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Integration of Key Bioprocesses in a Biorefinery Model for the Valorization of Pig Manure: A Proposal Based on Bibliometrics

Integración de procesos clave en un modelo de biorrefinería para la valorización de estiércol de cerdo: una propuesta basada en la bibliometría

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ABSTRACT

Biorefineries have emerged as crucial elements in the circular economy, offering a sustainable solution for converting residual biomass into diverse valuable bioproducts by integrating various biotechnological pathways. Despite the challenges posed by the scale of animal waste production, biorefineries have demonstrated their ability to overcome these obstacles and unlock the inherent value of these resources. In this work, a comprehensive bibliometric analysis of specialized literature and patents on the valorization of pig manure was conducted. Among the various techniques, anaerobic digestion (AD) emerged as the most promising method for waste valorization, serving as a platform for biorefinery conceptualization. AD enables the segregation of biorefinery streams and exhibits considerable potential for generating a wide array of subproducts. The relationship between production and environmental indices has been established worldwide. This work proposes a conceptual biorefinery model that incorporates relevant biotechnological routes for the identified bioproducts. These include biogas, hydrogen, electricity, microalgae, bioethanol, volatile fatty acids, organic amendments, biofertilizers, and biodiesel. The limitations and advantages of the most significant processes have been duly considered and included in the model.

Keywords: agro-industrial waste, anaerobic digestion, bibliometric analysis, bioproducts, circular economy.

RESUMEN

Las biorrefinerías han surgido como elementos cruciales en la economía circular al ofrecer una solución sostenible para convertir biomasa residual en diversos bioproductos de valor mediante la integración de distintas rutas biotecnológicas. A pesar de los desafíos que plantea la escala de la producción de residuos animales, las biorrefinerías han demostrado su capacidad para superar estos obstáculos y aprovechar el valor inherente de los recursos. En este trabajo se realizó un análisis bibliométrico integral de la literatura especializada y de patentes sobre la valorización del estiércol porcino. Entre las diversas técnicas, la digestión anaerobia (DA) se destacó como el método más prometedor para la valorización de residuos, al servir como plataforma para la conceptualización de biorrefinerías. La DA permite segregar las corrientes de la biorrefinería y presenta un potencial considerable para la generación de una amplia gama de subproductos. La relación entre los índices de producción y los índices ambientales ha sido establecida a nivel mundial. En este trabajo se propone un modelo conceptual de biorrefinería que incorpora rutas biotecnológicas relevantes para los bioproductos identificados. Estos incluyen biogás, hidrógeno, electricidad, microalgas, bioetanol, ácidos grasos volátiles, enmiendas orgánicas, biofertilizantes y biodiésel. Las limitaciones y ventajas de los procesos más significativos han sido debidamente consideradas e incorporadas en el modelo.

Palabras clave: residuos agroindustriales, digestión anaerobia, análisis bibliométrico, bioproductos, economía circular

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Introduction

The global consumption of animal products—including meat—has significantly increased in recent years, contributing to 30-40% of the world's organic waste and substantially impacting the environment [1]. Among the various types of meat, the consumption of white meats, such as fish, poultry, and pork, has witnessed considerable growth due to factors such as changing dietary preferences, affordability, and availability [2]. However, along with the increased consumption of white meats comes the generation of significant quantities of animal waste, which poses several environmental challenges [3].

Of particular concern are the waste residues generated from pig production: an average of 2.35 kg of manure per animal per day [4]. Considering that between 10 and 20 L of water are consumed per animal per day in pigsties cleaning [5], liquid pig manure production is estimated to be between 6300 and 11 400 million cubic meters worldwide per year. This manure is characterized by a high nitrogen content [6, 7] and the presence of pharmaceutical products such as antibiotics [8]. In 2021, pork production reached 120.4 million tons, being the second most consumed meat in the world, with China as the largest producer (41%), followed by the United States (9.1%). Latin America produced 8.9 million tons of pork (107.84 million heads), representing 7.42% of the world's production [9]. As the human population expands—reaching eight billion people in 2022—the demand for animal protein is expected to increase [10].

Against this backdrop, diversifying value-added products from pig waste is regarded as a strategy to move towards economic and environmental sustainability. Biorefineries have been deemed promising for obtaining a series of bioproducts, with anaerobic digestion (AD) as a strategic process to achieve this objective [11], [12]. The management of animal waste is a critical issue that needs to be addressed in order to mitigate its environmental impact. In this context, the concept of *biorefinery* has emerged as a promising solution for the valorization of organic waste. Biorefineries utilize advanced biological technologies to convert residual biomass into value-added products [13]. By integrating different biotechnological pathways based on the chemical characteristics of the waste [13], they can efficiently extract multiple valuable outputs from a single waste source, optimizing resource utilization and reducing economic and environmental burdens.

AD has emerged as a promising technique for waste valorization, serving as a central process in the proposed biorefinery model. It enables the segregation of biorefinery streams (solid, liquid, and gases), and exhibits significant potential for generating a wide array of subproducts [12, 14]. In this work, to explore the potential of biorefineries for pig waste valorization, we conducted a comprehensive bibliometric analysis of scientific articles, review papers, and patents related to this field.

Bibliometrics is an emerging field that has gained significant importance due to the vast volume of technical and scientific literature that is produced daily around the world [15]. This analysis methodology has been widely recognized by leading journals, which are increasingly incorporating articles based on bibliometric data [16, 17, 18, 19]. Our analysis aimed to identify trends in research and development regarding pig waste valorization, as well as relevant value-added bioproducts. Based on the findings, we developed a conceptual biorefinery model that integrates pertinent biotechnological routes for the identified bioproducts, including biogas, hydrogen, electricity, microalgae, bioethanol, volatile fatty acids, organic amendments, biofertilizers, and biodiesel.

Methodology

Literature search

To identify relevant scientific literature and patents related to pig waste valorization, a systematic search was conducted in the Scopus and Web of Science databases, as well as in the Orbit database for patents, encompassing documents published until March 2023. To refine the search, a set of predefined search terms was established, including various synonyms and combinations of keywords such as "pig," "swine," "hog," "manure," "waste," "dung," "excrement," "droppings," "feces," "poop," "biorefinery," "biofactory," "valorization," "added value," "bioconversion," "biotransformation," "technologies," "processes," "bioprocesses," "integration," "coupling," "pairing," "bioprospecting," and "circular economy." These keywords were combined in equations with Boolean operators (Table S1-S2).

The search of scientific literature in databases was conducted while considering three categories: (i) research articles (ART), (ii) review articles (REV), and (iii) patents. In turn, the search was classified by a set of countries into three categories: (i) United States (US) and China, (ii) Latin America, and (iii) all other countries. This categorization was based on the fact that China and the US are the largest pork producers in the world, while Latin American countries have received fewer resources for research and exhibit lower industrial development [20, 21, 22]. The process for selecting the documents is summarized in Fig. 1.

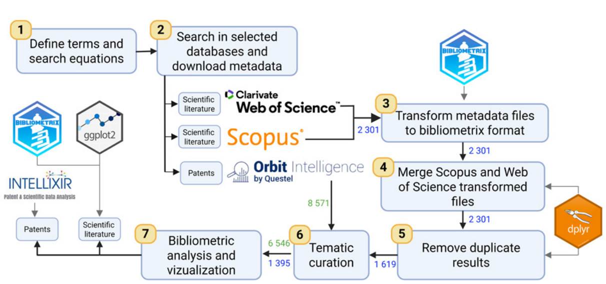

Figure 1. Flow diagram showing the study selection process. 1: Terms and search equations were defined; 2: a literature and patent search

was conducted in selected databases, and metadata were downloaded; 3: literature metadata files were converted to the Bibliometrix format using the *Bibliometrix* package in R; 4: the transformed Scopus and Web of Science files were merged into a single file for each search equation using the *Dplyr* package in R; 5: duplicate results were removed from each merged file using *Dplyr*; 6: manual data curation; 7: visualization of curated data using *Bibliometrix*; 8: data curation and visualization.
Source: Authors

The files obtained from Scopus and Web of Science for each search equation were converted to the Bibliometrix format using the *Bibliometrix* package in R [23]. Subsequently, the transformed files were merged into a single file for each search equation. To ensure data accuracy, duplicate titles were removed, and thematic curation was conducted using R's *dplyr* package [24]. Briefly, in addition to the search equations used in the databases, the articles were further refined through a keyword-based filtering of the titles and abstracts. We excluded any articles that did not include the selected keywords, *i.e.*, "waste," "residue," "biorefinery," "valorization," "bioprospecting," "circular economy," "biotransformation," "bioconversion," "biomass," "renewable energy," "bio-products," "bioprocess," "biodiesel," "fermentation," "biofuels," "effluent," "anaerobic," "pyrolysis," and "manure." Regarding quality assessment, we considered the impact factor of the journals in which the articles were published: 70% of the analyzed articles were published in journals with an impact factor greater than 4.

The curated data were visualized using *Bibliometrix* [23], and the patent search data were processed using Orbit-Intelligence [25]. R's *Ggplot2* package and Orbit-Intelligence were also used for data visualization. After integrating the data, a total of 1290 research articles, 105 reviews, and 6546 patents were obtained.

Relationship between knowledge generation, meat production, and environmental performance

We aimed to examine whether there is a potential relationship between the number of scientific articles and patents produced in a given country (as indicators of knowledge generation related to pig manure treatment), the amount of pork produced, environmental performance indices, and greenhouse gas emissions. A principal component analysis (PCA) was performed to relate knowledge generation to pig meat production [9], nitrous oxide emissions from the pig industry [4], and the environmental performance index (EPI) [26]. The data used for this analysis are presented in Table S3.

Selection and integration of bioprocesses and model data

The literature selected for analysis underwent a comprehensive bibliometric assessment, which involved the examination of co-occurrence visualizations in order to identify key terms associated with bioproducts derived from pig manure. The selected articles were thoroughly analyzed (Table S4), and relevant valorization procedures were extracted from the literature. Based on these findings, a conceptual biorefinery model was developed, encompassing a range of processes that are theoretically compatible with the gaseous (*e.g.*, methane, carbon dioxide), liquid (organic acids, ammonia), and solid (mineral nutrients) products of AD as the central process for the transformation of pig waste. A description of the potentialities, limitations, and main products of each process was used as input to design its integration into the proposed model.

Results and discussion

Global perspective of knowledge production around the valorization of pig wastes

Research articles and reviews. A total of 2301 papers were retrieved from Scopus and Web of Science. After curation, 1395 were analyzed. The US and China displayed the highest scientific production, with 322 and 760 records, respectively, aligning with their positions as the largest pork producers [27]. In Europe, Spain stood out with 208 papers, followed by Italy with 118, while other countries showed similar production levels. Among the Latin American countries, Brazil led with 141 papers, followed by Mexico with 43, and Colombia with 20.

