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Reducing Charcoal Ash Waste by Implementing the COHRV Model: Food Truck Case Study in Ciudad Juarez

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Abstract

Within the food industry, research on mobile gastronomy has increased from the consumer perspective. Food trucks play an important role as economic units worldwide, serving as a culinary alternative to traditional restaurants. They have emerged as an innovative initiative and business model that offers a disruptive alternative to home cooked meals. One of the aspects most appreciated by consumers is the charcoal-grilled food offered by food trucks. Globally, charcoal is widely used as an energy source and cooking fuel, with an annual production of approximately 53.2 million tons. Its characteristics and low cost make charcoal a dominant energy resource, and it plays a fundamental role in cooking in both low- and high-income countries due to the distinctive flavor and texture it imparts to food. Research has focused on air pollution and health risks, supplemented with information on the types of charcoal, characteristics and properties, production techniques, and added value. Charcoal ash residue production has not been fully analyzed, providing an opportunity for research to obtain data and evaluate various criteria, such as kilograms of charcoal purchased and food trucks' residual charcoal ash. To address this gap, the authors propose a horizontal collaboration perspective through the application of the COHRV model to (1) collect data and create a database from food-truck business owners in Ciudad Juarez, Chihuahua; (2) develop a circular economy model for charcoal ash as a sustainable strategy within the food industry; and (3) estimate charcoal consumption during the grilling process and the generation of charcoal ash residue in the food truck sector.

Keywords: charcoal ash valorization; circular economy system; horizontal collaboration; SMEs; sustainable development

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1. Introduction

The food industry has attracted significant research interest due to its importance and growth within the industrialized food system. This growth in innovation and technological infrastructure is driven by several factors, including population growth, economic development, and urbanization worldwide. However, while this expansion generates economic and social benefits, it also has negative environment consequences, as the overproduction of food throughout the entire supply chain—e.g., harvest, storage, transport, primary processing, post-production, and wholesale—is causing stress in two areas: (1) the agri-food industry and (2) waste management [1,2].

Research on mobile gastronomy has increased from the consumer perspective. Food trucks have emerged as an innovative initiative and business model, offering a disruptive alternative to home-cooked meals. Between 2016 and 2021, this sector experienced an annual growth rate of approximately 6.6% [3]. As economic units, food trucks play an important role in any country, with market growth projected to reach approximately $26.3 billion by 2027 [4], highlighting their growing social and economic relevance among consumers [5].

Millennials represent the largest market segment for this type of business because they seek diverse culinary options that are easily accessible and closely linked to social media trends [3,6,7]. Cross-sectional survey studies have found that consumers' intention to use food trucks stems from attitude, subjective norms, and behavioral control [8,9]. Additionally, a food truck's image and employee friendliness positively influence customer loyalty and repeat patronage [3,10] and food trucks also tend to emphasize social and environmental responsibility, offering an innovative value proposition aligned with a more sustainable food industry [5].

Food Trucks in Mexico

Food trucks have experienced rapid growth in Mexico since 2014 and are widely recognized for providing unique culinary experiences featuring traditional regional cuisine. They are meeting the rising demand for street food, as three out of every ten Mexicans allocate 9.8% of their annual food budget to this economic business model [11]. Unlike the United States, Mexico lacks a clear regulatory framework for this type of business, as they are categorized as street vendors, even though they are micro-enterprises that pay taxes and have trademarks registered at the Mexican Institute of Intellectual Property (or IMPI, its acronym in Spanish) [7].

Ciudad Juarez, Chihuahua, is not exempt from this culinary experience. Located in northern Mexico, bordering El Paso, Texas, and Doña Ana, New Mexico, it has a bilateral economic dynamic that fosters an entrepreneurial environment. These micro-businesses can be found around public parks, food truck parks, and social and sports events. These enterprises serve a niche market but are considered street vendors. An initial screening of the National Statistical Directory of Economic Units (or DENUE, its acronym in Spanish) from the National Institute of Statistics and Geography (or INEGI, its acronym in Spanish), using search fields such as Economic activity "72233—mobile food preparation service"; enterprise size "0 to 5 persons" AND "6 to 10 persons"; and geographic area "Juarez", resulted in only 39 registered establishments [12].

To supplement this information, a field study was conducted over a two-month period. The study involved visits to public spaces, public parks, street food markets, and outdoor social events—places where food trucks are commonly found. Between May and July 2025, a total of 149 responses were collected, providing information on the food truck market and business model in Ciudad Juarez. Among the analyzed data, records from respondents who did not wish to disclose their brand name were excluded. Duplicate records were then removed. Using these exclusion criteria, the survey yielded a total of 143 records of street food cart businesses. The data collected made it possible to map the locations of food trucks in six areas of Ciudad Juarez, as shown in Figure 1.

From a market perspective, the sample of 143 food trucks demonstrates a well-established presence and defined operating schedules. Most businesses operate three days per week, typically on Thursdays, Fridays, and Saturdays. Their market presence is influenced by both their years in operation and the quality of the services they provide. Specifically, 30.77% of the businesses have been operating for less than five years, 25.87% for 6–10 years, 25.17% for 11–15 years, and 18.18% for more than 15 years. Furthermore,

business owners differ in the number of food trucks they operate, which reflects their market participation. Among the respondents, 30.77% own one food truck, 24.48% own two, 17.48% own three, and 27.27% own four or more food trucks, as shown in Table 1.



Figure 1. Distribution of food trucks by areas in Ciudad Juarez, Chihuahua.

Table 1. Food truck units and market position by years in business.

No. of FTs	0 to 5 Years	6 to 10 Years	11 to 15 Years	More than 15 Years
One food truck	19	9	8	8
Two food trucks	13	9	9	4
Three food trucks	4	8	6	7
Four or more food trucks	8	11	13	7

The importance of food trucks within the street food sector depends on their business model and supply chain. One of the main competitive advantages each business presents is its cooking process and how it delivers food.

The charcoal supply chain involves different actors and specific production methods. Charcoal is considered a versatile product because it is used to provide heat, prepare dishes, make incense for religious events, and fuel street food [13]. The growing interest in grilling for outdoor cooking has increased demand for charcoal production. Customers prefer charcoal brands that offer better combustion performance, with stable temperatures, minimal flames, and minimal production residue (ash), because this translates into lower costs and better food quality. Although authors have studied charcoal for grilling, both

outdoors and indoors, research has focused on air pollution and health risks; it has also included information on the types of charcoal, their characteristics and properties, and production techniques and added value. Mencarelli et al. [14] have reported chemical analyses conducted on various samples of charcoal ash, concluding that the chemicals present in the charcoal ash used in grills depend on the type of wood (e.g., tree wood, furniture wood, or other types of wood waste).

Charcoal is widely used as a biomass fuel in developing countries, valued for its easy availability, low price, and widespread use [15,16]. In recent years, high-income countries have increasingly used charcoal as a fuel for grilling food, both at home and in restaurants. As described by [16], the charcoal situation presents gaps, as information on its supply chain is limited. Research analyzes charcoal-making processes, technology, and the chemicals involved in charcoal production and the generation of charcoal ash, but there is no information available on the amount of ash produced in the food industry, let alone by street food vendors.

Food trucks represent an innovative and flexible business model within the food industry, however, this sector has not been thoroughly studied in all of its dimensions [8,9], particularly in terms of the use of charcoal for grilling, its residue (charcoal ash), its disposal, and the environmental, economic, and social impacts related to waste valorization. Research on the supply chain is limited; it focuses on the raw material stage (planting and harvesting various tree types), production (stages of wood carbonization), packaging, distribution, and sales. However, the studies found in the literature are limited; ref. [17] analyzes post-use charcoal, conducting laboratory analyses of its characteristics, emissions, and the amount of charcoal ash generated during combustion in grills. This research, along with the limited information in the literature review, presents an opportunity to conduct the present study, which focuses on collecting data under real-world conditions on the use of charcoal in food trucks and analyzing the production of charcoal ash after the combustion process, applying the formulas mentioned in [17].

To address this gap, the authors propose a horizontal collaboration perspective by applying the Resource and Value Horizontal Collaboration (or COHRV, its acronym in Spanish) model to present three main contributions, including (1) collecting data and creating a database from food truck business owners in Ciudad Juarez, Chihuahua; (2) developing a circular charcoal ash economy model as a sustainable strategy within the food industry; and (3) estimating charcoal usage for the grilling process and charcoal ash residue in the food truck sector. To ensure the objective of this article, the authors list the following research questions:

- Can the COHRV model serve as a visual framework for micro-business owners to collaborate on a joint venture in the food industry?
- Can charcoal ash residue be valorized as a new raw material within a circular economy?

This paper is structured as follows: Section 2 provides a brief review of the circular economy system, the COHRV model as a horizontal collaboration framework, and the food truck industry. Section 3 describes the research methodology. Section 4 presents the data analysis and results of the COHRV model implementation. Section 5 discusses the main findings, and Section 6 outlines the limitations and future research.

2. Literature Review

2.1. Circular Economy as Systems Thinking

Businesses have shown increased interest in integrating sustainable strategies into their business models to remain competitive in their respective markets [18,19]. As defined by [2,20], sustainability focuses on meeting the needs of the present without compromising the ability of future generations to meet their own needs. These strategies tend to innovate

within a sustainability systems thinking framework that considers the three pillars of sustainability: economic, social, and environmental, allowing a holistic view across multiple organizational levels and across the supply chain [2,21].

Previous articles have linked waste valorization, sustainability, and the circular economy, showing an increase in research on biomass and fruit management as a new raw material. From an initial list of 141 articles found in the Springer Nature database, articles were filtered using the following criteria: (1) titles that did not mention one of the following terms: valorization, sustainability, or one of the three pillars—economic, social, or environmental, and (2) articles that deal with characterization, industrial applications, or methods for industrial applications, as well as literature reviews or bibliometric studies, were excluded. Figure 2 shows the results, indicating that research on fruit and biomass in the context of the circular economy or sustainability has gained interest since 2021. Biomass, as represented in the articles by leaves, plants, or wood, is the subject of increasing research; two articles stand out, as they describe, from the perspective of stakeholders and policymakers, the reuse of wood ash [22] or biomass briquettes for various applications [23].

