the Biodiesel Enterprise Take-back (BET) model, suggesting operational efficiencies and economic viability of TPT, as supported by Zhang et al. [19]. However, the reasons behind regional or collector-specific preferences for TPT and BET models warrant further exploration.

Contrasting with other regions, the UK's WCO recycling process lacks direct governmental guidance and financial incentives. While studies like Zhang et al. [19], Loizides et al. [54], and Greenea [12] emphasize the role of legislation and government subsidies in structuring recycling frameworks, the UK market is driven primarily by competitive dynamics, as indicated by our interviews and corroborated by ECOFYS [7]. This leads to a unique competitive landscape in the UK WCO recycling industry.

5.3. Challenges of Applying BCT in Restaurants

5.3.1. Technological Complexity and Cost Barriers

According to research conducted by Clohessy and Acton [78], complexity and investment costs are significant factors in businesses' decisions to adopt BCT. In our study, we focused specifically on the WCO recycling industry of in the UK. Our conclusions are consistent with previous findings.

Both Ganguly [75] and Kamble et al. [80] noted the technological complexity as a significant barrier to BCT adoption. Our research examined these aspects in the WCO industry, focusing on efficiency enhancement. Manager Int-05(2) suggested BCT should not complicate employee tasks, overlooking BCT's potential benefits in enhancing organizational efficiency [81]. However, Int-02 and Int-06(2) indicated limited enthusiasm among restaurants for WCO recycling and conversion, impacting the perceived benefits of BCT [79]. Hence, while BCT can increase transparency, its practical utility might not be immediately apparent in daily restaurant operations, potentially adding complexities.

Furthermore, the high cost of BCT implementation discourage firms from adopting it [59,78]. With the low-cost availability of WCO [19], it is challenging for restaurants to derive significant economic benefits from this sector. This perspective aligns with Int-06(1) but partially contrasts with insights from Int-01. The primary concern for many enterprises, especially small businesses, is the initial expense of BCT, posing a substantial financial challenge [63]. Many businesses cite these high costs as a key impediment to BCT adoption [78]. Considering the difficulties in extracting substantial economic value from

WCO, the prospective costs of BCT appear disproportionately high, a critical consideration for BCT company in its future initiatives.

5.3.2. Lack of Stakeholder Knowledge and Recognition

Restaurants show a notable lack of understanding of BCT, a key barrier to its adoption as identified by Dehghani et al. [79] and Kouhizadeh et al. [83]. Building on Thong's [101] assertion that technological knowledge and skills drive new technology adoption, and organizations are unlikely to adopt technologies they don't fully understand. Clohessy and Acton [78] further suggest that technical knowledge acquisition is essential for technology acceptance. Our study indicates that the restaurant industry's limited understanding of BCT leads to a reluctance to adopt it in recycling practices. This situation is not unexpected, given the nascent stage of BCT application in recycling and the general lack of experience in both academic and industrial circles [63]. Additionally, the recycling industry's low digital adoption rate exacerbates this technological knowledge gap [63].

Furthermore, the resistance of restaurants towards BCT reflects broader challenges in incorporating informal collectors into the recycling chain [63]. The attitude of restaurants, as key stakeholders in the WCO recycling chain [19], significantly influences the spread of BCT [76]. Since the interviewed restaurants had minimal knowledge of BCT and did not prioritize recycling, they were generally skeptical of the technology. Successful BCT adoption depends on partner support [78]. Therefore, BCT proponents must demonstrate leadership to ensure stakeholders recognize its potential benefits, perhaps through internal incentives or educational initiatives [78].