The top authors in global scientific production were Y. Wang (n=27), Z. Zhang (n=22), J. Li (n=19), M. K. Awasthi (n=17), Q. Wang (n=16), Y. Zhang (n=16), Y. Liu (n=15), H. Wang (n=15), Y. Chen (n=14), and R. Li (n=14). These ten authors contributed to a total of 175 publications, with notable affiliations such as the Northwest A&F University (n=99), China Agricultural University (n=73), and the Institute of Environment and Sustainable Development in Agriculture (n=61). These institutions primarily represent China, which leads in scientific knowledge generation and technological production. The most prominent journals in terms of publications were *Bioresource Technology* (n=106), *Waste and Biomass Valorization* (n=68), and *Science of the Total Environment* (n=67). These journals have maintained their excellence since 1970 and are highly regarded within their respective research fields—which is reflected in their Q1 and Q2 rankings—for their quality and prestige.

Patents. A total of 8571 patents were retrieved from Orbit, and, after curation, 6546 were analyzed. China leads the technological output with 1 445 patents, followed by the US with 450. Other notable countries include Canada (n=300), Japan (n=298), and Australia (n=259). Authors such as B. Bruchmann (n=12), A. Eipper (n=12), X. Hu Xinjun (n=8), Q. Lu (n=8), B. Wei (n=8), Z. Yang (n=8), X. Ye (n=8), G. Zhao (n=8), Z. Chen (n=7), and J. Du (n=7) stand out for their contributions to technological production. Peking University of Science and Technology leads in affiliations contributing to the technological output (n=34), followed by Guangdong University of Technology (n=23), BASF (n=21), Pfizer US (n=15), and Zhejiang University (n=15).

Notably, the institutions driving technological output primarily consist of Chinese universities, along with the participation of two companies. In Latin America, Brazil and Mexico exhibit significant patent activity, with 203 and 134 documents, respectively. The number of registered patents serves as an indicator of unique inventions and discoveries, reflecting a country's progress and competitiveness in the scientific and technological sectors [28]. Notably, Latin America shows a higher number of patents compared to its scientific production.

Comparison between the different levels of scientific, conceptual, and technological production

Scientific output is reflected in research articles, conceptual production in review articles, and technological output in patents. The results indicate that, together, the US and China account for 75% of the total research articles. Latin America contributes 9% of research articles and 7% of review articles (Fig. 2b). The number of scientific journals (Fig. 2a) and the number of authors (Fig. 2c) follow a similar trend. These findings suggest limited knowledge generation and proposed developments in Latin America regarding pig waste management under the concept of *biorefineries*, as reflected in the lower number of patents.

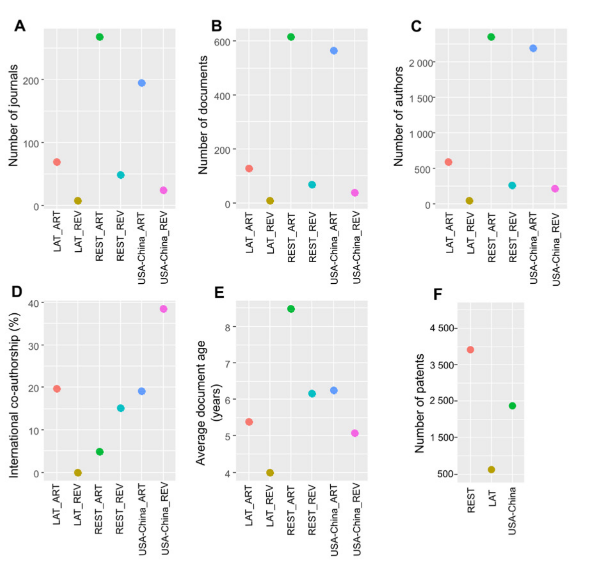

Figure 2. General summary of our bibliometric analysis of scientific and technological literature on the valorization of pig waste. a) Number of journals; b) number of documents; c) number of authors; d) percentage of international co-authorships; e) average age of the document; f) number of patents. LAT: Latin America, ART: research articles, REV: review articles. REST: other countries excluding the US, China, and Latin America. Created with the *Ggplot2* package. Data obtained from the *Bibliometrix* package in R Studio V 2022.02.03.
Source: Authors

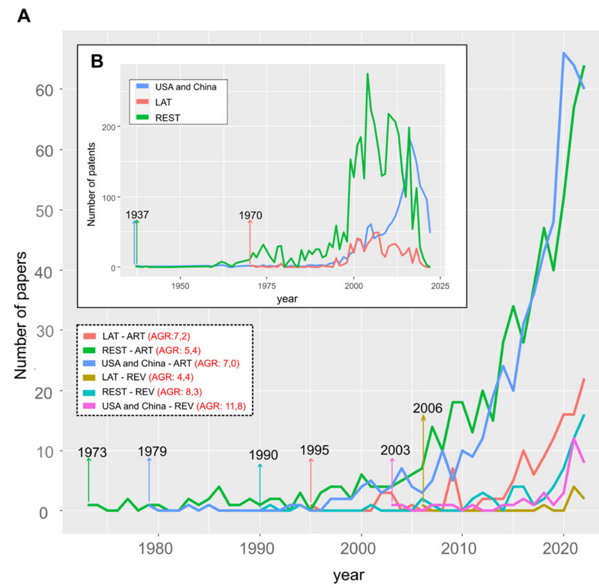

Figure 3. a) Scientific production per year and annual growth rate of research articles and review articles; b) patent production per year. LAT: Latin America, REST: other countries excluding the US, China, and Latin America, AGR: annual growth rate, ART: research articles, REV: review articles. The year in which the first publications/patents appear is indicated with arrows. Created with the *Ggplot2* package based on data from *Bibliometrix* V 2022.02.03.
Source: Authors

The results also indicate that scientific production in Latin America is characterized by a high international collaboration for research articles and a low collaboration for reviews (Fig. 2d), whereas the opposite is observed for scientific production in the rest of the world. This trend can be partly attributed to the limited number of review articles published on the subject (eight articles), most of which are affiliated with one or two institutions located in the same geographic region. Furthermore, these eight articles have the lowest average age (Fig. 2e), indicating that emerging experts in the field have yet to gain international recognition. Regarding technological production in terms of patents, the rest of the countries dominate with 3998 patents, followed by China and the US with 1925, while Latin America exhibits a lower production level.

Fig. 3 illustrates the exponential growth in the number of research papers and reviews worldwide since the early 21st century. Research related to pig waste valorization in Latin America started in 2003, while reports had already been published in other parts of the world since the 1980s (Fig. 3a). However, Latin America shows the highest annual growth rate for research articles (Fig. 3a), indicating a genuine concern in the region to seek and propose sustainable pig waste management, which is steadily increasing.

On the other hand, patents exhibit a different dynamic. In the case of Latin America and the rest of the world, there was a peak in patent production between 2000 and 2008, followed by a decline. The same phenomenon is observed in the US and China, with the difference that their peak in patent production occurred between 2010 and 2020. These differing trends between patent and article production are mainly related to the decision whether to publish or not. In the case of scientific articles, academia alone is involved in this process, whereas, for patents, political and economic actors also play a role [29].

Until 2008, there was an increase in the number of patent filings worldwide (Figure 3b) (except for the US and China). This surge, however, coincided with a continuous decline in the patent yield, defined as the number of first patent filings per unit of constant-dollar business sector R&D expenditure [30]. In other words, although more patents were being filed, the efficiency of patenting—*i.e.*, how many patents were obtained per dollar invested in R&D—was steadily decreasing. This inverse relationship suggests that the global rise in patent filings up to 2008 was not necessarily driven by greater R&D productivity, but rather by other factors such as strategic patenting behavior, legal incentives, or increased R&D spending with diminishing marginal returns. As a result, in more recent years, there has been a noticeable decline in the number of patent publications. This may reflect both the decreasing efficiency of turning R&D investment into patents and a possible shift in innovation strategies. For the USA and China, the same phenomenon was identified; it only occurred a few years later [31].

Relationship between environmental performance and scientific and technological production

EPI scores and nitrous oxide emissions were used as indicators of environmental performance. China, the US, and Brazil are the largest pork producers [9], but only the US have a high EPI score and low nitrous oxide emissions. Despite China's efforts to improve its environmental indices, there was no significant increase in its 2022 EPI score—it was 50.74 in 2018. The same phenomenon was observed in the case of the US, whose EPI score decreased from 71.19 in 2018 to 51.1 in 2022 [26]. Moreover, the results indicate a positive correlation between pork production, knowledge production (articles, reviews, and patents), and nitrous oxide emissions (Fig. 4). European countries, Japan, and Australia show higher EPI scores, evidencing their commitment to environmental sustainability. In contrast, a group of Latin American countries, along with other nations, exhibit lower EPI scores and higher levels of nitrous oxide emissions. This situation calls for an increased focus on scientific and environmental contributions to improve EPI scores and address the environmental challenges associated with pig waste management. Notably, countries such as Guatemala, Haiti, India, and Vietnam report the lowest EPI scores alongside high nitrous oxide emissions and limited knowledge production regarding articles and patents. On the other hand, Canada stands out for its scientific output and patent creation. However, there is still room for improvement in its EPI performance.

These findings emphasize the urgent need for enhanced scientific collaboration and knowledge transfer in Latin America, especially regarding contextual and technological global opportunities. Although the need for collaboration is a global concern, this issue is particularly critical in Latin America due to several underexplored factors, including the fragmentation of regional research networks, limited access to funding and cutting-edge infrastructure, underrepresentation in global datasets, and language barriers that restrict the visibility and transferability of research outcomes. According to our bibliometric analysis, international collaboration networks (Fig. S1) reveal that Latin America remains largely isolated, with few strong ties to the global scientific community. Strengthening international collaboration can facilitate knowledge exchange, foster scientific recognition, and contribute to sustainable pig waste management practices. In parallel, efforts should also be directed towards improving EPI scores and mitigating the environmental impacts associated with pig waste management in the region.