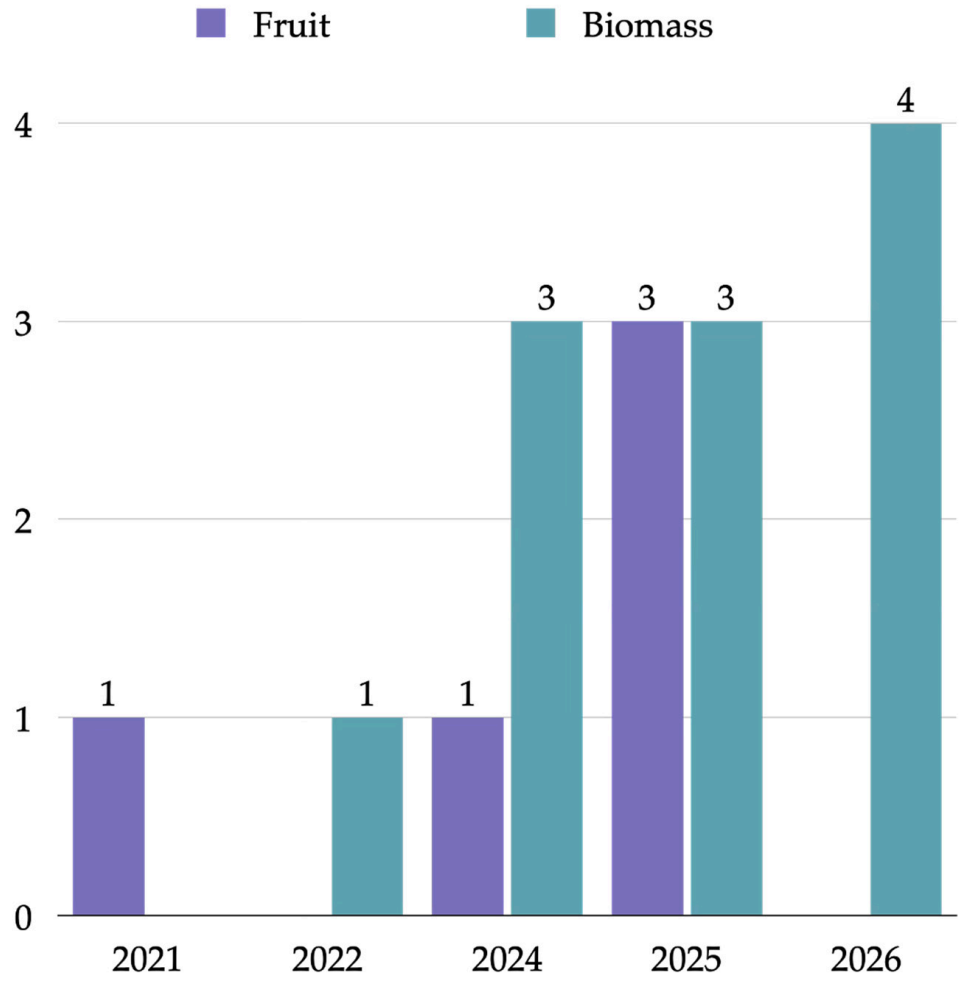


Figure 2. Research interest in fruit and biomass in circular economy strategies.

The circular economy has gained significance and is a relatively new concept that is opening opportunities in both research and business. Its definition remains ambiguous because it depends on who uses it and in what context [24–26]. One of these strategic approaches, driven by consumer trends, is a transition from a linear 'take-make-dispose' model to a circular 'reuse-recycle-reduce' model.

The primary objective of the circular economy transition is to create a circular pattern of reusing or remanufacturing waste, moving away from the linear economy paradigm toward a circular economy, thereby promoting resource efficiency and waste reduction [27–29]. It has been recognized that circular economy practices are connected to the economic, social, and environmental aspects of a firm [21,24,27].

Economic pillar: The role of the circular economy among stakeholders, policymakers, and business leaders is important for cultural change; however, frameworks for implementing the circular economy as a system still present opportunities for future research [30]. Various approaches have been developed to address this new concept. Among them, the circular economy has been documented as a driver of firm and operational performance through circular economy practices focused on recovering waste and used materials [24,29]. A previous study in the agro-industry applied AHP and TOPSIS analyses, showing that accounting for transparency in waste availability or waste streams and acknowledging several suppliers for their production lines can positively influence the economic pillar of a business [31].

Social pillar: This pillar receives the least attention in the literature; however, ref. [32] highlights its contributions by addressing a specific global situation: the COVID-19 pandemic. The study focuses on the north of England, where it demonstrates how individuals saw opportunities by working together and looking out for one another, establishing new supply chains from food waste or raw material residue to produce goods and supply the local market.

Environmental pillar: In [33], the circular economy concept is examined through a comparative analysis of its application in academic and business contexts from 2017 to 2022, highlighting two key aspects: (1) the "reduce-reuse-recycle" model as the core principle of the circular economy and (2) enablers, with particular attention to the business model, which is not sufficiently studied or applied in research, and to the role of consumers in consumption practices and awareness of circular economy practices.

The circular economy is presented as a systems thinking approach to create a closed loop of materials, implementing the "reduce-reuse-recycle" principles within the supply chain levels—production, distribution, and consumption. It is also presented as a systems thinking approach by applying a reverse logistics approach, establishing collaboration arrangements, and defining what is produced, food loss or food waste [34]. Additionally, ref. [27] describes the circular economy as a systems thinking approach that helps decision-makers and stakeholders identify challenges, compare strategies, and evaluate results across the three pillars of sustainability.

Circular Economy Business Model

The world is witnessing steady growth across all three pillars of sustainability: the social pillar, driven by population growth, quality of life, culture, and stability; the economic pillar, driven by high demand for production and consumption, standardization, and market positioning; and the environmental pillar, driven by climate change, waste in both social and economic contexts, and a cultural shift toward a society and industry that are more environmentally friendly and empathetic. These factors have sparked interest in both academia and practice. Several companies are seeking ways to develop solutions within their organizations to maintain production and consumption while minimizing waste, either by pursuing a reuse–reduce–recycle approach or by implementing other measures.

The circular economy business model (CEBM) provides a framework for enterprises to develop and implement strategies and practices for the circular economy and sustainability. As described by [35], circular economy business models conceptualize the value proposition, customer involvement, and supply chain management. In [2], a study was conducted

among companies in the agricultural supply chain to identify the strategies each company implemented to assess circular economy performance. Furthermore, fourteen CEBMs were analyzed and grouped to provide guidelines for the wind energy industry for a sustainable supply chain approach [36].

Moreover, several frameworks stood out for conceptualizing the circular economy from economic, social, or environmental perspectives. In [21], the authors present an assessment tool and framework to analyze and evaluate each participant's processes in the supply chain and it is tailored to, designed for, and validated in the European agribusiness sector. Furthermore, the ReSOLVE framework is described as a model that assesses from an environmental perspective by reducing the need to invest in new equipment and increasing the utilization rate, though it has limited application because it works best in strong linear operations [21]. The context, intervention, mechanism, and outcome (CIMO) framework is used to evaluate and contextualize business processes in order to see how they work and what results are achieved that are most closely aligned with sustainable practices, analyzing collaboration between start-ups to identify two opportunities: the outsourcing of circular activities and the way in which a large business can adopt circular principles without changing its business model entirely [37,38]. Finally, the CVES framework, a proposed circular-thinking framework inspired by nature, is supported by robust economic and social drivers and human management [21].

2.2. COHRV Model: Framework for Circular Economy System

Collaboration is a means for enterprises to contribute to specific activities by strengthening the skills, knowledge, and assets of participating companies through a joint project—in this case, implementing circular economy practices tailored to a specific market and in partnership with policymakers [21,29]. From a systems thinking perspective, the horizontal collaboration model facilitates the development of new value creation by considering new market share, policymakers, and the value proposition.

For a new business model to be created, the entire supply chain, from suppliers through production, distribution, and consumption, must be considered. Innovative projects, such as the one proposed in this article, must be viewed and analyzed as a whole system.

The COHRV model is a framework designed to incentivize horizontal collaboration, aiming to create a competitive advantage for companies participating in such projects. The design is based on a review of the literature on business models, knowledge management, and manufacturing strategies. Drawing on manufacturing strategies, the model is structured around the three sustainable pillars: economic, social, and environmental. It identifies key factors such as (1) common goals, (2) decision-making, (3) communication, (4) shared resources, (5) alignment of incentives, and (6) knowledge transfer [39]. The model was then constructed by applying a multicriteria decision methodology, the CODAS–Hamming–Mahalanobis method, to identify hierarchical horizontal collaboration factors, which present seven final components and the factors with the highest incidence [40]:

1. Knowledge transfer: By collaborating on the same project, tacit or explicit knowledge tends to be transferred between enterprises;
2. Organizational structure: This is a horizontal structure showing which companies are participating in the joint venture;
3. Value proposition: This criterion is determined and established by the participating businesses and varies depending on the proposed project;
4. Incentive: This is stated by the participating enterprises based on the project's value proposition;

5. Content: This group what the activities are by defining firm performance, production flexibility, operational performance, goal alignment, research and development, process performance, value creation, negotiation performance, and waste reduction;
6. Structure: This group how the activities will be linked, working by quality, communication, costs, and market strategy;
7. Governance: This includes who factors, which are determined by the team that will cooperate by confidentiality, business strategy, absorption capacity, trust, leadership, business model identification, commitment, and cooperation.

Figure 3 conceptualizes the COHRV model to encourage the development of collaborative projects among companies at the same level of a supply chain.