5.3.3. Lack of Legal and Regulatory Oversight

The lack of specific legal frameworks and regulations has led to diminished emphasis on WCO recycling in restaurants, thereby affecting the conditions for using BCT in the recycling process. Clear regulations can enhance effective WCO recycling and management, encouraging businesses to focus on recycling practices [56]. However, current UK legislation on WCO recycling is not stringent [7], providing only a broad framework without detailed provisions. This leads to low regulatory compliance and insufficient incentives for WCO suppliers. The decreased regulatory pressure during the 'corona time' has further impacted this, contributing to why restaurants, as significant waste producers, often overlook WCO recycling efforts. This situation also explains the persisting issues of transparency and accountability in converting WCO into biofuels [34,59]. Nonetheless, the implementation of BCT could address these concerns by enhancing regulatory compliance and transparency in the recycling process.

5.4. Practice Gaps and Applied Insights

5.4.1. Analytical Objectives

There are challenges in applying BCT to WCO recycling in the UK, while the PROJECT provides insights into successful application. A cross-case comparison is made below to highlight the gaps that exist between the two, as well as management recommendations for applying the BCT.

5.4.2. The Main Gap between UK and Southern Europe

Broadly speaking, incorporating BCT into the recycling of WCO poses challenges in the UK. These challenges arise from pronounced discrepancies between the UK and Southern Europe PROJECT in several aspects, primarily pertaining to micro-level recycling practices and macro-level legislative, policy, and regulatory frameworks.

Firstly, unlike Southern Europe's extensive household WCO collection, the UK primarily relies on restaurants for WCO collection. The PROJECT success in applying technology to both households and restaurants in Southern Europe, with a lot of the collection points, contrasts with the UK's restaurant-centric model. This necessitates adapting the business

model for the UK, focusing on restaurant collections due to the lack of household WCO collection regulations [78,79].

Secondly, the success of the PROJECT is supported by well-defined legal and regulatory frameworks, as noted by Project Manager Int-01. Precise regulations and clear recycling objectives encourage more active recycling participation [7,56]. In the UK, however, legal and regulatory ambiguities reduce focus on recycling, posing obstacles to BCT adoption. The absence of stringent legal mandates and the fluctuating regulatory stance on recycling hinder the integration of BCT in WCO recycling efforts [59].

Overall, these discrepancies between the UK and Southern Europe necessitate a tailored approach to effectively integrate BCT into the UK's WCO recycling landscape.

5.4.3. Recommendation for Future Application

Implementing BCT for recycling WCO in the UK presents more challenges compared to Southern Europe, primarily due to weaker WCO recycling incentives and uncertain legislative frameworks. Nonetheless, the RTFO in the UK, with its monitoring mandates, offers potential for BCT application.

Key to successful BCT implementation is collaboration with crucial stakeholders, particularly collectors, who influence the adoption and effectiveness of BCT [75,76]. The PROJECT's experience underscores the strategic value of partnering with certified collectors who connect with both ends of the recycling chain. However, as collectors may have limited interest in downstream waste processing, this approach may not be universally effective [63]. For the UK context, recycling models like 'Supplier and Collector-BET' and 'Specialist commercial collector-BET' are more suitable due to their integrated biofuel plant operations, offering a comprehensive framework for recycling.

Certainly, in this process, larger organizations should be the primary candidates. The size of an organization influences its adoption of BCT, with bigger organizations typically more receptive to novel technologies due to their extensive knowledge and capabilities [75,78]. Additionally, the inherent resources of large organizations can support the implementation of BCT. In contrast, small and medium-sized enterprises, with limited resources, may face difficulties in implementing BCT [83]. According to Z company's practices, peer pressure plays a role in driving market acceptance of BCT [77], and the adoption of BCT by larger organizations can increase this pressure. However, the drawback of relying on large entities is their tendency to follow rather than lead, organizations tend to observe early adopters and their application of BCT [63], thus requiring foresight for improved strategizing.

All contributors within the chain are integral in promoting the practical implementation of BCT [76]. Therefore, it is crucial that all stakeholders in the recycling chain possess adequate knowledge of this technology. However, our research reveals that a substantial knowledge gap exists within many restaurants regarding BCT, acting as a significant obstacle to its application in the real world [79,83]. If on-chain participants remain passive or cannot efficiently harness BCT, projects may face challenges [76]. In this context, BCT proponents should exercise their influence by implementing internal reward mechanisms or extensive educational initiatives, educating all stakeholders on the potential value of BCT [76,78].