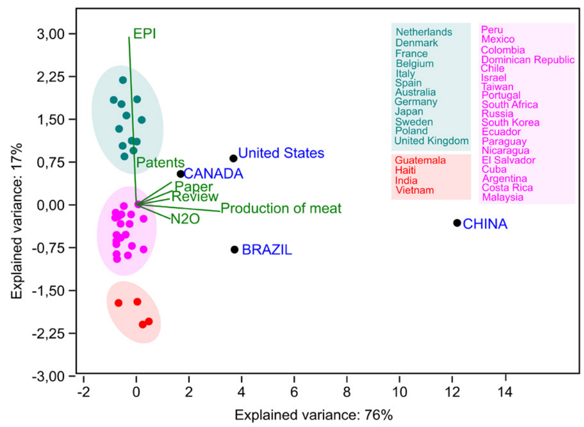

Figure 4. Principal component analysis. Variables: environmental performance index (EPI) (on a scale of 1 to 100), number of articles and reviews, number of patents, nitrous oxide emissions (NO_2 in ktons), meat production (tons). Created with the *Ggplot2* package.
Source: Authors

Identification of key technologies

Our bibliometric analysis enabled the identification of key technologies (Table S4). The identified bioproducts are presented in Fig. 5, including bioenergy (biofuels and energy), gaseous streams (CH_4, H_2, CO_2), solid streams (compost, amendment, fertilizers), nutrients (C, N, P, K, NH_4^+, NO_3^-), algae culture, and volatile fatty acids. Notably, in Latin America, the concepts of *bioenergy* and *gas streams* stand out at the proposal level of reviews, indicating the region's recognition of the potential of this technological approach. However, at the research level, the focus across all three country categories shifts towards the importance of nutrients and gas streams. This shift may be attributed to the increased co-occurrence of terms related to AD (CH_4, CO_2, and H_2) at the research level, where volatile fatty acids (VFAs) are also produced and can be utilized [7]. At the patent level, while the significance of nutrients is still recognized, there is also an increasing proportion of co-occurring terms associated with the solid streams. This suggests a growing emphasis on the invention of systems and processes that harness the mineral components resulting from the bioconversion of pig manure [32, 33].

Fig. 6 presents two clusters of common concepts. The first cluster (blue) is related to the production of biogas and organic amendments from manure, with AD and composting as the transformation processes. The second cluster (red) is linked to the fermentation, bioconversion, and biotransformation of organic waste, including manure, food waste, and wastewater. Interestingly, the process of AD is present in both thematic groups. Notably, the term *biorefinery* did not appear in any of the identified thematic groups. This suggests that the transformation of pig waste under a biorefinery or biofactory approach has not been widely studied—and that was precisely one of the motivations for proposing this conceptual model

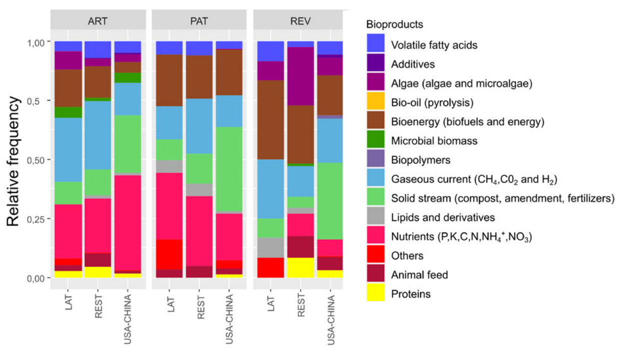

Figure 5. Bioproducts obtainable from pig manure, analyzed in terms of word frequency from data processed with the *Biblioshiny* package. ART: research articles PAT: Patents, REV: review articles, LAT: Latin America, REST: other countries excluding USA, China, and Latin America.
Source: Authors

On a technological scale, biogas and solid digestate as an organic amendment for agricultural soils are the primary bioproducts derived from manure. However, on an experimental and pilot scale, studies have focused on a limited number of bioproducts.

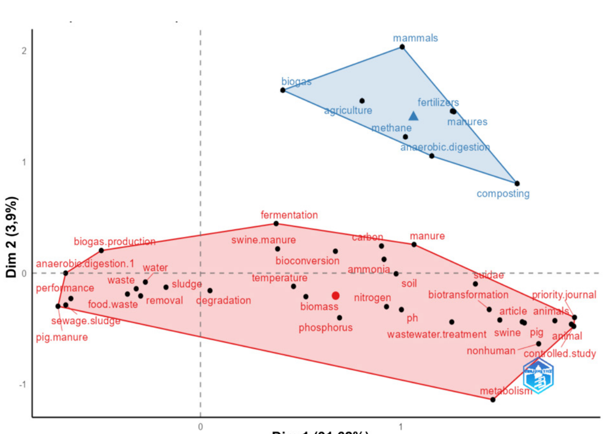

Figure 6. Principal component analysis through the multiple correspondence method. Clusters of common concepts retrieved from scientific documents. Created with *Biblioshiny - Bibliometrix* V 2022.02.03.
Source: Authors

Proposed biorefinery model for pig waste valorization

The development of our biorefinery model for pig waste valorization involved several steps. Firstly, a bibliometric analysis was conducted on the results shown in Fig. 5, which provided insights into the most studied technologies and approaches in the scientific literature. Then, a detailed review of the selected documents was performed in order to gather relevant information about the technologies to be integrated (Table S4). Finally, the research group's expertise in the field contributed to the formulation of the models shown in Figs. 7 and 8.

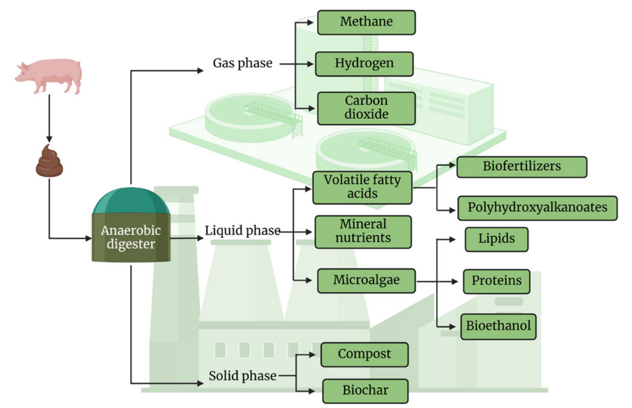

Figure 7. Proposal of a general biorefinery model for pig waste valorization
Source: Authors

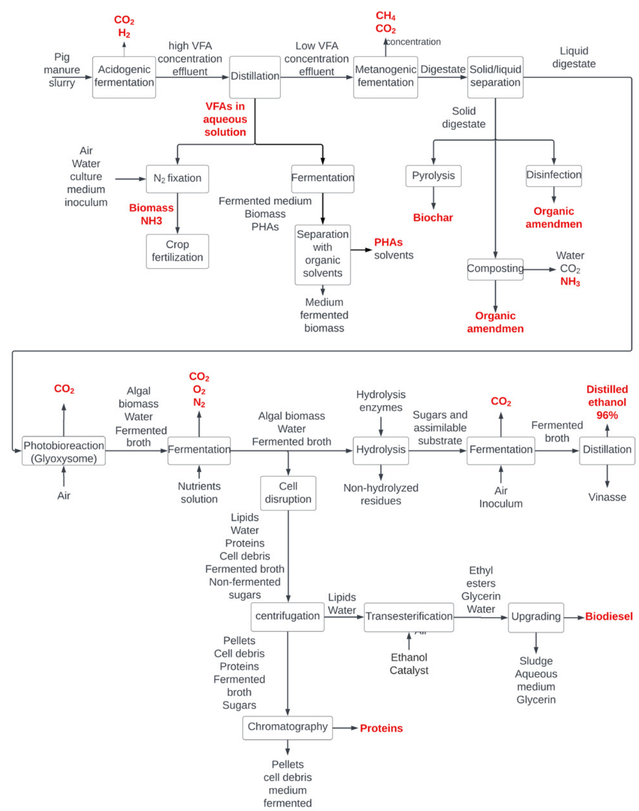

Figure 8. Detailed biorefinery block diagram of our proposal for pig waste valorization
Source: Authors

Different approaches have been explored in the scientific literature for the valorization of pig waste. These include experimental evaluations of ethanol and methane production [34], algae protein and methane production [35], hydrogen and volatile fatty acids generation [36], the use of theoretical models for biogas and nutrient production estimation [37], and lifecycle assessments [38]. Furthermore, at the patent level, integrated processes for pig manure valorization have been developed, focusing on the recovery of biogas and nutrients for use as fertilizer [32, 33]. Despite these advancements, the concept of *biorefinery* as a strategy for pig waste valorization has not yet been widely adopted on a global scale, mainly due to the limitations that need to be overcome in order to ensure the feasibility and sustainability of each subproduct [39].

Fig. 7 presents a general AD-based biorefinery model that groups bioproducts according to each phase of the anaerobic reactor's effluents, as detailed below. The technical information of each bioprocess and its integration within the biorefinery model are shown in a block diagram (Fig. 8). Each bioprocess was selected based on its theoretical potential to effectively utilize the input stream and generate specific bioproducts as the stream passes through the biorefinery's components.

AD is a well-studied technology and has grown significantly as an energy source around the world. According to the European Biogas Association [40], there were 1322 biomethane-producing facilities in Europe as of April 2023, with a growth of 30% compared to 2021. Although AD can process various types of organic waste, their performance often depends on the characteristics of the feedstock, especially the carbon-to-nitrogen (C/N) ratio. High C/N ratios can limit nitrogen availability, reducing the biogas yield, while low ratios may lead to ammonia toxicity, impairing methanogenic activity and carbon utilization [41].

Animal waste is rich in nitrogen, which may require co-digestion with rich-carbon substrates to equilibrate the C/N ratio [36, 42], [43], with additional costs for transportation, or the use of nitrogen separation technologies such as zeolite adsorption [44]. Specifically, the chemical composition of pig manure exhibits nitrogen, phosphorus, and potassium contents above 1% (C/N ranging from 5 to 12.5) [45, 46, 47]. The quantity and quality of pig manure can vary due to the age and physiological maturity of the animal, the intake volume and dietary quality, the volume of water consumed, and the climate [5]. Therefore, it is important to identify the source of the manure in order to estimate its composition and properly design and operate the anaerobic system.

Since pig manure is rich in nitrogen, it promotes ammonia concentration during AD, which inhibits methanogens, delaying the conversion of VFAs into methane and leading to their progressive accumulation [48]. This scenario may be adverse for methane production, but it may also be an opportunity for the valorization of other products present in the liquid and solid streams of AD through other anaerobic system designs. Two-stage AD, for instance, stands out for the possibility of optimizing the production of organic acids, hydrogen, and methane by implementing acidogenic and methanogenic stages in separate bioreactors 49], 49], diversifying the products that can be obtained.