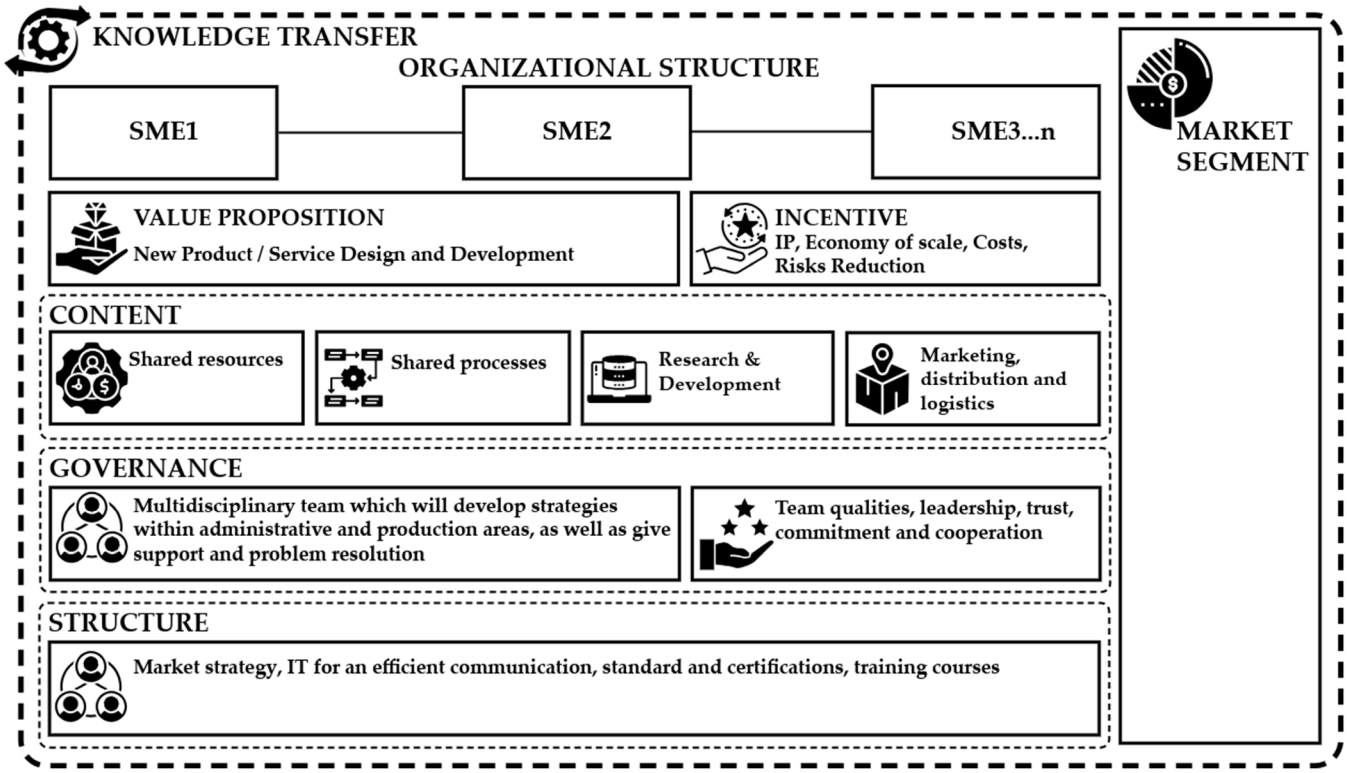


Figure 3. COHRV model to develop horizontal collaboration projects [40,41].

Since this framework proposal, the COHRV model has been applied to small- and mid-sized enterprises in the manufacturing industry, enabling them to participate in sustainable manufacturing ventures [41].

Unlike other proposed models, the COHRV framework incentivizes collaboration among enterprises—specifically those at the same level, or competitors, to form joint ventures regardless of industry, as it is designed to operate in various settings and focuses on fostering innovation in new technologies, processes, or markets. From the literature review of circular economy business models, the COHRV model stands out, as the CEBMs have limited applicability by considering only one enterprise at a time. In other words, each of the models presented—such as CIMO, CVES, and ReSOLVE—has been applied to different projects, but only to a single company per project. Meanwhile, although the COHRV model has only been applied once in the manufacturing industry [41], it has proven capable of accommodating multiple companies participating in the same project. Table 2 presents the circular economy frameworks, the COHRV model, and its general characteristics.

Table 2. Comparative table between CEBM frameworks and the COHRV model.

Framework	Objective	Characteristics	Weakness	Enterprises
ReSOLVE [3,4,21,42]	Six action areas for businesses wanting to move towards the circular economy	Effective under strong linear patterns of operation	Does not include social benefits; further exploration required to facilitate cohesive integration between diverse actors	One per project
CIMO [37,38]	Analysis to identify opportunities between large companies and start-ups: outsourcing circular activities and asking how a large business can adopt circular principles without entirely changing its business model	Context (need or problem), intervention (what will be valued), mechanism (outsourcing, partnership), and outcome (value proposition)	Only provides information for decision-makers to participate in a collaboration between start-ups towards a CE	Six Start-ups
CVES [21]	Model that focus on transforming industrial waste into returns, decoupling economic development to transform linear production into circular value extended systems	Production highlighting social, environmental and economic benefits	Recently applied to a single-use plastic industry	SUP industry
COHRV [40,41]	Encourage horizontal collaboration among companies at the same level in the supply chain to develop or improve processes, technology, or products	Content (what each company will contribute to the project), structure (how will the joint venture will work), governance (who will integrate the multidisciplinary team)	Recently applied in the manufacturing industry	Nine SMEs

2.3. Charcoal Ash Production

The circular economy is important to the food industry for overcoming the production and consumption model that is based on continuous growth. In this industry, a circular nutrient economy offers business owners an opportunity to recover waste materials and reuse them in agricultural production [43]. A system transformation is presented as a two-fold approach: (1) a closed-loop for nutrient materials, cascading materials, or recovering energy from biological waste, incentivizing a redistribution of activities to create new resource flows; and (2) creating regenerative and restorative cycles for agriculture, allowing a rural–urban dynamic to foster a more sustainable cycle between harvesting, planting, production, and organic waste [32,44].

Additionally, ref. [2] presents a framework that serves as a roadmap for monitoring the transition toward a circular economy model. This is achieved through a strategy and an assessment of indicators. To play a decisive role in reducing environmental limits that are exceeded, ref. [43] proposes a three-scale assessment model that focuses on developing strategies at the micro (products, services, businesses, and consumers), meso (eco-industrial parks, supply chains, and industrial symbiosis), and macro (regions, nations, globe) levels. Moreover, ref. [45] presents an evaluation and an overview of the farm to fork strategy and proposes a framework to assess the environmental and energy performance of food systems.

Although previous research has demonstrated growing interest and relevance in waste valorization, especially food waste, there is no evidence of charcoal ash valorization within

a "reuse–reduce–recycle" system. Several approaches have been developed to address charcoal use, including health risk assessment in production [46], charcoal production and its environmental and social challenges [47], and a detailed analysis of the qualitative characteristics and properties of charcoal lumps and briquettes for barbecue [48]. Further, the use of biomass derived from agriculture to produce bio-briquettes and the analysis of their burning index and properties [49] have been examined, and improvements to traditional production systems are proposed to achieve sustainable goals [50].

Globally, charcoal is used as an energy source or for cooking, with production of approximately 53.2 million tons. Its characteristics and low cost make charcoal a dominant energy resource in low-income countries and rural and urban areas [48,50]. In addition, it plays a fundamental role in cooking in both low- and high-income countries due to the flavor and texture it imparts. Production of charcoal has increased, driven by its use as a raw material, from the iron industry to the food industry's barbecue sector and it has established a niche market of internal demand and exports, depending on each country's demand [48]. Research has focused on characterizing the properties of charcoal [48], on the production process and proposals in chemistry and technology to make its production more efficient and environmentally friendly [17,50], and on the health issues caused by charcoal from its production through to its use, whether for industrial purposes or for cooking food [46].

Charcoal ash is produced by the chemical modification of biomass, driven by the temperature rise during pyrolysis. This procedure begins with the pyrolysis of the cellulose and hemicellulose in the raw material, followed by the slow breakdown of lignin, yielding a porous material low in volatiles and rich in carbon [14,51]. Ash content is related to the quality of the raw material and the carbonization process described above, and it directly affects the quality of charcoal-grilled food, with carbon (C) and nitrogen (N) released during the combustion of charcoal-grilled food. Charcoal ash content can range from 0.5 to 5.0% [51] or less than 8% [14], depending on charcoal quality.

Food Trucks: Charcoal Ash Valorization

An analysis presented in [52] provides a list showing the percentage of food organic waste versus the percentage of waste treated and recycled by country. Mexico ranks 86th, with a recycling rate of 5.0% compared with a rate of 52.4% of food organic waste. The relevance of this ranking is evident in its direct impact on the opportunity to incorporate circular economy principles in the food industry, particularly a system-based approach that operates within a collaborative model to create value from charcoal ash generated by food trucks' grilling processes.

Food trucks in the Ciudad Juarez area are well known as street food vendors, and most of these micro-businesses are informal. As described by [14], within a 30 m radius, at least 3 out of 10 restaurants offer charcoal-grilling services, indicating growth in the gastronomic and residential sectors [13,14]. Charcoal enhances food quality and imparts a distinctive aroma and taste, but it also produces ash as a residue. Lump charcoal, commonly used in food truck grilling, has low mechanical resistance, resulting in particles of approximately 10 mm and contributing to fine and ultrafine ash residues. The accumulation of ash residues on the grill during each workday reduces combustion efficiency, and periodic cleaning is needed to prevent incrustation and fouling [17].

The charcoal supply chain lacks information on charcoal ash generation under real-world conditions. From the survey, the authors obtained reliable data on charcoal demand (kg) for charcoal grilling in food trucks. The field study was conducted from May to July 2025 and yielded 143 responses, as mentioned in Section 1. As described by [14], not all restaurants use charcoal for grilling; of the 143 respondents, only 47.55% use charcoal as

fuel for cooking, amounting to 68 micro enterprises. This final sample is used in the present article to create a database of charcoal demand and charcoal ash production from the food truck sector.