Finally, considering the UK's diverse WCO recycling models, customizing BCT frameworks to fit each model's specific needs is vital for effective implementation.

6. Conclusions

This study is an early exploration of WCO recycling in the UK, looking at the current state and practical operation of the UK's WCO recycling market. Additionally, it examines the potential use of BCT in the WCO recycling industry, drawing on insights from the PROJECT.

Addressing the first research question, we deeply analysed the market conditions, especially focusing on the overall landscape, the relevant legal and policy aspects. Notably,

based on the established collector's types, we identified seven unique WCO recycling chain models present in the UK. This groundbreaking finding not only enriches academic research on WCO recycling but also unveils, for the first time, the business models within the UK's WCO recycling sector. This serves as a reliable point of reference for future research as well as commercial applications.

Regarding the second research question, following thorough selection, we selected four restaurants in the Southampton area as our interviewees, with the objective of ascertaining the latest practices in WCO recycling and exploring the potential of BCT applications. Combining insights from the first research question, we presented a comprehensive overview of the existing recycling practices, motivational factors for recycling, and potential procedural challenges. When examining how BCT may enhance the effectiveness of WCO collection processes, it becomes clear that its implementation in restaurants is met with considerable hurdles. By utilizing the TOE theoretical framework, we have systematically presented these challenges in the first analysis of the practical applications and difficulties of BCT implementation within the recycling sector of the UK's WCO domain.

In relation to the third research query, we performed two comprehensive interviews with project managers from Z company to obtain distinctive insights into the utilization of BCT within Southern Europe's WCO recycling sector. By applying the TOE framework, we identified five principal enabling factors. Subsequently, chapter 5 delves into integrating findings from all three research questions, exploring disparities between the UK and Southern Europe in this domain, and offering recommendations for further applications of BCT in the UK. This aims at providing invaluable managerial insights for future corporate strategies.

This study makes significant contributions to both academia and industry by conducting a thorough analysis of the UK's WCO recycling practices and incorporating insights from the PROJECT. It reveals previously unidentified WCO recycling chain models in the UK and assesses the practicality of incorporating BCT, thereby enhancing our understanding of the current WCO recycling practices. The comparison with the PROJECT highlights regional differences and proposes strategies for implementing BCT in the UK. These essential insights, particularly emphasizing seven recycling models in the UK and the potential applications of BCT, provide a foundation for future research and business ventures.

However, due to time and resource constraints, this study is limited in its scope. Several key stakeholders declined to participate during data collection. While the study focuses on restaurants, as the primary source of WCO in the UK, its findings may not fully translate to the broader industry. Moreover, the emphasis on Southampton-area restaurants may not accurately reflect national trends; therefore, further investigation of archival data is warranted. Moreover, the study's comprehensiveness and comprehensibility may be restricted due to the limited knowledge of WCO recycling and related fields.

For further research, several improvements are recommended with more time and resources. Additional participants from various regions involved in WCO recycling should be included in the interview scope to generate more comprehensive data. Industry experts should also be consulted to provide more profound insights into BCT application and legal intricacies. Conducting a comprehensive examination of the previously identified recycling models may uncover the conditions for their execution and more opportunities for the integration of BCT. Finally, relevant experiments should also be scheduled to ensure the profitability of the entire project.