When considering algae production using raw wastewater effluents, some challenges may arise, including the need for pre-treatments to remove organic matter and clarify the effluent to ensure an efficient radiation transfer [50]. Additionally, anaerobic digestate and wastewaters often require dilution to manage mineral salt concentrations that can impact algae growth, and it should be considered that outdoor cultivation systems are affected by seasonal variations (solar radiation, temperature, and precipitation). Harvesting and concentrating microalgal biomass can increase costs and energy consumption, but techniques like screening, separation, and dewatering can improve efficiency [51]. It should be noted that the compounds derived from microalgae cannot be directly used in the human food sector without the necessary approval studies [50], whereas public resistance and strict health regulations may limit their use [51]. However, they hold potential applications in animal feed [53], biodiesel [53], and bioethanol production [54, 55].

An emerging proposal is the use of short-chain or volatile fatty acids as a replacement for low-cost carbon sources in the production of polyhydroxyalkanoates as precursors of biopolymers [56, 57, 60]. VFAs could also be utilized as a carbon source for cultivating nitrogen-fixing microorganisms, since they require high amounts of carbon in their metabolism to fix nitrogen. Recent studies have showcased the use of reactive grade acetate, butyrate, pyruvate, and citrate for the culture of nitrogen-fixing microorganisms [59, 60, 61]. The separation and purification of VFAs are key steps to further valorization processes. However, it has been demonstrated that these represent 60-80% of the production cost [62]. Membrane technologies stand out among the alternatives for VFA recovery [63, 64], but they are still considered to be in the early stages of development [65]. Distillation, a process with greater technological maturity, can also be used for the separation of individual VFAs, but it is an intensive energy consumption process [66] mainly because an anaerobic effluent contains only 3-5% of VFAs, which implies even more energy consumption for their recovery [67]. Additionally, most recovery techniques require the prior acidification of the fermentation effluent, so that the VFAs reach the protonated form and their separation is facilitated [66]. This generates an acidic byproduct that must be considered for further applications (*i.e.*, nitrogen recovery or methanogenic fermentation). The remaining solid fraction from AD can be composted [68] or directly used as a fertilizer, but this requires pathogen elimination and the removal of present pharmaceuticals [69]. Alternative approaches for solid fraction include post-treatment using advanced oxidation processes [70] and biochar obtention through pyrolysis [71].

Recommendations for decision-makers

The proposed biorefinery model aims to valorize pig waste by generating value-added bioproducts, and it could also be replicated for similar types of waste. However, it should be noted that these bioprocesses must also address the proper treatment/disposal of byproducts with lower organic load to avoid environmental risks. Although the biorefinery model is a promising approach to converting waste into valuable products with commercial potential, it is crucial to assess the proposed bioproducts' economic viability as well as their environmental and social impact.

A key aspect in the consolidation of biorefineries is scaling, which faces several critical challenges. First, the technology readiness level (TRL) can vary significantly across different technologies, which may complicate their integration and industrial implementation. Additionally, costs and energy consumption during scale-up must be carefully managed. In this regard, emerging tools such as artificial intelligence (AI) and machine learning (ML) offer promising solutions for process optimization, predictive analytics, and advanced monitoring systems [72].

Although significant progress has been made in the valorization of pig waste, there is still room for improvement, especially in Latin America. Specific challenges have been identified in this region, including the stabilization of the feedstock supply for biorefineries; the need for techno-economic analyses focused on identifying viable technologies and project alternatives; and the inclusion of stakeholder analysis to ensure the long-term success and acceptance of biorefinery initiatives [73].

Furthermore, economic, policy and environmental factors must be taken into account when developing biorefineries [74]. Addressing these factors can promote greater collaboration, enhance knowledge sharing, and encourage the adoption of biorefinery approaches. This, in turn, supports more sustainable pig waste management practices while contributing to environmental preservation and improved resource efficiency.

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CRediT author statement

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Conflicts of interest

The authors declare no conflict of interest.

Access to research data

The datasets generated and/or analyzed during this study are available from the authors upon reasonable request.

Statement on artificial intelligence

The authors did not use artificial intelligence in the preparation of this work and take full responsibility for the content of this publication.

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Table S1. Search equations and number of records of scientific production retrieved from Scopus and Web of Science databases.

Complete search equation for U.S. and Chinese scientific articles	Database	Number of records	Search date
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND (LIMIT-TO (AFFILCOUNTRY,"China") OR LIMIT-TO (AFFILCOUNTRY,"United States")) AND (LIMIT-TO (DOCTYPE,"ar"))	Scopus	4	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND (LIMIT-TO (AFFILCOUNTRY,"China") OR LIMIT-TO (AFFILCOUNTRY,"United States")) AND (LIMIT-TO (DOCTYPE,"ar"))	Scopus	180	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND (LIMIT-TO (AFFILCOUNTRY,"China") OR LIMIT-TO (AFFILCOUNTRY,"United States")) AND (LIMIT-TO (DOCTYPE,"ar"))	Scopus	138	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "China") OR LIMIT-TO (AFFILCOUNTRY , "United States"))	Scopus	41	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND bioprospecting) AND (LIMIT-TO (AFFILCOUNTRY,"China") OR LIMIT-TO (AFFILCOUNTRY,"United States")) AND (LIMIT-TO (DOCTYPE,"ar"))	Scopus	0	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "China") OR LIMIT-TO (AFFILCOUNTRY , "United States"))	Scopus	19	02/03/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND CU=(USA OR PEOPLES R CHINA) AND DT=ARTICLE	WoS	27	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND CU=(USA OR PEOPLES R CHINA) AND DT=ARTICLE	WoS	268	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND CU=(USA OR PEOPLES R CHINA) AND DT=ARTICLE	WoS	72	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND CU=(USA OR PEOPLES R CHINA) AND DT=ARTICLE	WoS	120	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND bioprospecting) AND CU=(USA OR PEOPLES R CHINA) AND DT=ARTICLE	WoS	2	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND CU=(USA OR PEOPLES R CHINA) AND DT=ARTICLE	WoS	26	26/02/2023

Complete search equation for US and China reviews	Database	Number of records	Search date
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND (LIMIT-TO (AFFILCOUNTRY,"China") OR LIMIT-TO (AFFILCOUNTRY,"United States")) AND (LIMIT-TO (DOCTYPE,"re"))	Scopus	2	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND (LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (AFFILCOUNTRY , "United States") OR LIMIT-TO (AFFILCOUNTRY , "China"))	Scopus	7	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND (LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (AFFILCOUNTRY , "China") OR LIMIT-TO (AFFILCOUNTRY , "United States"))	Scopus	3	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND (LIMIT-TO (AFFILCOUNTRY,"United States") OR LIMIT-TO (AFFILCOUNTRY,"China")) AND (LIMIT-TO (DOCTYPE,"re"))	Scopus	2	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND bioprospecting) AND (LIMIT-TO(DOCTYPE, "re") AND (LIMIT-TO (AFFILCOUNTRY , "United States") OR LIMIT-TO (AFFILCOUNTRY , "China"))	Scopus	0	02/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND (LIMIT-TO (AFFILCOUNTRY,"China") OR LIMIT-TO (AFFILCOUNTRY,"United States")) AND (LIMIT-TO (DOCTYPE,"re"))	Scopus	1	02/03/2023

ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND CU=(USA OR PEOPLES R CHINA) AND DT=REVIEW	WoS	5	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND CU=(USA OR PEOPLES R CHINA) AND DT=REVIEW	WoS	16	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND CU=(USA OR PEOPLES R CHINA) AND DT=REVIEW	WoS	6	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND CU=(USA OR PEOPLES R CHINA) AND DT=REVIEW	WoS	7	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND bioprospecting) AND CU=(USA OR PEOPLES R CHINA) AND DT=REVIEW	WoS	0	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND CU=(USA OR PEOPLES R CHINA) AND DT=REVIEW	WoS	9	26/02/2023

Complete search equation for scientific articles from Latin America	**Database**	**Number of records**	**Search date**
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	4	01/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	48	01/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	8	01/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	3	01/03/2023

TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioprospecting)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	0	01/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	22	01/03/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	8	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	63	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	12	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	13	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND bioprospecting) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	0	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	23	26/02/2023

Complete search equation for Latin American reviews	**Database**	**Number of records**	**Search date**
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND (LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	0	01/03/2023

TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND (LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	2	01/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND (LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	2	01/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND (LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	0	01/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioprospecting)) AND (LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	0	01/03/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND (LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (AFFILCOUNTRY , "Brazil") OR LIMIT-TO (AFFILCOUNTRY , "Mexico") OR LIMIT-TO (AFFILCOUNTRY , "Chile") OR LIMIT-TO (AFFILCOUNTRY , "Colombia") OR LIMIT-TO (AFFILCOUNTRY , "Argentina") OR LIMIT-TO (AFFILCOUNTRY , "Peru") OR LIMIT-TO (AFFILCOUNTRY , "Ecuador") OR LIMIT-TO (AFFILCOUNTRY , "Uruguay") OR LIMIT-TO (AFFILCOUNTRY , "Venezuela") OR LIMIT-TO (AFFILCOUNTRY , "Costa Rica") OR LIMIT-TO (AFFILCOUNTRY , "Cuba") OR LIMIT-TO (AFFILCOUNTRY , "Puerto Rico") OR LIMIT-TO (AFFILCOUNTRY , "Guatemala") OR LIMIT-TO (AFFILCOUNTRY , "Bolivia") OR LIMIT-TO (AFFILCOUNTRY , "Panama") OR LIMIT-TO (AFFILCOUNTRY , "Dominican Republic") OR LIMIT-TO (AFFILCOUNTRY , "Paraguay") OR LIMIT-TO (AFFILCOUNTRY , "Nicaragua") OR LIMIT-TO (AFFILCOUNTRY , "Honduras") OR LIMIT-TO (AFFILCOUNTRY , "Haiti") OR LIMIT-TO (AFFILCOUNTRY , "El Salvador"))	Scopus	3	01/03/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	0	26/02/2023

ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	4	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	1	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	1	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND bioprospecting) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	0	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND CU=(ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	4	26/02/2023