The demographic data for the 68-business sample are as follows: 52.94% are food truck owners, 25% are in management, and 22.06% are employees. The age distribution is as follows: 18–23 years old (9 respondents), 24–29 (12), 30–35 (13), 36–41 (5), 42–47 (16), and 48 or older (13). Respondents' education levels are elementary (7), junior high (13), high school (11), bachelor's degree (22), and graduate programs (15).

Based on the number of companies and the survey responses, the average charcoal demand (kg) per weekend was calculated. To do this, two factors were considered: (1) the number of food carts per owner; and (2) the total kilograms of charcoal purchased per weekend. Table 3 shows the results obtained from the survey; the minimum and maximum values were calculated by weight range, and the average amount of charcoal used per weekend per food cart per owner was calculated.

Table 3. 68-business sample and number of charcoal kilograms per weekend.

No. of FTs	No. of Owners	Charcoal kg	Min.	Max.	Average	Total kg
One food cart	8	0 to 5 kg	1	5	3	24
	5	6 to 10 kg	6	10	8	40
	4	11 to 15 kg	11	15	13	52
	6	More than 15 kg	16	20	18	108
Two food carts	3	0 to 5 kg	1	5	6	18
	3	6 to 10 kg	6	10	16	48
	5	11 to 15 kg	11	15	26	130
	5	More than 15 kg	16	20	36	180
Three food carts	6	0 to 5 kg	1	5	9	54
	3	6 to 10 kg	6	10	24	72
	4	11 to 15 kg	11	15	39	156
	4	More than 15 kg	16	20	54	216
Four or more food carts	2	0 to 5 kg	1	5	12	24
	2	6 to 10 kg	6	10	32	64
	5	11 to 15 kg	11	15	52	260
	3	More than 15 kg	16	20	72	216
TOTAL	68					1662

Table 3 shows the demand for charcoal, in kilograms, per weekend (Thursday, Friday, and Saturday), totaling 1662 kg. The micro-businesses survey provides an opportunity to create a database of approximate charcoal usage by food carts. Therefore, it is important to determine how much charcoal ash each food cart generates per weekend and to estimate the value of the waste. As part of the survey, respondents were asked to describe the steps they take when cleaning the grill, how often they clean it, and how and where they dispose of the charcoal ash.

The survey provided information on the culture of disposing of charcoal ash after the grill-cleaning process: 25 respondents clean the grill at the end of the workday, 22 every 2–3 days, and 21 weekly. The way they dispose of the charcoal ash is as follows: 34% collect the ash in a trash bag and place the bag in a trash container, 25% bury it in the garden; 24% throw it in a landfill, 15% place it in sacks for later reuse, and the remaining 3% throw it directly down the drain, as illustrated in Figure 4. Even though charcoal ash is rich in

minerals such as calcium, potassium, and silica [53], its disposal in food trucks is among the activities that do not generate value.

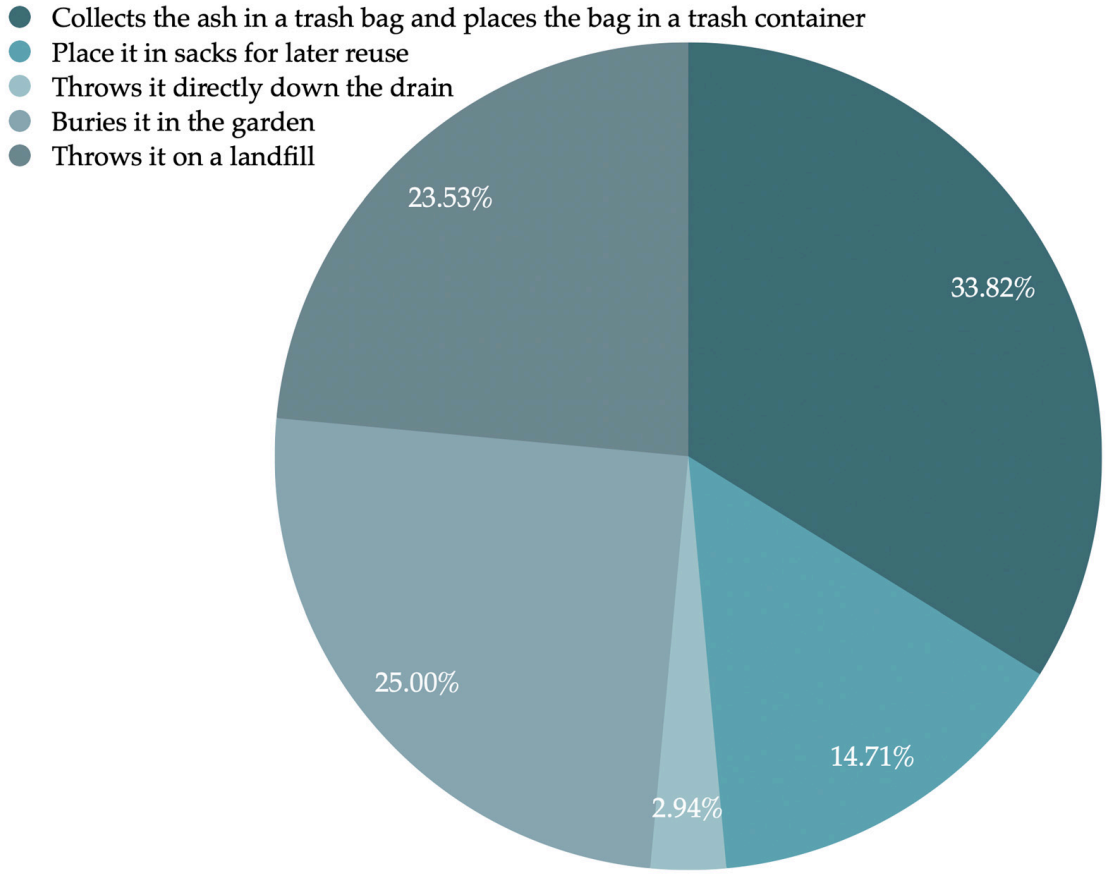


Figure 4. Actions taken by food trucks to dispose of charcoal ash.

3. Research Methodology

This study proposes a COHRV-based approach for charcoal-grill businesses to valorize charcoal ash through a new circular economy business model. As food trucks are micro businesses, they have operational flexibility and can modify certain processes to pursue sustainability. Given their strong presence in the culinary market and their clients' alignment with influencers and social media, their scope can be more effective in creating a culture of circularity.

Charcoal use for grilling has increased in households and restaurants because it enhances the flavor and texture of grilled food. However, charcoal ash production has not been quantified under real-world conditions. To address this gap, the COHRV model is proposed as a framework for food truck enterprises to collaborate and quantify charcoal use for grilling, and therefore charcoal ash production from this process. Figure 5 illustrates the methodology that comprehensively details the development of this study.

3.1. Food Truck Sector in Ciudad Juarez

The database was constructed based on the field survey, as explained in Section 1. The questionnaire consists of 10 questions, divided into 3 sections: (1) Demographic data, (2) charcoal usage habits, and (3) circular economy and collaboration. Table 4 presents the questionnaire structure.

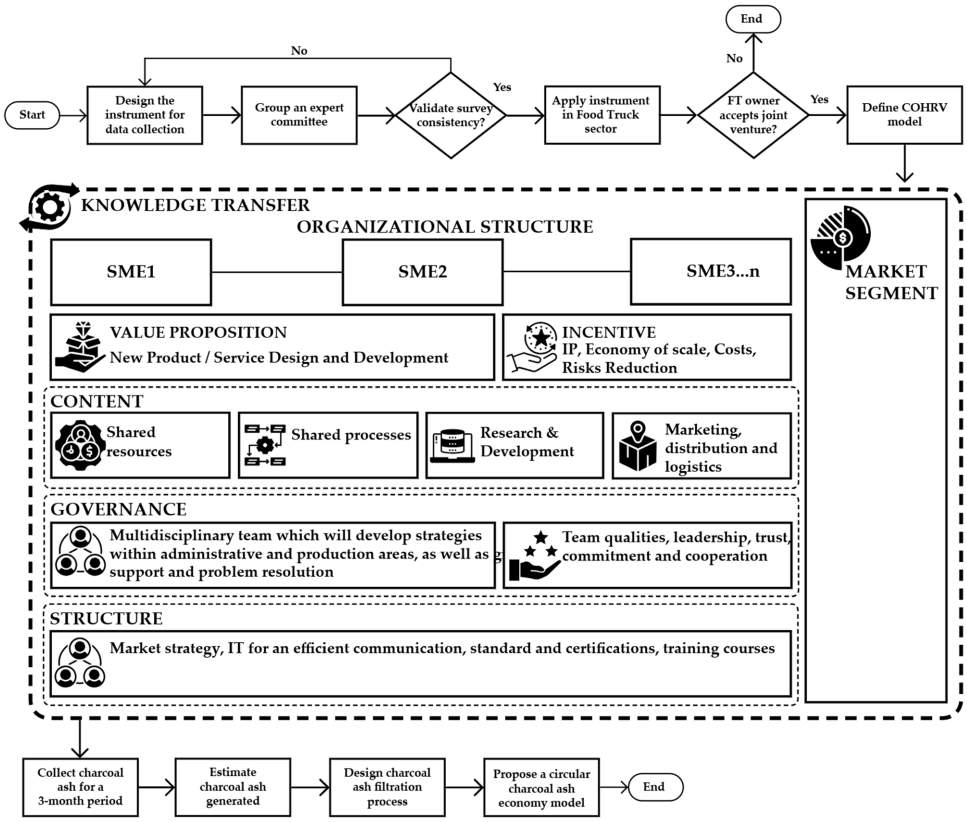


Figure 5. Methodology followed to reach this paper's objective.

Table 4. Sections and questions for data collection.