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Institutional Review Board Statement: The study was conducted in accordance with the ethical requirements of University of Southampton, and approved by the Ethics Committee of Southampton business School, University of Southampton.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Interview Protocol

Questions	Follow-up Questions/Notes
Introduction	
Thank you for taking the time in our research. The interview will be recorded by us, is it fine for you? Your identity will be kept totally anonymous.	
I will introduce myself and the research before we start the interview. I'm Hengyi Zhang, currently joining the research project of the UoS. The interview will be semi-structured with open-ended questions, so you can answer based on your own perspective.	
If you have some concerns about some of the questions, you can refuse to answer them, I can promise you that all the information is only used for the research and will not be disclosed to others. If any questions are not applicable to your business or not easy for you to answer, you can also say "not applicable for me", and we can just jump to the next question, anyway, I really appreciate for your help.	
Now let's start the interview. The questions are divided into 3 themes.	
Operation:	
1. Could you please give some information about your work, and how long have you been in this area?	
2. What is the current output of waste oil from restaurants?	What are the main types and sources of waste oil from the restaurant?
3. Is there a special filter for waste oil or does it go directly into the waste oil container?	What types of containers you are using? (20 L, 40 L. . .)
	Are there any storage costs (container costs) associated with the storage of oil?
	Who is responsible for this cost?
4. Can you please tell me about the process of collecting the waste oil?	What is the frequency of oil collection? (daily, weekly)
	Do you need to call the collector or they will come here regularly?
	Are the people who send the new oil and the people who collect the waste oil the same one?
	Will they give a document to you once the oil has been collected?
	Is there any contact information for the waste oil collector?
5. What is the price of the waste oil?	The reward.
	Can you please tell me what is the price you pay for new oil?
6. Sometimes, if the restaurant has too little or not enough waste oil, how should it be collected and how should the price be calculated?	
7. Do you know the reason/use for collecting waste cooking oil?	Can be used to produce biodiesel or other products
8. Are there anything else in the restaurant that is worth recycling?	

Questions	Follow-up Questions/Notes
9. What factors do you think prevent or facilitate the proper handling and recycling of your used oil?	
10. Do you think any difficulties/problems/concerns have arisen during this process?	Inconvenient contact, irregular oil collection, inaccurate oil quantities, theft, etc.
Legislations:	
11. What is your motivation for collecting the waste oil?	Monetary rewards or legal requirements
12. Do you know the UK legislation on waste oil?	If don't know, what should you do with the waste oil if the oil collectors don't come?
13. What is the frequency of routine inspections by Food Hygiene?	Will there be waste oil issues involved?
14. Have food hygiene inspections been stricter compared to the previous years?	If not strict, was it strict before?
Technology:	
15. What parts of the oil collection process concern you?	Oil collection, transportation, delivery, refining, etc.
16. Are there any techniques that have been applied to this process?	e.g., oil quantity recording, testing, traceability
17. What problems would you like to solve by using technology in this process?	
18. There are currently some news reports the problem in the process of collecting the WCO, like lack of transparency, inaccurate volume, and oil theft, are you aware of this situation? Are there any concerns about this?	One method is to add a sensor to the container that sends messages through the recycling chain, and if it experiences a drop in capacity it will also tell the people-would you welcome the use of this technology?
19. The sensor also gives you a real-time report on the volume of used oil and automatically contacts the collector when sufficient volume has been collected, helping you to record the volume of oil collected each time (tamper-proofing and archiving the data)-would you consider using this technology? Do you accept the same technology from the PROJECT?	Which point would you be more concerned about if this technology were applied?
	What problems do you wish you had the technology to solve that you are currently experiencing?
20. If you do not want to use this type of technology, what points are you considering?	The difficulties.
Closing:	
21. From your point of view, what other problems or inconveniences do you see with the waste oil recycling process?	Is there a desire for appropriate laws and technology to solve the questions?
22. Finally, do you know or can you easily recommend the appropriate oil collector or restaurant? This would enable a more accurate assessment of the current situation	
23. Do you have any questions to ask me?	
Well, that's the end of my interview, really thank you for sparing your valuable time for this interview, all this information has been very helpful to me, if you have any concerns or follow-up answers, you are welcome to contact me, and I will reply to you at once.	

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