Complete search equation for scientific articles from other countries	**Database**	**Number of records**	**Search date**
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (EXCLUDE (AFFILCOUNTRY , "China") OR EXCLUDE (AFFILCOUNTRY , "United States") OR EXCLUDE (AFFILCOUNTRY , "Brazil") OR EXCLUDE (AFFILCOUNTRY , "Mexico") OR EXCLUDE (AFFILCOUNTRY , "Chile") OR EXCLUDE (AFFILCOUNTRY , "Colombia") OR EXCLUDE (AFFILCOUNTRY , "Cuba") OR EXCLUDE (AFFILCOUNTRY , "Argentina") OR EXCLUDE (AFFILCOUNTRY , "Ecuador") OR EXCLUDE (AFFILCOUNTRY , "Uruguay") OR EXCLUDE (AFFILCOUNTRY , "Peru") OR EXCLUDE (AFFILCOUNTRY , "Costa Rica") OR EXCLUDE (AFFILCOUNTRY , "Venezuela") OR EXCLUDE (AFFILCOUNTRY , "Bolivia") OR EXCLUDE (AFFILCOUNTRY , "Dominican Republic") OR EXCLUDE (AFFILCOUNTRY , "Guatemala") OR EXCLUDE (AFFILCOUNTRY , "Puerto Rico") OR EXCLUDE (AFFILCOUNTRY , "Nicaragua") OR EXCLUDE (AFFILCOUNTRY , "Haiti") OR EXCLUDE (AFFILCOUNTRY , "Honduras") OR EXCLUDE (AFFILCOUNTRY , "Panama") OR EXCLUDE (AFFILCOUNTRY , "Paraguay") OR EXCLUDE (AFFILCOUNTRY , "El Salvador"))	Scopus	18	27/02/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"ar"))	Scopus	224	27/02/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"ar"))	Scopus	124	27/02/2023

TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"ar"))	Scopus	44	27/02/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioprospecting)) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"ar"))	Scopus	2	27/02/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"ar"))	Scopus	57	27/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	49	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	285	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	43	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	116	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND bioprospecting) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	1	26/02/2023

ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=ARTICLE	WoS	66	26/02/2023

Complete search equation for scientific articles from other countries	Database	Number of records	Search date
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"re"))	Scopus	3	27/02/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"re"))	Scopus	8	27/02/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"re"))	Scopus	6	27/02/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"re"))	Scopus	7	27/02/2023

TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioprospecting)) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"re"))	Scopus	0	27/02/2023
TITLE-ABS-KEY ((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) AND (EXCLUDE (AFFILCOUNTRY,"China") OR EXCLUDE (AFFILCOUNTRY,"United States") OR EXCLUDE (AFFILCOUNTRY,"Brazil") OR EXCLUDE (AFFILCOUNTRY,"Mexico") OR EXCLUDE (AFFILCOUNTRY,"Chile") OR EXCLUDE (AFFILCOUNTRY,"Colombia") OR EXCLUDE (AFFILCOUNTRY,"Cuba") OR EXCLUDE (AFFILCOUNTRY,"Argentina") OR EXCLUDE (AFFILCOUNTRY,"Ecuador") OR EXCLUDE (AFFILCOUNTRY,"Uruguay") OR EXCLUDE (AFFILCOUNTRY,"Peru") OR EXCLUDE (AFFILCOUNTRY,"Costa Rica") OR EXCLUDE (AFFILCOUNTRY,"Venezuela") OR EXCLUDE (AFFILCOUNTRY,"Bolivia") OR EXCLUDE (AFFILCOUNTRY,"Dominican Republic") OR EXCLUDE (AFFILCOUNTRY,"Guatemala") OR EXCLUDE (AFFILCOUNTRY,"Puerto Rico") OR EXCLUDE (AFFILCOUNTRY,"Nicaragua") OR EXCLUDE (AFFILCOUNTRY,"Haiti") OR EXCLUDE (AFFILCOUNTRY,"Honduras") OR EXCLUDE (AFFILCOUNTRY,"Panama") OR EXCLUDE (AFFILCOUNTRY,"Paraguay") OR EXCLUDE (AFFILCOUNTRY,"El Salvador")) AND (LIMIT-TO (DOCTYPE,"re"))	Scopus	5	27/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory)) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	4	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value))) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	31	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation)) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	5	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing)) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	12	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND bioprospecting) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	0	26/02/2023
ALL=((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy) NOT CU=(USA OR PEOPLES R CHINA OR ARGENTINA OR BOLIVIA OR BRAZIL OR CHILE OR COLOMBIA OR COSTA RICA OR CUBA OR ECUADOR OR EL SALVADOR OR GUATEMALA OR HONDURAS OR MEXICO OR NICARAGUA OR PANAMA OR PARAGUAY OR PERU OR PUERTO RICO OR DOMINICAN REP OR URUGUAY OR VENEZUELA OR HAITI) AND DT=REVIEW	WoS	15	26/02/2023

Table S2. Search equations and number of records of technological production obtained in the Orbit database

Complete search equation for patents	Database	Number of records	Search date
((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (biorefinery OR biofactory))/TI/AB/CLMS/DESC/ODES/OBJ/ADB/ICLM/KEYW/TX	Orbit	59	06/03/2023
((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (valorization OR (added AND value)))/TI/AB/CLMS/DESC/ODES/OBJ/ADB/ICLM/KEYW/TX	Orbit	6115	06/03/2023
((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (bioconversion OR biotransformation))/TI/AB/CLMS/DESC/ODES/OBJ/ADB/ICLM/KEYW/TX	Orbit	599	06/03/2023
((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND (technologies OR processes OR bioprocesses) AND (integration OR coupling OR pairing))/TI/AB/CLMS/DESC/ODES/OBJ/ADB/ICLM/KEYW/TX	Orbit	1256	06/03/2023
((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND bioprospecting)/TI/AB/CLMS/DESC/ODES/OBJ/ADB/ICLM/KEYW/TX	Orbit	8	06/03/2023
((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND circular AND economy)/TI/AB/CLMS/DESC/ODES/OBJ/ADB/ICLM/KEYW/TX	Orbit	534	06/03/2023
((pig OR swine OR hog) AND (manure OR waste OR dung OR excrement OR droppings OR feces OR poop) AND ((anaerobic AND digestion) OR biodigestion OR biomethanation) AND (valorization OR (added AND value)))/TI/AB/CLMS/DESC/ODES/OBJ/ADB/ICLM/KEYW/TX	Orbit	540	06/03/2023

Table S3. Data for the principal components figure.

Countries	Articles	Reviews	Patents	EPI* (scale of 1 to 100)	N_2O (Ktons)	Meat production (Tons)
China	682	46	1445	28.4	317.106	53907071
United States	294	29	480	51.1	2.116	12559966
Brazil	141	3	204	43.6	102.562	4679889
Mexico	41	2	134	45.5	46.857	1763482
Argentina	3	0	59	46.7	1.341	738394
Chile	11	2	31	46.7	0.6766	578095
Colombia	20	1	33	42.2	16.736	495352
Ecuador	1	0	29	46.5	0.2643	185808
Peru	2	0	10	39.8	0.8143	184961
Bolivia	1	0	0	40.1	0.8005	122827
Venezuela	2	0	0	46.4	0.7482	90358
Dominican Republic	0	0	15	42.2	0.13	80224
Paraguay	0	0	0	40.9	0.3325	76812
Costa Rica	8	0	34	37.7	0.0987	69683
Panama	0	0	9	50.5	0.0912	46626
Haití	0	0	0	26.1	0.252	32544
Uruguay	1	0	18	43.6	0.0404	10314
Honduras	0	0	8	36.5	0.1149	9157
El Salvador	0	0	12	40.8	0.0623	6667
Puerto Rico	0	0	0	32.4	0.0126	6059
Cuba	5	0	9	47.5	0.2795	150.47
Guatemala	0	0	14	28	0.7385	38.21
Nicaragua	0	0	4	37.7	0.132	14.46
Germany	60	2	226	66.8	0.7848	5527769
Spain	72	11	146	60.3	0.9873	3555606
Russian	0	3	78	39	12.037	2973928
Vietnam	0	8	80	20.1	16.947	2431000

Israel	0	0	103	48.2	0.0619	2431000
France	47	7	122	62.5	0.4136	2120315
Canada	72	9	300	50	0.3823	1962760
Poland	30	2	72	60	0.561	1864500
Denmark	28	2	99	77.9	0.4031	1593900
Netherlands	18	3	69	60	0.3474	1370890
Italy	102	14	73	57.2	0.2572	1327822
Japan	23	0	300	59.6	0.702	1263599
South Korea	54	2	233	46.9	0.8523	1200000
Belgium	34	1	49	58.2	0.1872	1118330
United Kingdom	15	1	116	62.3	0.155	863000
Taiwán	0	0	64	46.4	0.4241	815257
Austria	6	0	119	66.5	0.0845	527442
Portugal	20	4	42	50.4	0.068	381656
Australia	9	3	259	62.3	0.1265	362192
India	26	12	166	19.3	0.4358	350001
Sweden	6	6	42	72.7	0.0416	236480
South Africa	1	0	89	44.2	0.5549	234463
Malaysia	15	12	50	35	0.1443	217558
Norway	2	0	63	57.6	0.0236	128820
Hong Kong	0	0	69	73.9	0.0123	124730
New Zealand	4	0	69	57.9	0.0131	47771

Table S4. Literature review on technologies to integrate a biorefinery model based on the anaerobic digestion of pig wastes