Section	Question	Options
Demographic data	How long has the food truck been in business?	Range of years from 0 to more than 20 years
	How many locations (food carts) does each owner has?	1 food cart, 2 food carts, 3 food carts, 4 or more food carts
	In which areas of the city is your business located? Select all that apply.	North, east, center, west, southeast, southeast peri-urban
Habits of charcoal usage	Do you use charcoal in the cooking process for your products?	Yes or no
	Approximately how many kilograms of charcoal do you purchase per week?	0 to 5 kgs, 6 to 10 kgs, 11 to 15 kgs, >15 kgs
	The charcoal ash that builds up every time you cook—how often do you remove it from the grill?	At the end of each workday, 2 to 3 days, weekly
	When you remove the charcoal ash, where and how do you dispose of it?	Collect it in a trash bag and place the bag in a trash container; place it in sacks for later reuse; throw it in their own garden; throw it directly down the drain; bury it in the garden; take it to a specific landfill
Circular economy and collaboration	Did you know that charcoal ash can be reused?	Yes or no
	Would you be interested in learning how to reuse charcoal ash waste?	Yes, I do not know, no
	Would you be willing to collaborate with other food truck businesses to collect charcoal ash waste?	I do not know, I have to ask the owner; no, I do not have an interest in participating in the collaboration project; yes, I do have an interest in participating in the collaboration project

To establish the questionnaire's reliability, the instrument's content validity was assessed using the I-CVI and S-CVI. The expert committee consisted of four people with experience in sustainability, multi-criteria decision-making, and project management. The objective was to analyze agreement among raters on whether they understood (1) or did not understand (0) each question [54], yielding a fair agreement of 0.2708 among raters. In the first round, an S-CVI of 0.80 was obtained, with perfect agreement on 6 items. After revising the items, the second round showed improvement, with an S-CVI of 0.975, indicating perfect agreement on 9 items.

The questionnaire was created in Google Forms to make it easier for food truck owners or personnel to complete, leveraging social events in public parks where food trucks are commonly found.

3.2. COHRV Model

The COHRV model was designed to be applied to two or more enterprises collaborating on a project. The 143-business sample served as the basis for a purposive sample selection of enterprises to participate in the horizontal collaboration project. Selection criteria were included in the survey and are as follows: (1) Food trucks that use charcoal as fuel in the cooking process; (2) food trucks that were willing to participate in a collaborative project; and (3) responses received from food truck owners. Considering the first three criteria, a total of 27 enterprises complied. Figure 6 shows the flow diagram for this sample selection.

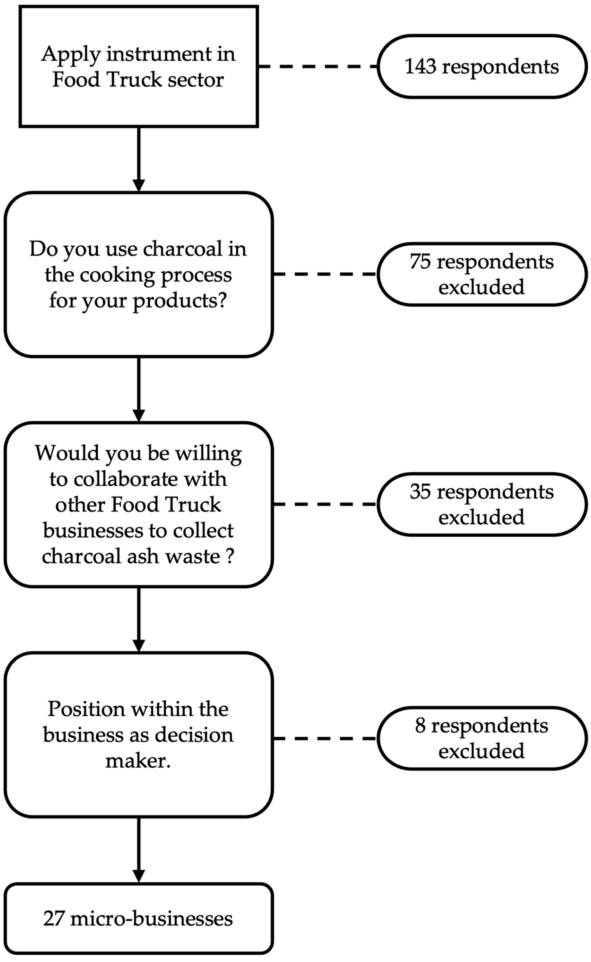


Figure 6. Flow diagram for sample selection for enterprises to participate in a joint venture.

After applying the exclusion filters, the sample population was estimated to include participants in the case study on horizontal collaboration. The statistical formula used to estimate the sample population is $n = \frac{NZ^2pq}{e^2(N-1)+Z^2pq}$, where N represents the population; Z is the confidence level, set at 95% (1.96); p is the probability that the event will occur, set to 0.5 if unknown; q is the probability that the event will not occur (1 − p); and e is the desired margin of error, set to 10%.

Once the participating sample had been identified, work began on defining the framework's structure. A project leader, FT#1, was selected to organize meetings with the other participants to develop and establish each of the COHRV model's guidelines. Figure 7 illustrates the COHRV model's guidelines for the case study, which aims to reach and propose a circular charcoal ash economy model.

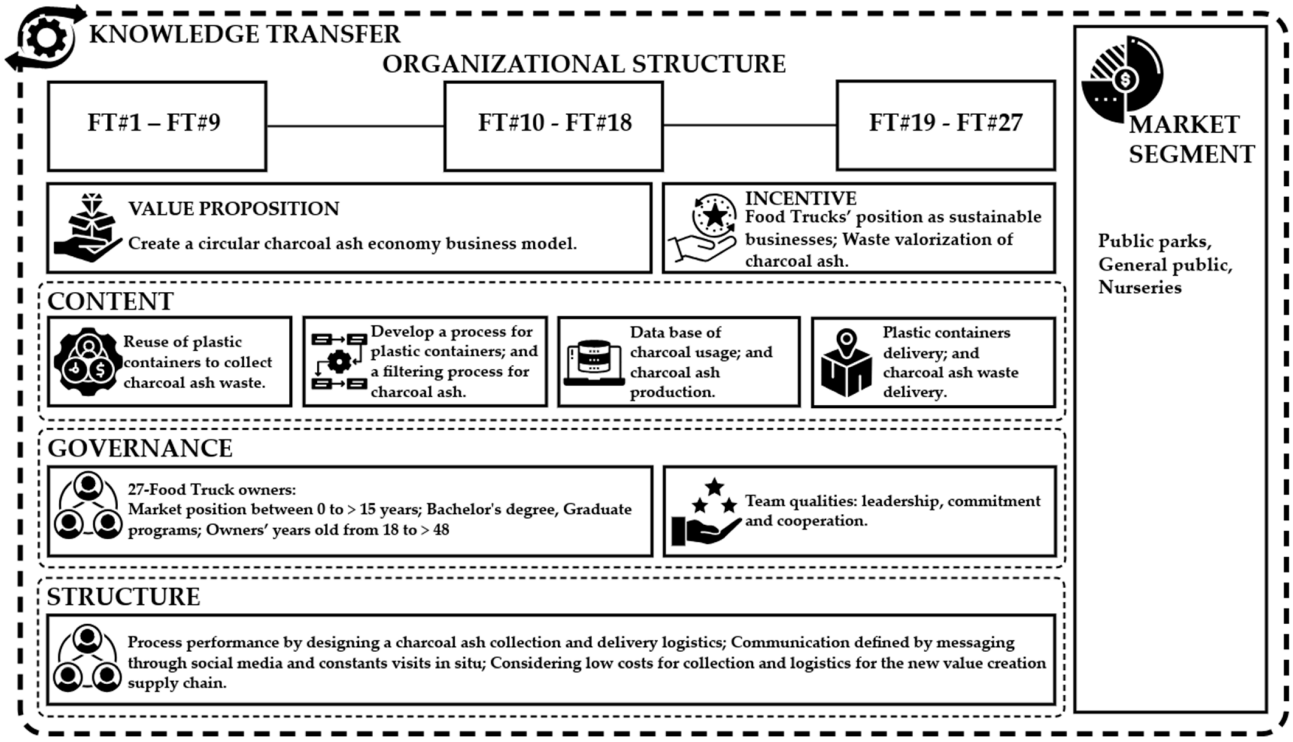


Figure 7. COHRV model guidelines for the horizontal collaboration project to create a circular charcoal ash economy model.

From this point forward, the COHRV model guidelines were established as follows:

- Value Proposition: As micro-businesses, food trucks have the flexibility to engage in new, sustainable projects. The value proposition is built on communication, exchange, and the impact they will gain from the collaboration. The main objective is to challenge the culture of disposing of charcoal ash generated by their cooking process and shift toward more circular thinking. Their business model can be redesigned to deliver value aligned with environmental and social goals, shifting from a linear economy of using and discarding charcoal ash waste to a more circular model that reduces impacts such as clogged pipes and leachate generation in landfills.
- Incentive: The team leader provided an overview of the joint venture's objective: positioning their businesses as sustainable and creating a new circular economy business model by recovering resources and adding value to charcoal ash residues.
- Content: It was agreed that each food truck owner will contribute to the joint venture as follows: (1) each owner will collect their empty plastic containers for reuse in collecting and storing charcoal ashes; (2) each owner will develop a cleaning process

for the plastic containers; (3) they will provide data to create a database of charcoal usage in the grilling process and the production of charcoal ashes per weekend over a three-month period; and (4) they will design a logistics process for delivering plastic containers full of charcoal ashes and a filtering process to clean the charcoal ashes of oil and food residues. Figure 8 presents the detailed flow diagram for the what component.