DOI	Title	Authors (year)	Substrate	Process description	Bioproducts	Production yield	Considerations for integration
https://doi.org/10.1016/j.chemosphere.2023.139098	Natural Ecuadorian zeolite: An effective ammonia adsorbent to enhance methane production from swine waste	Ruiz-Bastidas, R. C., Turnes, G., Palacio, E., & Cadavid-Rodríguez, L. S. (2023)	Pig manure pH: 6.41, TS (% FM): 30.57, VS (% TS): 78.31, TAN (mg L^{-1}): 2535.49, VFAs (mg L^{-1}): 13387.87, Alkalinity (mg L^{-1}): 8401.45, C (% TS): 43.99, H (% TS): 5.89, O (% TS): 27.31, N (% TS): 3.00, S (% TS): 0.50	UASB reactor 0.7 L, was incubated for a week at 37 ± 1 °C to eliminate all easily digestible organic matter before starting the experiment, pH 6.41, TS 8%. Each treatment was run in triplicate. The headspaces of all reactors were flushed with N2 gas to create an anaerobic environment inside the reactors and they were incubated at 37 ± 2 °C with a stirring speed of 60 rpm.	Methane	zeolite dose of 4.0 g L−1 provides the highest methane production and improve biogas quality.	Advantages: natural Ecuadorian zeolite can effectively adsorb ammonia from swine waste during anaerobic digestion, leading to a significant increase in methane production.
https://doi.org/10.3390/pr9081324	Optimization of Hydrolysis-Acidogenesis Phase of Swine Manure for Biogas Production Using Two-Stage Anaerobic Fermentation	Chiu-Yue Lin, Wai Siong Chai, Chyi-How Lay, Chin-Chao Chen, Chun-Yi Lee and Pau Loke Show (2021)	Pig manure COD (mg L^{-1}): 37,934; TS (mg L^{-1}): 28,870; VS (mg L^{-1}): 21,190; NH_3-N (mg L^{-1}): 1,310	Two-stage Anaerobic digestion: Acidogenic phase: continuous operation, OLR 4 g COD/L-d, volume 1L, pH 6.5, temperature 35°C, HRT 1.5 days. Inoculum pretreated ar 90°C, 1h Methanogenic phase: continuous operation, OLR 4 g COD/L-d, volume 2L, pH 7, temperature 35°C, HRT 28.5 days. Inoculum without pretreatment	VFAs and Methane	Methane production rate: 163 mL*g COD rem $^{-1}$ Methane production yield: 38 mL*g SV^{-1} VFAs concentration: 7 g*L^{-1} VFA production increased 22.4% Hydrolysis rate increased 15,3%.	Advantages: the separation in two stages allows to optimize conditions for different products
https://doi.org/10.1016/j.biortech.2022.128140	Revealing mechanism of micro-aeration for enhancing volatile fatty acids production from swine manure.	Qitao Cao, Wanqin Zhang, Tianjing Lian, Shunli Wang, Fubin Yin, Tanlong Zhou, Xiaoman Wei, Hongmin Dong (2022)	Pig manure TS (% FM): 30.7±0.4; VS (% FM): 24.4±0.4; pH: 8.62±0.03; CP (% TS): 22.05±0.23; CF (% TS): 37.04±0.18; C (% TS): 39.3±0.6; N (% TS): 3.4±0.1; C/N ratio: 11.4±0.3	Acidogenic fermentation with micro-aireation. Batch bioreactor, total volume 6.5L, liquid volume 6L, substrate VS 4%, I/S ratio 1/9, initial pH 10, temperature 35°C, micro-aireation 1000 mL O2/L-d. Inoculum preheated at 85°C, 3h.	VFAs	VFAs distribution: Acetic (61,8%), propionic (23,4%) VFA production increased 22.4% Hydrolysis rate increased 15,3%.	Advantages: Microaireation increases VFAs production

https://doi.org/10.3303/CET2292011	Pilot-Scale Assessment of Biohydrogen and Volatile Fatty Acids Production via Dark Fermentation of Residual Biomass	Carol Rangel, Jeisson Sastoque, Juan Calderón, Jeniffer Gracia, Iván Cabeza, Sergio Villamizar, Paola Acevedo (2022)	Pig manure TKN (% FM): 2.07±0.15 TS (% FM): 29±0.3 VS (% FM): 22.92±0.34 Coffee mucilage TKN (% FM): 0.56±0.20 TS (% FM): 19.7±0.5 VS (% FM): 19.19±0.43 Cocoa mucilage TKN (% FM): 0.058±0.050 TS (% FM): 2.1±0.87 VS (% FM): 1.82±0.75	Pilot plant for batch acidogenic fermentation, total volume 5 L, liquid volume 4 L, subtrate VS 10g, I/S ratio 1, pH 5.5, temperature 35°C, stirring 80 rpm, Retention time 11 days. Inoculum preheated at boiling temperature, 30 min.	VFAs and Hydrogen	Hydrogen production yield: 91,85 mL/g SV VFAs concentration: 4952 mg COD/L VS removal eficiency: 84,4%	Advantages: operational conditions increase VFAs production
https://doi.org/10.1016/j.biortech.2021.126173	Effect of mixing ratio and total solids content on temperature-phased anaerobic codigestion of rice straw and pig manure: Biohythane production and microbial structure	Rongzhan Liu, Xiangyu Chen, Ke Zhang, Yunping Han, Yeqi Tong, Juan Wang, Benyi Xiao, Junxin Liu (2022)	Pig manure pH: 7.30±0.22; TS (% FM): 8.21±0.08; VS (% FM): 6.11±0.88; COD (mg g^{-1}): 118.10±2.02; C/N: 10.86 Rice straw TS (% FM): 95.12±0.13; VS (% FM): 80.27±2.45; COD (mg g^{-1}): 988.21±29.00; C/N ratio: 40.82	Co-digestion, rice straw/pig manure ratio: 5/1, TS 6%. Continuous operation, flow 200 mL/d Acidogenic thermophilic reactor, total volume 1 L, liquid volume 0.6L, temperature 55 +/- 1°C, HRT 3 d. Inoculum pretrated with acid. Methanogenic mesophilic reactor, total volume 8 L, liquid volume 5.4 L, temperature 37 +/- 1°C, HRT 27 d. Inoculum without pretreatment.	Hydrogen, VFAs and Methane	Hydrogen production yield: 73,09 +/-3,03 mL/gVS VFAs concentration 1,5 g/L VFA distribution: Acetic (24,26%,) n-Butyric (65,64%) Methane production yield: 235,81+/-9,30 mL/gSV	Advantages: the separation in two stages allows to optimize conditions for different products
https://doi.org/10.1007/s12649-020-01023-3	A Multiproduct Biorefinery Approach for the Production of Hydrogen, Methane and Volatile Fatty Acids from Agricultural Waste	Righetti, Edoardo; Nortilli, Simone; Fatone, Francesco; Frison, Nicola; Bolzonella, David (2020)	Cattle manure TS (kg tFM^{-1}): 80–95; VS (kg tFM^{-1}): 70–73; COD (kgO_2 tFM^{-1}): 44–54; NH_3-N (kgN tFM^{-1}): 1–1.3; TKN (kgN tFM^{-1}): 1.9–3.6; TP (kgN tFM^{-1}): 0.3–0.7 Grass silage TS (kg tFM^{-1}): 350–400; VS (kg tFM^{-1}): 313–360; COD (kgO_2 tFM^{-1}). 312–360; NH_3-N (kgN tFM^{-1}): 0.1–0.2; TKN (kgN tFM^{-1}): 4.7–5.9; TP (kgN tFM^{-1}): 1–2.3	Pilot plant. Fermentation unit: volume 4 m3, feed flow 1m3/day, temperature 35°C, OLR 18 kgCOD/m3-d, HRT 4d Screw-press separation unit separates solid/liquid fraction from fermentation unit. Solid fraction was feeded to an anaerobic digester: temperature 35°C, volume 1 m3, feed flow 0.2 m3/d, OLR 3,6 kg COD/L-d, HRT 25 days. Liquid fraction (0,8 m3/d) was proposed for PHAs production	Hydrogen, VFAs and Methane	Acidogenic fermentation: 1,68 m3 biogas/d, SGP 0,10 m3/kgVS VFA producion yield 0,12 gCOD/gTVS Solid/liquid separation: Solid fraction: 0,2 m3/d Liquid fraction: 0.8 m3/d Methanogenic fermentation: Biogas 15 m3/d, SGP 0.35 m3/kgVS	Advantages: the separation in two stages allows to optimize conditions for different products
https://doi.org/10.1016/j.jclepro.2022.133680	Food waste valorization into bioenergy and bioproducts through a cascade combination of bioprocesses using anaerobic open mixed cultures	Silvia Greses, Elia Tomás-Pejó, Cristina González-Fernández (2022)	Food wastes TCOD (g L^{-1}): 76.4±4.4; TS (g L^{-1}): 54.5±0.3; VS/TS (%): 90.0±0.7; NH_4+N (g L^{-1}): 0.04±0.01; pH: 4.2±0.3	Two-stage Anaerobic digestion Acidogenic fermentation: CSTR, total volume 5L, liquid volume 3L, temperature 55°C, OLR 3 g VS/L-d, HRT 20.1 d, pH 5.5 - 6.0. After reaching steady state, AF effluent was centrigued; liquid phase was used to recover metabolites, and solid phase was sent to Methanogenic fermentation. Methanogenic fermentation: CSTR,, total volume 1.5L, liquid volume 1L, temperature 35°C, OLR 1.5 gCDO/L-d, HRT 20 d.	Hydrogen, VFAs and Methane	Acidogenic fermentation: Hydrogen production yield: 98,8 mL/gCOD fed VFAs concentration: 23,8 g/L, production yield: 0,82 g COD/gVS fed COD removal 4,6%, acidification 83,1%, bioconversion 51,3% Methanogenic fermentation: Methane production yield: 187,8 mL/g COD fed COD removal 54,2%	Advantages: the separation in two stages allows to optimize conditions for different products