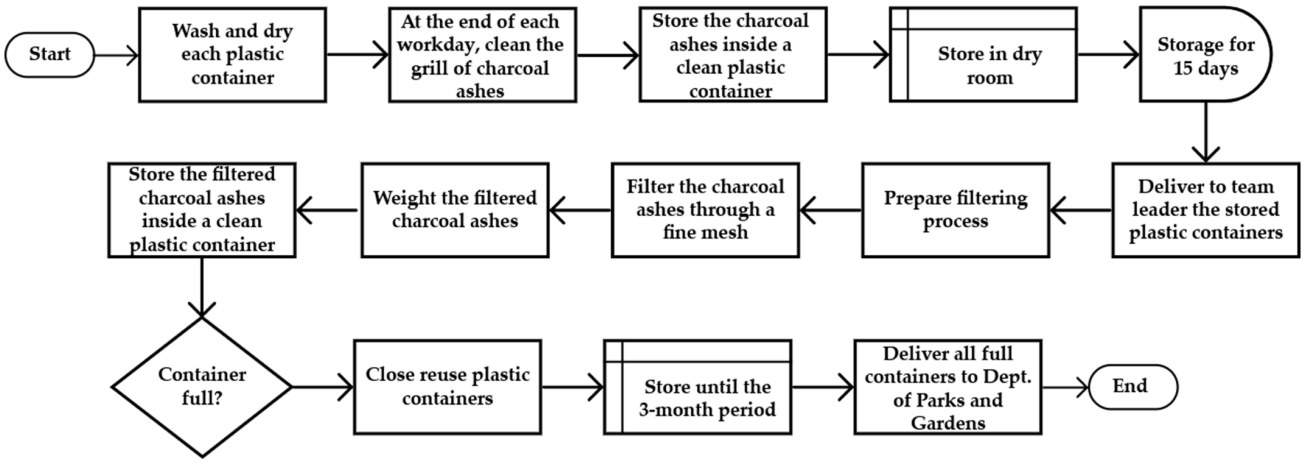


Figure 8. Charcoal ash filtering and storage process as a result of the joint venture.

- Governance: The team, composed of a multidisciplinary group of owners and employees from the 27-business sample, was committed to working together to collect the charcoal ash residues at the end of every workday and deliver them to FT#1 every 15 days. The owners oversaw communication, and their employees were also committed to collecting the charcoal ash and delivering the plastic containers to FT#1.
- Structure: It was agreed that they will maintain communication throughout the collaboration via cellphone calls and social media messaging; in addition, they will establish a low-cost process for collecting and filtering charcoal ashes;
- Market Share: As part of the circular charcoal ash economy model proposal, FT#1 secured participation from the city's parks and gardens department, which will receive the ashes collected during the project for future analysis and characterization to assess possible reuse in public parks, gardens, and nurseries. To achieve this, the authors estimated the quantity of charcoal ash collected over the three-month period and applied the formulas presented in [17] to determine the amounts of combustion ash and unburned material that charcoal can produce during combustion in a grill.

  Combustion ash % (Equation (1)):

$$CB = \frac{m_A}{m_0} * 100, \quad (1)$$

where m_A is the mass of unburned fine material no greater than 2 mm and m_0 is the weight of charcoal before the combustion.

Unburned material % (Equation (2)):

$$UM = \frac{m_{UM}}{m_0} * 100, \quad (2)$$

where m_{UM} is the mass of unburned coarse material greater than 2 mm and m_0 is the weight of charcoal before the combustion.

Knowledge transfer: The participating food truck owners agreed to share specific data within a three-month period. From how many plastic containers they disposed of and how many kilograms of charcoal they used per day on each weekend, to how many plastic containers they disposed of and how much charcoal ash residue they produced.

4. Results

This section presents a detailed view of the case study, enhancing the COHRV model's usability as a tool for incentivizing and developing horizontal collaboration projects. Value can be created by rethinking how waste can be reused within a new business model [25]. The implementation of the COHRV model in this paper enabled micro-businesses to work together in a joint venture to create value from cooking residue—charcoal ash—by analyzing the use of charcoal as fuel for charcoal-grilled food within the food truck sector in Ciudad Juarez, Chihuahua, and by proposing a charcoal ash supply chain for reuse. The horizontal collaboration project achieved three main objectives: (1) a database of charcoal and charcoal ash under real-world conditions; (2) a strategic alliance with the city's department of parks and gardens; and (3) a circular economy business model that considers the environmental, social, and economic impacts of reusing charcoal ash.

4.1. Charcoal Ash Database: Waste Valorization

First, the COHRV model, as a framework for horizontal collaboration projects, was used to develop the charcoal ash joint venture. It is important to note that companies participating in the COHRV model must be decision-makers within their organizations, as they must build trust among their members and make decisions regarding meetings, information sharing, agreements, and other factors. From the food truck sample recovered by a two-month period survey, and following the flow diagram presented in Figure 6, Section 3, a total of 27 micro-enterprises were found eligible. The statistical formula was used to estimate the sample population, with a total of 22 enterprises in the study, presented as a representative pilot collaboration. Nonetheless, information on charcoal use and the production of charcoal ash was collected from the entire population.

Their locations are as follows: three were in the north, five in the east, five in the center, five in the west, four in the southeast, and five in the southeastern peri-urban area. Then, contact was established with each owner to confirm their interest in participating in the joint venture. After the first contact with the 27 entrepreneurs, FT#1 showed the greatest interest in the horizontal collaboration project and proactively engaged the other food truck owners, who agreed to participate.

Eleven of the 27 owners were aware that charcoal ash could be reused; their grill-cleaning routines varied as follows: 11 cleaned the grill at the end of each working day, 6 cleaned it every 2 to 3 days, and 10 cleaned it weekly. Table 5 presents general data for the 27-COHRV sample.

Table 5. 27-COHRV sample general data.

ID	Age	Degree	Years in Business	No of FT	Zone	Kg of Charcoal/Week	How Often Do You Clean the Grill?	Where and How Do You Dispose of Charcoal Ash?
FT#1	18–23	High school	0 to 5	2 units	Southeast peri-urban	6–10 kg	At the end of each workday	Collects it in a trash bag and places it in a trash container
FT#2	42–47	Bachelor's degree	0 to 5	1 unit	Southeast peri-urban	>15 kg	At the end of each workday	Buries it in the garden

Table 5. *Cont.*

ID	Age	Degree	Years in Business	No of FT	Zone	Kg of Charcoal/Week	How Often Do You Clean the Grill?	Where and How Do You Dispose of Charcoal Ash?
FT#3	48+	Graduate program	0 to 5	1 unit	Southeast peri-urban	6–10 kg	At the end of each workday	Throws it on a landfill
FT#4	24–29	Bachelor's degree	0 to 5	2 units	Center	>15 kg	At the end of each workday	Collects it in a trash bag and places it in a trash container
FT#5	30–35	High school	0 to 5	1 unit	East	>15 kg	At the end of each workday	Buries it in the garden
FT#6	24–29	Junior high	6 to 10	4+ units	East	0–5 kg	At the end of each workday	Place it in sacks for later reuse
FT#7	42–47	Bachelor's degree	>15	1 unit	Southeast peri-urban	>15 kg	At the end of each workday	Buries it in the garden
FT#8	36–41	Elementary	0 to 5	2 units	Southeast peri-urban	0–5 kg	At the end of each workday	Collects it in a trash bag and places it in a trash container
FT#9	30–35	Bachelor's degree	0 to 5	1 unit	West	0–5 kg	At the end of each workday	Collects it in a trash bag and places it in a trash container
FT#10	42–47	Graduate program	11 to 15	1 unit	Southeast	11–15 kg	At the end of each workday	Collects it in a trash bag and places it in a trash container
FT#11	48+	Junior high	6 to 10	1 unit	Southeast	11–15 kg	At the end of each workday	Buries it in the garden
FT#12	30–35	Elementary	11 to 15	2 units	Center	11–15 kg	2 to 3 days	Place it in sacks for later reuse
FT#13	30–35	Bachelor's degree	0 to 5	1 unit	East	0–5 kg	2 to 3 days	Collects it in a trash bag and places it in a trash container
FT#14	30–35	Bachelor's degree	6 to 10	4+ units	West	6–10 kg	2 to 3 days	Throws it directly down the drain
FT#15	48+	Graduate program	11 to 15	3 units	West	6–10 kg	2 to 3 days	Throws it on a landfill
FT#16	42–47	Bachelor's degree	6 to 10	4+ units	West	11–15 kg	2 to 3 days	Collects it in a trash bag and places it in a trash container
FT#17	48+	High school	6 to 10	3 units	Southeast	0–5 kg	2 to 3 days	Place it in sacks for later reuse
FT#18	48+	Bachelor's degree	11 to 15	4+ units	Center	11–15 kg	Weekly	Collects it in a trash bag and places it in a trash container
FT#19	42–47	Bachelor's degree	0 to 5	4+ units	Center	0–5 kg	Weekly	Collects it in a trash bag and places it in a trash container
FT#20	48+	Graduate program	>15	3 units	Center	>15 kg	Weekly	Throws it on a landfill
FT#21	42–47	Junior high	0 to 5	2 units	North	11–15 kg	Weekly	Place it in sacks for later reuse
FT#22	24–29	Junior high	11 to 15	4+ units	North	11–15 kg	Weekly	Place it in sacks for later reuse
FT#23	48+	Graduate program	6 to 10	3 units	North	0–5 kg	Weekly	Throws it on a landfill
FT#24	36–41	Bachelor's degree	11 to 15	4+ units	East	11–15 kg	Weekly	Throws it on a landfill

Table 5. *Cont.*

ID	Age	Degree	Years in Business	No of FT	Zone	Kg of Charcoal/Week	How Often Do You Clean the Grill?	Where and How Do You Dispose of Charcoal Ash?
FT#25	48+	Bachelor's degree	11 to 15	3 units	East	6–10 kg	Weekly	Buries it in the garden
FT#26	42–47	Elementary	6 to 10	1 unit	West	6–10 kg	Weekly	Throws it on a landfill
FT#27	30–35	High school	>15	4+ units	Southeast	>15 kg	Weekly	Collects it in a trash bag and places it in a trash container

Next, the COHRV model was established by specifying each module and its guidelines. The horizontal collaboration project was to be developed within a three-month period, from August to October 2025, during which data were collected for further analysis. This was achieved by maintaining constant communication among the 27 food truck owners and keeping a log of the charcoal bags purchased on each working day. A working day was defined as being either Thursday, Friday, or Saturday. Table 6 summarizes the information obtained from the joint venture, showing the kilograms of charcoal used per weekend from one food cart per owner.