https://doi.org/10.1016/j.watres.2015.12.044	Volatile fatty acids (VFAs) production from swine manure through short-term dry anaerobic digestion and its separation from nitrogen and phosphorus resources in the digestate	Weiwei Huang, Wenli Huang, Tian Yuan, Ziwen Zhao, Wei Cai, Zhenya Zhang, Zhongfang Lei, Chuanping Feng (2016)	Pig manure TS (% FM): 37.1±0.2; VS (% TS): 77.6±0.2; TAN (mg gVS^{-1}): 10.6±0.3; TKN (mg gVS^{-1}): 19.3±1.1; VFAs (mgCOD gVS^{-1}): 39.1±1.1; C/N ratio 18.0±0.5; pH 8.6±0.1	Shor-term anaerobic digestion followed by ammonia stripping Anaerobic digestion: cylindrical batch reactor, liquid volume 100 mL, natural pH (8,6), temperature 55˚C, total solids 20%, 8 days Wet ammonia stripping: The bubbling reactor was purged with air (216 mL/min), temperature 55˚C, initial pH 11, 3h.	VFAs and Ammonia	VFAs production yield: 94,4 mg/gVS Ammonia production yield: 20 mg/gVS Phosphorus production yield: 10,6 mg/gTS (58,9% bioavailability) 99,7% ammonia removal	Avantages: VFA concentration in digestate remained stable after 3 hours stripping
https://doi.org/10.1016/j.biortech.2017.11.061	Recovery of mixed volatile fatty acids from anaerobically fermented organic wastes by vapor permeation membrane contactors	Senem Aydin, Hatice Yesil, A. Evren Tugtas (2018)	Digestate from a laboratory-scale CSTR mesophilic anaerobic digester, fed with chicken manure and poppy straw. Acids composition (mg L^{-1}): Acetic: 2,665; Propionic: 1,985; Valeric: 189; Caproic: 4,533.	Vapor permeation membrane contactor Permeate side with 0,5 N NaOH solution. Hydrophobic membrane trioctylamine-filled PTFE (0.2 um), area 19,25 m^2. Continuous recycle flow on feed and permeate solution was 130 L d^{-1}. Temperature 38˚C. Permanent pH adjustement was needed to maintain pH below 4	VFAs recovered from digestate	Recovery rate: 43% for Acetic, 80% for Propionic, 0% for n-Butyric, below 25% for n-Valeric and below 5% for Caproic.	Disadvantages: low recovery possibly due to hig conductivity and high solid content in chicken manure digestate
https://doi.org/10.1680/jenes.18.00005	Model-based optimisation and economic analysis to quantify the viability and profitability of an integrated nutrient and energy recovery treatment train	Vaneeckhaute, C., Remigi, E. U., Tack, F. M. G., Meers, E., Belia, E., & Vanrolleghem, P. A. (2019)	Pig manure Composition based on secondary sources	i) a heating unit to heat up the input streams to the digester, ii) an anaerobic digestion unit producing biogas, iii) a solid-liquid phase separation unit producing an organic fertilizer, iv) a chemical dosing unit in order to adjust the pH and magnesium content for subsequent struvite precipitation, v) a struvite precipitation/crystallization unit, vi) a heating unit to heat up the input stream to the stripping unit, vii) a stripping unit to recover gaseous ammonia, viii) a scrubbing unit to absorb the gaseous ammonia as ammonium sulfate, ix) an acid dosing unit to add sulfuric acid for absorption, x) an air flow that circulates between the stripper and the scrubber. C	New Nutrient Recovery Model (NRM) - nutrients and biogas	Economic analysis Under the optimized conditions and assumptions made, potential financial benefits for a large-scale anaerobic digestion and nutrient recovery project treating 2700 m3/d of pig manure were estimated at US$2.8–6.5/m3 based on net variable cost calculations, or an average of ~$2/(m3 year), equivalent to $40/(t total solid year), over 20 years in the best case when also taking into account capital costs.	Avantages: The potential of the NRM library for optimization of the operational settings of a selected nutrient and energy recovery treatment train was presented by means of a case study for pig manure. An economic analysis indicated that in the best-case scenario a ZeroCost-Biorefinery for nutrient and energy recovery could be constructed
https://doi-org/10.1007/s12649-017-9981-2	The Biorefinery Concept Applied to Bioethanol and Biomethane Production from Manure	Daniela Bona, Alessia Vecchiet, Michela Pin, Flavio Fornasier, Claudio Mondini, Raffaele Guzzon & Silvia Silvestri (2018)	Manure from different animals, diluted to 30-50 g L^{-1}	Four different treatments on each type of manure: control, acid hydrolysis, enzymatic hydrolysis and combined acid and enzymatic hydrolysis. Manure acid hydrolysis was performed in a 500 mL glass bottle by adding 3.5% (w/w) of 96% sulphuric acid	Ethanol and Methane	56.32 mg g−1 ethanol 102.11 Nml g−1 DM of cattle DW, 172.83 Nml g−1 DM of pig DW and 166.62 Nml g−1 DM of poultry DW - biomethane	Avantages: the study increases knowledge about the use of manure in biofuel production, in relation to proper exploitation of organic content, particularly lignocellulosic content, in a biorefinery concept.
https://doi.org/10.1016/j.cep.2009.03.006	Effect of temperature and nitrogen concentration on the growth and lipid content of Nannochloropsis oculata and Chlorella vulgaris for biodiesel production	Attilio Converti, Alessandro A. Casazza, Erika Y. Ortiz, Patrizia Perego, Marco Del Borghi (2009)	Bold's Basal medium	Photobioreactor Batch operation in 2 L - Erlenmeyer flasks, 14 days, artificial light, air (source of CO_2) pumped from environment to flask, temperature 25 ˚C, NaNO3 0,75 g L^{-1}, Inoculum *C. vulgaris*.	Algae lipids	Lipids production rate: 14,37 g/100g dry algae Lipids productivity: 20,44 g/L-d Cellular growth rate 0,14 d-1	Advantages: this study increases knowledge about algae culture, specifically about the response to process factors such as temperature and nitrogen concentration

https://doi.org/10.1016/j.biombioe.2022.106534	Production of microalgae using pilot-scale thin-layer cascade photobioreactors: Effect of water type on biomass composition	Silvia Villaró, Ana Sánchez-Zurano, Martina Ciardi, Francisco Javier Alarcón, Elisa Clagnan, Fabrizio Adani, Ainoa Morillas-España, Carlos Álvarez, Tomás Lafarga (2022)	Diluted pig slurry $N–NH_4+$ (mg L^{-1}): 120.8 ± 6.5; $N–NO_3$- (mg L^{-1}): 9.5 ± 4.5; $P-PO_4^{3-}$ (mg L^{-1}): 21.1 ± 1.3; COD (mg L^{-1}): 415.3 ± 9.8; Turbidity (NTU): 11.6 ± 1.2	Photobioreactor with the microalga *Tetradesmus almeriensis* The optimal light intensity, culture temperature, nitrogen source, and initial nitrogen level were 700 µmol/m 2 s, 35 °C, nitrate, and 6.6 mM, respectively. Aeration with CO2 (2.5%, 0.2 vvm) was used as carbon source	Algae lipids	Lipids concentration: 6.2%	Advantages: It showed potential for use in the food and feed industries, as well as in the development of agricultural products, namely biofertilizers, biostimulants or biopesticides. Disadvantages: the type of water and nutrients used will greatly influence the quality of the biomass produced; For example, if it is produced using wastewater, the microalgae biomass cannot be used for human consumption.
Patent US20060086660	Integrated technology for treatment and valorization of organic waste	Hodgkinson, D. G., Royer, R., & Laganiere, G. (2006)	Animal manure	Integrated technology for treatment	Use of gas, liquid and solid streams	NR	Advantages: utilization of animal waste and use of liquid fraction and solid fraction
Patent US10703683	Facility for treating and recycling animal waste comprising methanisation, cultivation of microalgae and macrophytes, and vermiculture	Guillard, R.-J. (2020)	An animal waste treatment and recycling facility	Comprising a waste methanization unit including treatment of the biogases obtained , a cogeneration unit supplying electricity and heat from the biogases , and a microalgae hydroponic cultivation unit in photobioreactors fed by the liquid phase of the organic waste from the methanization .	Biogas, electricity, heat	NR	Advantages: integration of processes for the production of bioproducts
https://doi.org/10.3389/fsufs.2018.00028	Recovery of Protein Concentrates From Microalgal Biomass Grown in Manure for Fish Feed and Valorization of the By-Products Through Anaerobic Digestion	Hernández, D., Molinuevo-Salces, B., Riaño, B., Larrán-García, A. M., Tomás-Almenar, C., & García-González, M. C (2018)	Pig manure	Microalgae biomass was outdoors using a thin layer photobioreactor with a total working volume of 1,200 L, and a surface of 33 m². The photobioreactor was fed with 10% diluted centrifuged pig manure at a hydraulic retention time of 0.3 days.	Protein	The highest protein recovery was 54.5 ± 3.2%	Advantages: the use of pig manure for fish feed may be a suitable source of proteins for fish feed due to: high protein content, low ash, and high amino acid digestibility
https://doi.org/10.1016/j.algal.2020.101972	Sequential valorisation of microalgae biomass grown in pig manure treatment photobioreactors	Judit Martín Juárez, Jelena Vladic, Silvia Bolado Rodríguez, Senka Vidovic	Pig manure TOC (mg L^{-1}): 17,100; IC (mg L^{-1}): 1,870; TN (mg L^{-1}): 5,500; TP (mg L^{-1}): 54	Photobioreactor - Cell disruption $SC-CO_2$ extraction *Chlorella vulgaris* Fed with centrifuged pig manure. Microalgae-based biomass was extracted with supercritical CO_2 - subcritical water	Protein	Protein concentration in microalgae-based biomass was 44.03% Protein recovery ranged from 67 to 73%	Advantages: It indicates that the extraction method applied does not appreciably break the cell wall when using these conditions and this type of biomass, therefore this product can be used in different ways. Disadvantages: More studies should be carried out on the subject to obtain greater benefits.