Table 6. Charcoal kilograms database from 27 samples over a three-month period.

Month	Week	Charcoal kg	Charcoal Ash kg
August	Week 32	513	182.12
August	Week 33	486	172.53
August	Week 34	513	182.12
August	Week 35	513	182.12
August	Week 36	621	220.46
September	Week 37	486	172.53
September	Week 38	567	201.29
September	Week 39	486	172.53
September	Week 40	513	182.12
October	Week 41	486	172.53
October	Week 42	486	172.53
October	Week 43	486	172.53
October	Week 44	540	191.70
October	Week 45	378	134.19
	TOTAL	7074	2511.27

As shown in Table 6, the quantity of charcoal purchased per weekend was derived from the 27-COHRV sample. This differs from the information presented in Section 2, where an approximate calculation was made based on the minimum and maximum values within the range of kilograms reported by the survey sample.

The collected data were submitted daily; that is, each food truck owner kept a log of the kilograms of charcoal used per day, considering only one food cart per owner. An average of 2358 kg of charcoal is used per month, and an average of 837.90 kg of charcoal ash is produced. Figure 9 represents the demand for charcoal and the production of charcoal ash as a residue from the combustion process in the grills.

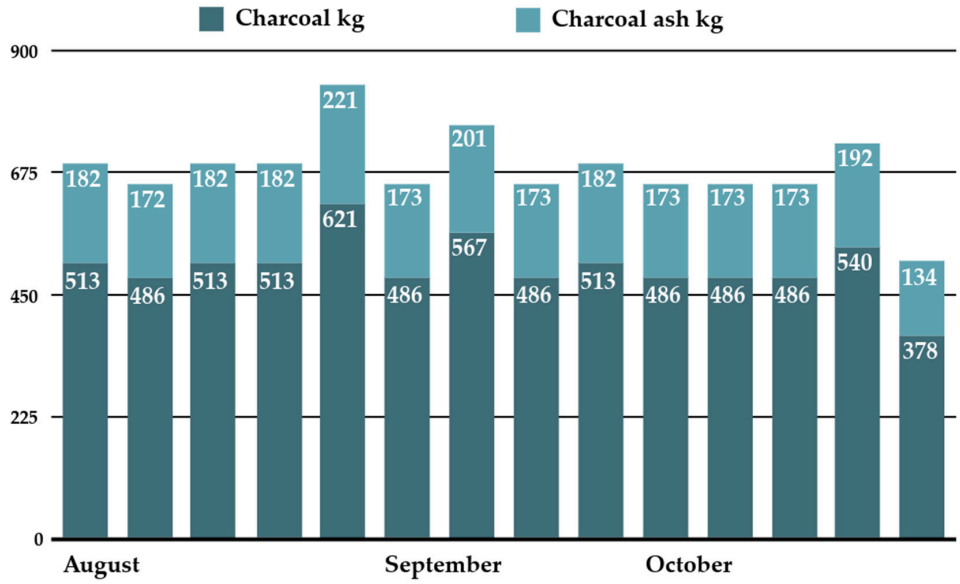


Figure 9. Charcoal demand (kg) and charcoal ash residue per weekend and per month.

Then, to continue with the COHRV model structure, food truck owners now handle logistics for collecting charcoal ash, as shown in Figure 9. To do this, each food truck purchases raw materials such as ketchup, mayonnaise, mustard, and pickles in 3.5 kg plastic containers. The owners agreed to recycle the plastic containers to store the charcoal ash collected at the end of each working day. It should be noted that the decision to recycle them stems from how frequently they are purchased as seasonings for the final product, and that each plastic container is discarded every 15 days.

For this reason, the 27-COHRV sample decided to reuse the plastic containers to store the charcoal ash collected from each grill. Once the ash is filtered, it is again stored in the plastic containers. To avoid contaminating the collected ash, a cleaning process is necessary [48,50]. Each container is washed with soap and water, rinsed thoroughly, and then dried. Moreover, a logistics process was designed and accepted by the micro-enterprises, under which charcoal ash will be collected as part of their grill-cleaning activities. Every 15 days, each food truck will deliver the plastic containers with the collected charcoal ash, as presented in Figure 8, Section 3.

From this point on, the charcoal ash database and valorization were established. The process involved collecting charcoal ash from each grill, sifting it through a fine-mesh filter to remove food and oil residues, as mentioned by [17], and storing the filtered ash in plastic containers. According to [14,47,48], each lump of charcoal can contain between 8% and 10% ash, depending on the wood's origin and tree species. Figure 10 shows the process used to filter and weigh charcoal ash after combustion and after filtering.

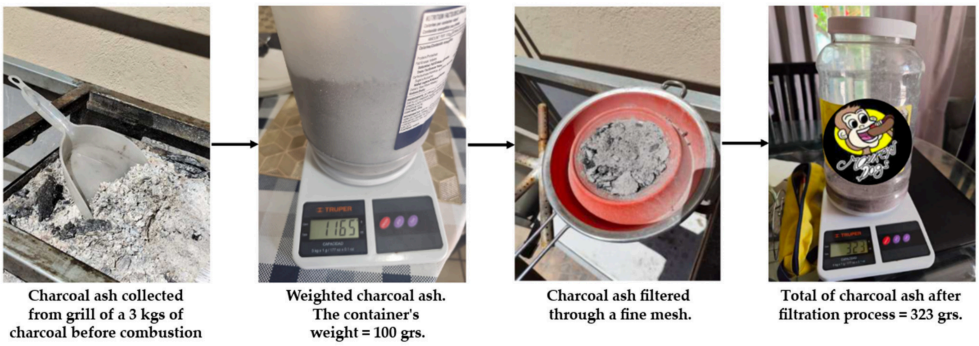


Figure 10. Process for charcoal ash residues from food trucks. Photo credit researcher (2025).

Figure 10 illustrates the new design process for the horizontal collaboration project for collecting, filtering and storing the charcoal ash. As shown in the second photo, the weight is 1165 kg. Each plastic container weighs approximately 100 g, so the total weight of the ash collected from the grill is 1.065 kg. The charcoal ash is then filtered through a fine mesh to remove food and oil lumps, as well as unburned material greater than 2 mm, so that the remaining residue can be stored with the charcoal residue, and clean charcoal ash can be delivered for possible reuse. The next step was to estimate the charcoal ash as the resulting material with less than 2 cm, known as combustion ash. These results were obtained by implementing the equations presented in [17] to calculate combustion ash and unburned material. However, this article presents data collected under real-world conditions and does not account for the volatility of different types of charcoal or the temperatures generated by each grill. Only the weight of the charcoal ash before and after filtration was measured to confirm the percentage of ash and unburned material mentioned in [17], as shown in Table 7.

Table 7. Charcoal ash production from a three-month period and its characteristics.

Month	Week	Charcoal Ash Characteristics [1]					
		m_0	m_f	m_A	m_{UM}	CB	UM
August	Week 32	513	182.12	41.99	140.13	8.18%	27.32%
August	Week 33	486	172.53	42.07	130.46	8.66%	26.84%
August	Week 34	513	182.12	44.51	137.61	8.68%	26.82%
August	Week 35	513	182.12	48.47	133.65	9.45%	26.05%
August	Week 36	621	220.46	56.22	164.23	9.05%	26.45%
September	Week 37	486	172.53	41.64	130.89	8.57%	26.93%
September	Week 38	567	201.29	52.61	148.67	9.28%	26.22%
September	Week 39	486	172.53	43.16	129.37	8.88%	26.62%
September	Week 40	513	182.12	42.60	139.52	8.30%	27.20%
October	Week 41	486	172.53	47.65	124.88	9.80%	25.70%
October	Week 42	486	172.53	42.35	130.19	8.71%	26.79%
October	Week 43	486	172.53	42.39	130.14	8.72%	26.78%
October	Week 44	540	191.70	45.53	146.17	8.43%	27.07%
October	Week 45	378	134.19	31.42	102.77	8.31%	27.19%

[1] m_0: weight sample before combustion; m_f: weight sample after combustion; m_A: mass of unburned material <2 mm; m_{UM}: mass of unburned material >2 mm; CB: combustion ash %; UM: unburned material %.

The literature indicates that charcoal and its quality depend on various factors, including the carbonization process, technology, temperature, and tree species. These characteristics can have positive or negative effects on charcoal as a fuel or energy resource. Specifically, in the food industry, and especially in food trucks, charcoal-grilled food is a competitive advantage for market position.

As a result of this horizontal collaboration project, information on charcoal use as a raw material and as fuel for the food truck sector has been identified and quantified. Moreover, charcoal ash production has been quantified from a log of a three-month period for the 27-micro-enterprise sample.

As described in [6], the percentage of charcoal ash depends on its origin and the type of tree used in the carbonization process. The combustion ash content in Central and North America averages 8–8.4% [7]. As shown in Table 7, the sample obtained under real-world conditions shows a percentage ranging from 8.18% to 9.80%, still below the average reported for the study sample, which was 17.6%.

4.2. Circular Charcoal Ash Economy Business Model

As the horizontal collaboration project advanced from the COHRV model's conceptualization through database construction and logistics design, the final action was to secure a market share for this new value creation from charcoal ash. FT#1 met with the municipal department of parks and gardens and formed a strategic alliance to deliver the stored charcoal ash for analysis and future reuse. Figure 11 illustrates the linear production moving toward a more circular outcome.