https://doi.org/10.1016/j.fuel.2022.125362	Experimental investigation on simultaneous production of bioethanol and biodiesel from macro-algae	Nagarajan Jeyakumar, Anh Tuan Hoang, Sandro Nižetić, Dhinesh Balasubramanian, Sriram Kamaraj, Prakash Lakshmana Pandian, Ranjna Sirohi, Phuoc Quy Phong Nguyen, Xuan Phuong Nguyen (2022)	3rd generation: Cultivation of macroalgae, marine microalgae and cyanobacteria.	Fermentation of macroalgae as *Padina tetrastromatica* and *Sargassum swartzii* (sustrato) con *Saccharomyces cerevisiae* and *Zymomonas Mobilis* Anaerobic fermentation at T=40°C, pH=4.5 and t=72 h, operated in batch mode for ethanol production from macroalgae biomass with previous enzymatic hydrolysis, this step allowed the separation of lipids for biodiesel production.	Ethanol	Ethanol yield with respect to algal biomass was 95.12% and 62.13 ± 1.5% (g/L ethanol/g/L initial sugars) from Padina tetrastromatica with Zymomonas Mobilis and Saccharomyces cerevisiae respectively.	Advantage: Coupling to algae growth bioprocesses, improved economic viability when incorporated into biorefineries, and more than one bioproduct can be obtained. Disadvantage: Not economically viable on its own.
https://doi.org/10.1016/j.biortech.2022.128002	Bioethanol production from microalgae biomass at high-solids loadings	Billriz E. Condor, Mark Daniel G. de Luna, Yu-Han Chang, Jih-Heng Chen, Yoong Kit Leong, Po-Ting Chen, Chun-Yen Chen, Duu-Jong Lee, Jo-Shu Chang (2022)	3rd generation: Cultivation of macroalgae, marine microalgae and cyanobacteria.	Fermentation of *Chlorella vulgaris*(substrate) with *Saccharomyces cerevisiae* and *Zymomonas Mobilis*. Anaerobic fermentation at T=30°C, batch operated for ethanol production from microalgae biomass with acid hydrolysis (H_2SO_4) prior.	Ethanol	The ethanol yield with respect to algal biomass was 18% for *Saccharomyces cerevisiae*, while Zymomonas Mobilis was unable to transform the biomass into ethanol.	Advantage: Use of microalgal biomass resulting from fermentation to generate other bioproducts. Disadvantage: Low yield compared to macroalgae and acid hydrolysis costs.
https://doi.org/10.1007/s00253-016-7576-7	Community proteomics provides functional insight into polyhydroxyalkanoate production by a mixed microbial culture cultivated on fermented dairy manure	Andrea J. Hanson, Nicolás M. Guho, Andrzej J. Paszczynski & Erik R. Abrigos (2016)	<u>Fermented dairy manure liquor</u> COD (g L^{-1}): 10,066; NH_3-N (mg L^{-1}): 1,370; Acids composition (mM): Acetic: 43.2; Propionic: 16.0; n-Butyric 9.7; iso-Butyric: 1.6; n-Valeric 1.8; iso-Valeric: 1.4; Caproic: 0.6	Enrichment of bacteria from cow manure for the production of PHA by means of a reactor operated in SRB. SBR operation, volume 1.8L, temperature 20-26°C, HRT 4 days.	PHAs	0,55 and 1,14 Cmmol PHA Cmmol VFA-1	Advantages: Microbial community of an enriched MMC as part of an ADF-driven, waste-grown, multi-stage PHA production system.
https://doi.org/10.1016/j.biortech.2020.124604	Bio-based conversion of volatile fatty acids from waste streams to polyhydroxyalkanoates using mixed microbial cultures	Mariel Perez-Zabaleta, Merve Atasoy, Kasra Khatami, Elsa Eriksson, Zeynep Cetecioglu (2021)	Raw and distilled VFAs	SBR and fed batch operation, volume 1L, HRT 1 day, tempure 21.1. The effluents were filtered with 200 μm bag-filters (Eurowater, Osby, Sweden) and kept at 4 °C until further use. 865 ml of minimal medium and 135 ml of VFA effluent to have an initial VFA concentration of 2 g L^{-1}	PHAs	3.3 g L^{-1} PHA	Advantages: VFAs derived from waste streams are promising substrates and anaerobic digestion process can be designed according to the desired composition of PHA.
https://doi.org/10.3390/fermentation8040180	Enhancement of PHA Production by a Mixed Microbial Culture Using VFA Obtained from the Fermentation of Wastewater from Yeast Industry	Carolina Ospina-Betancourth, Sergio Echeverri, Claudia Rodriguez-Gonzalez, Julien Wist, Marianny Y. Combariza and Janeth Sanabria (2022)	<u>Yeast wastewater</u> pH: 7.65; VS (%): 5.64; COD (g/L): 5; VFAs (g/L): 1.36	Acidogenic fermentation coupled to PHA production Acidogenic fermentation: SBR operation, liquid volume 1.7 L, inoculum volume 0.1 L, HRT 18 days, stirring speed 110 rpm. Aerobic reactor: SBR operation, liquid volume 0,2 L, inoculum volume 0.1 L, HRT 2 days, total length of operation 70 days, air flow 6 $Lmin^{-1}$.	VFAs and PHAs	VFA concentration: 2,125 g/L PHB concentration: 1,2 g/L, corresponds to 17% of dry biomass	Advantages: developing alternative methods for the production of biopolymers based on a circular economy contributes to the achievement of the United Nation's Sustainable Development goals. In this study, we demonstrated the importance of pretreating the sludge and wastewater from the yeast production industry for PHA production in a three-step coupled biotechnological process.
https://doi.org/10.1111/1462-2920.14955	Carbon substrate re-orders relative growth of a bacterium using Mo-, V-, or Fe-nitrogenase for nitrogen fixation	Katja E. Luxem, Anne M. L. Kraepiel, Lichun Zhang, Jacob R. Waldbauer, Xinning Zhang	Acids composition (mM): Acetic: 20; Butyric: 10	The bacterium *Rhodopseudomonas palustris* presents a differential rate of nitrogen fixation depending on the carbon source used.	Nitrogen fixing microbial biomass	0.8 cell*day^{-1}	This study demonstrated the use of acetate and butyrate as carbon source for biological nitrogen fixation.

https://doi.org/10.1371/journal.pgen.1009617	Disrupting hierarchical control of nitrogen fixation enables carbon-dependent regulation of ammonia excretion in soil diazotrophs	Marcelo Bueno Batista, Paul Brett, Corinne Appia-Ayme, Yi-Ping Wang, Ray Dixon	Acids composition (mM): Acetic: 15; Pyruvic: 15	It was shown that the regulation of nitrogen fixation and ammonium excretion is determined by the nature of the carbon source used.	Nitrogen fixing microbial biomass	10 mM of NH_4	This study demonstrated the use of acetate and pyruvate as carbon sources for biological nitrogen fixation.
https://doi.org/10.3390/microorganisms10071464	Exploiting the Potential of Bioreactors for Creating Spatial Organization in the Soil Microbiome: A Strategy for Increasing Sustainable Agricultural Practices	Carlos Fernando Gutiérrez, Nicolás Rodríguez-Romero, Siobhon Egan, Elaine Holmes, andJaneth Sanabria.	Citrate as carbon source	It was shown that growth of a microbial community can be obtained using citrate as a carbon source.	Nitrogen fixing microbial biomass	25 mg*L^{-1} TN	This study demonstrated the use of citrate as carbon source for biological nitrogen fixation.
https://doi.org/10.1016/j.jenvman.2022.115860	Co-production of biogas and humic acid using rice straw and pig manure as substrates through solid-state anaerobic fermentation and subsequent aerobic composting	Jie-Li Ji, Fen Chen, Shuai Liu, Yingwu Yang, Changjun Hou, Yong-Zhong Wang (2022)	Anaerobic digestate pH: 8.14; TS (%): 29.75; VS (%TS): 58.81; TN (g Kg^{-1}): 23.65; C/N ratio: 12.87	Composting from solid digestate of anaerobic digestion of a mixture of rice chaff and pig manure Aeration rate: f 0.75 L/min; TO: 25 days; temp: 25˚C	Matured compost	ST: 50%; pH: 8,45; VS: 61%; Humic acids (HA): 100,89mg/g, C/N: 14 Degradation rate, HA content, and the germination index (GI) value were up to 19.16%, 100.89 mg/g, and 103.07%, respectively,	Advantages: co-fermentation of rice straw and pig manure for co-production of biogas and humic acid was innovatively investigated in this work
https://doi.org/10.1016/j.jaap.2022.105729	Pyrolysis characteristics of anaerobic digestate from kitchen waste and availability of Phosphorus in pyrochar	Yuheng Feng, Tong Bu, Qian Zhang, Mengxi Han, Zhe Tang, Guoan Yuan, Dezhen Chen, Yuyan Hu (2022)	Solid digestate from the DA of kitchen wastes	The pyrolysis behavior of the digestate was characterized by TG-MS, TG-IR and DTA. TG-MS was carried out using a TA Instruments SDT 650 and Discovery MS, with a mass spectrometry in the M/Z:1–400 range, coupled to an MCT detector, a gas cell and transmission line at 300 ˚C, and a gas flow rate of 100 mL/min. TG-IR was carried out using a TA Instrument	Biochar	Due to the high Ca content (28.60 %), P was present in AP and enriched in pyrochar, whose TP increased from 8.38 mg/g in RD to 14.81 mg/g in DPY-700	Advantages: use of waste by pyrolysis of digestate for pyrocarbon P availability.
https://doi.org/10.1080/03601234.2019.1667190	Anaerobic digestion of livestock and poultry manures spiked with tetracycline antibiotics	Kasumba, J., Appala, K., Agga, G. E., Loughrin, J. H., & Conte, E. D. (2020)	Swine, cattle, and poultry manures containing tetracycline antibiotics (tetracycline [TC], oxytetracycline [OTC] and chlortetracycline [CTC])	The manures were anaerobically digested inside polyvinyl chloride batch reactors for 64 days at room temperature. The degradation rate constants and half-lives of the parent tetracyclines were determined following firstorder kinetics	Biogas	NR	Advantages: the tetracyclines were found to degrade faster in cattle manure, which had the lowest concentrations of organic matter and metals as compared to swine and poultry manures.

Note: fresh matter (FM), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), total solids (TS), volatile solids (VS), total kjeldal nitrogen (TKN), total organic carbon (TOC), inorganic carbon (IC), crude protein (CP), crude fiber (CF), volatile fatty acids (VFAs), polyhydroxyalkanoates (PHA), polyhydroxyalkanoates (PHA), not reported (NR)

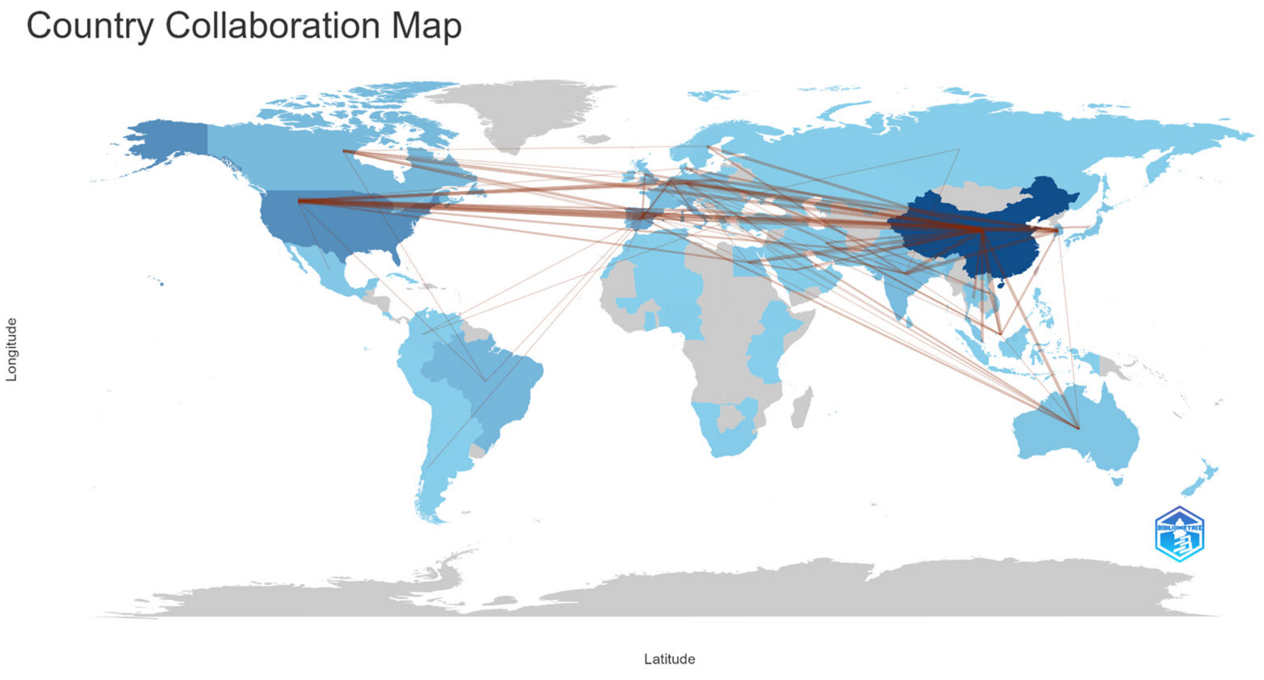

Figure S1. Countries Collaboration World Map