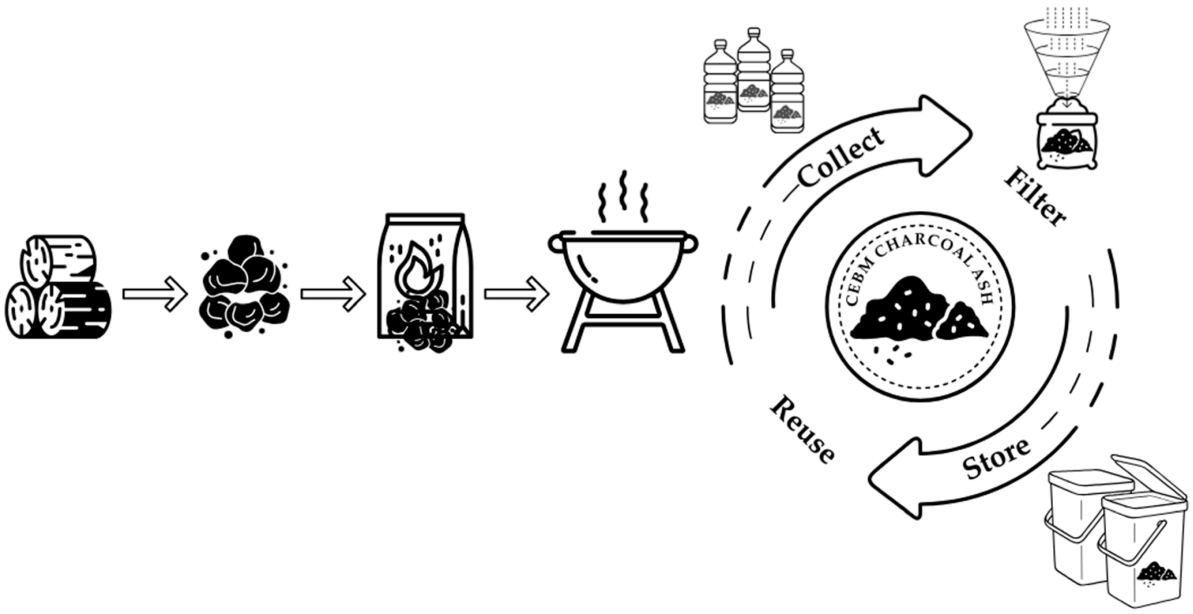


Figure 11. Propose a circular economy business model for charcoal ash.

Waste valorization has gained interest since 2022, with the main objective of exploring the reuse or recycling of waste materials, such as charcoal ash. Moreover, charcoal, as a cooking fuel, has gained interest in the food industry, particularly in the food truck sector, which is one of the supply chain levels that demand charcoal for grilling. As described by [4], the food truck sector will grow by 2027, and, as noted by [13,14], 3 out of 10 restaurants in the food industry use charcoal as fuel for cooking. These data, along with the 68-food truck sample conducted in Ciudad Juárez, Chihuahua, which represents 47.55% of food trucks confirmed to use charcoal as fuel for their cooking process, highlight the need to design and propose a circular economy business model to prevent and reduce the improper disposal of charcoal ash produced in this industry and to enable the reuse of this waste.

5. Discussion

This section highlights previous studies and the present paper's findings, which are significant for entrepreneurs and researchers. The main goal is to raise awareness of charcoal use and the production of charcoal ash in the food industry, and to identify potential solutions to environmental issues arising from disposal practices. To achieve this, the authors identify a gap in the literature review regarding the quantity of charcoal used as fuel in the grilling process and, moreover, the quantity of charcoal ash residue produced by combustion. The section also includes a CEBM proposal based on a horizontal collaboration project conducted over a three-month period with 27 food truck owners.

From a collaboration perspective, efficiency can be enhanced and a competitive advantage achieved within businesses in the food industry [55]. Horizontal collaboration has gained interest, especially in logistics management, and focuses on three levels: strategic,

tactical, and operational [39,55]. Nonetheless, one of the challenges of any horizontal collaboration is planning and specifying certain variables, such as building strong relationships with partners, aligning interests, and investing in communication to adopt a circular economy [56]. In this paper, the authors present how collaboration enhances social, environmental, and economic sustainability. They emphasize the importance of developing horizontal collaboration projects among companies in the same industry, with the goal of creating new business models that add value to waste and proposing new circular economy business models.

For the COHRV model application, enterprises willing to participate in a horizontal collaboration model must be identified. A two-month survey of 143 food truck microenterprises was conducted, and an exclusion filter was applied, resulting in a sample of 68 food trucks that confirmed the use of charcoal as their competitive advantage due to their charcoal-grilled food. From this list, a second exclusion filter was applied to identify businesses willing to participate in a joint venture. Finally, this process yielded a 27-COHRV sample of food truck owners who, as decision-makers, committed to collaborating on the charcoal ash project.

Next, the COHRV model's guidelines were defined, including who would participate in the project, how the work would be carried out, and what specific tasks would be performed. As a result, a three-month period was established to develop and carry out this horizontal collaboration project, from August to October 2025. Finally, a strategic alliance was achieved by incorporating the parks and gardens department of Ciudad Juarez, making it a new recipient of the collected charcoal ashes for future research and characterization of the filtered residues for a new reuse process.

As described in [57], circular business model strategies can create opportunities to develop and commercialize new products that increase the reuse of biowaste, in this case, charcoal ash, thereby adding waste valorization to their competitive strategy. The proposed circular charcoal ash economy business model shifts production from a take–make–dispose model to a cycling model through reuse, as illustrated in Figure 11.

The results from the 27-COHRV food truck sample underscore the importance of the present paper, as it quantifies, under real-world conditions, the amount of charcoal used as fuel in the food truck sector and, at the same time, the amount of charcoal ash produced by combustion from each grill. From a sustainable perspective, the study addresses the following aspects:

Social pillar: Food trucks have been in the market and gaining interest since 2020, with an estimated annual growth rate of 6.6%. Charcoal-grilled food offers innovative value through taste and texture, leading to an increase in food trucks that demand charcoal as fuel. This culinary experience aligns with social media customers, presenting an opportunity to balance the creation of a new culture for charcoal ash disposal with its valorization as a new reuse product.

Environmental pillar: Analysis of the food truck sector within the food industry indicates that 47.65% of food trucks use charcoal as fuel for grilling. A five-year business growth projection is derived from the growth rate reported in [3] and the number of food trucks identified in the study. Table 8 shows the projected growth of food trucks in Ciudad Juarez, underscoring the importance of the circular charcoal economy model proposed by the authors, which results from a horizontal collaborative project.

Table 8. Five-year projection in the growth of food trucks.

	2026 [1]	**2027**	**2028**	**2029**	**2030**
Local	72	77	82	88	94

[1] Considering 2025 to have approximately 68 food trucks because of the study.

The results in Table 8 are highly important given the current culture of charcoal ash disposal. As analyzed in the present study, the food truck sector performs six actions, including throwing the ashes into a landfill, collecting them in trash bags and placing them in trash containers, burying them in a garden, and throwing them directly down the drain. These five actions account for 85% of charcoal ash disposal and directly impact the environment, leading to clogged pipes and leachate generation in landfills. Only 15% take a different action, placing the charcoal ashes in a sack for later reuse.

Estimating the amount of charcoal ash, considering the food truck growth rate shown in Table 8, the charcoal ash residue for 68 food trucks is 6272.05 kg at a 6.6% annual growth rate, as presented in Table 9.

Table 9. Five-year projection of charcoal ash residue.

	2025	2026	2027	2028	2029	2030
Food truck's growth	68	72	77	82	88	94
Charcoal ash	6272.05	6686.00	7127.28	7597.68	8099.13	8633.67

Economic pillar: The circular economy business model incentivizes new products and the commercialization of waste valorization. The proposed circular charcoal ash economy business model presents an opportunity for new business creation as a collect–filter–store–deliver enterprise. As shown in Figure 1, six zones were identified as food truck markets, creating an opportunity to install containers in specific zones for the collection of charcoal ash. The new enterprise will then design an industrial filtering process to remove unburned material greater than 2 mm and food and oil residues from grills. Finally, it will store and deliver charcoal ash for proper reuse. As studied by [53], charcoal ash can be reused as a geopolymer for cement production.

The circular economy is being researched and implemented across various industries, providing opportunities to apply new business models that offer infrastructure and guidance to companies as they develop and implement sustainable strategies across the economic, social, and environmental pillars [8,9].

6. Limitations and Future Research Directions

The COHRV model has been applied and validated in the manufacturing industry by [40,41] as a framework for developing and implementing horizontal collaboration projects. The application in the present paper underscores the importance of this framework for involving companies in the same industry—that is, companies that view each other as competitors. A sample of 27 was achieved through a two-month field study that led to a horizontal collaboration project. The COHRV model helps participants visualize what they will share, work on, and collaborate on within the project; how they will connect, communicate, and lead throughout the project timeline; and who will be part of the project's multidisciplinary team. In addition, the model offers a broader view from economic, social, and environmental perspectives, illustrating how a new circular economy business model can create value from waste and propose a new business model for cycling reuse. It contemplates the following perspectives: (1) economic, by involving 27 businesses, the innovation risk is lower because it is shared, and time efficiency and personnel training costs are lower; (2) social, acceptance among personnel is easier as the new process is explained by the team leader, and stakeholder participation is improved through shared resources, time management, and communication; and (3) environmental, the entrepreneurs uphold environmental standards by changing their disposal culture for charcoal ash, preventing it from entering sewers or landfills in plastic bags.

Future research should focus on (1) the proper disposal of charcoal ash; (2) the standardization of the proposed collecting–filtering–storing–delivering process for charcoal ash; (3) the characterization and property analysis of charcoal ash for possible reuse as fertilizer in public parks, gardens, and nurseries. Additionally, the COHRV model has been applied in practice across two sectors, with results implemented by several industry players; therefore, the authors believe that the model could be useful across a wide range of fields. However, it would be advisable to implement additional measures to reinforce this view.

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Abbreviations

The following abbreviations are used in this manuscript:

IMPI	Instituto Mexicano de la Propiedad Industrial
COHRV	Colaboración Horizontal de Recursos y Valor

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