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Are human urine recycling technologies becoming a worldwide trend in Agri-Food sector? A review by bibliometric analysis from 1999 to 2020

As tecnologias de reciclagem da urina human estão a tornar-se uma tendência mundial no setor Agro-Alimentar? Análise de revisão bibliométrica de 1999 a 2020

¿Se están convirtiendo las tecnologías de reciclaje de orina humana en una tendencia mundial en el sector agroalimentario? Una revisión mediante análisis bibliométrico desde 1999 hasta 2020

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Abstract
The recovery of organic fertilizers from human urine as one of the solutions for the sustainable management of effluents and sanitation can be very promising, by the strategy of reuse urban wastewater, combined with the development of agricultural input. The aim of this study was to conduct a bibliometric analysis of the publications available in the ScienceDirect and Wiley Online Library databases on the subject of human urine nutrient recovery for the period from 1999 to 2020 to respond whether human urine recycling can improve cities resilience, through urban water management has the potential to become a competitive solution in the Agri-Food global market based on scientific findings. The process of bibliometric analysis exploring databases were divided in 8 steps: 1) Key-word selection, 2) Period selection, 3) Database selection, 4) Scanning the publications, 5) Removal of duplicates, 6) Verification of publications, 7) Selection of the publications with the highest adherence, 8) Final classification. A total of 985 scientific publications were selected from the Wiley Online Library and 996 from Science Direct. Out of these, only 45 were selected for being potentially aligned with urine recycling technologies relate to water management in a worldwide perspective. Human urine as a bio-fertilizer has the potential to the Agribusiness market, based on statistical data analysis, however to become a marketable product, especially in low-middle income countries, sustainability assessment studies of urine technologies, integrating economic, social and environmental aspects are needed.
Keywords: Urban Agriculture; Statistical methods; Alternative farming systems; Bioeconomy; Fertilizer; Agricultural food market.

Resumo
A recuperação de fertilizantes orgânicos da urina humana como uma das soluções para o manejo sustentável de efluentes e saneamento pode ser muito promissora, pela estratégia de reuso de águas residuárias urbanas, combinada com o desenvolvimento de insumos agrícolas. O objetivo deste estudo foi conduzir uma análise bibliométrica das publicações disponíveis nos bancos de dados ScienceDirect e Wiley Online Library sobre o tema da recuperação de nutrientes humanos da urina para o período de 1999 a 2020 para responder se a reciclagem humana da urina pode melhorar a resiliência das cidades, através da gestão urbana da água tem o potencial de se tornar uma solução competitiva no mercado global Agroalimentar com base em descobertas científicas. O processo de análise bibliométrica explorando bancos de dados foi dividido em 8 etapas: 1) Seleção das palavras-chave, 2) Seleção do período, 3) Seleção da base de dados, 4) Escaneamento das publicações, 5) Remoção das duplicatas, 6) Verificação das publicações, 7) Seleção das publicações com a maior aderência, 8) Classificação final. Um total de 985 publicações científicas foram selecionadas da Biblioteca Wiley Online e 996 da Science Direct. Destas, apenas 45 foram selecionadas por estarem potencialmente alinhadas com as tecnologias de reciclagem de urina relacionadas à

gestão da água em uma perspectiva mundial. A urina humana como biofertilizante tem o potencial para o mercado do agronegócio, com base na análise de dados estatísticos, porém para se tornar um produto comercializável, especialmente em países de baixa renda média, são necessários estudos de avaliação de sustentabilidade das tecnologias de urina, integrando aspectos econômicos, sociais e ambientais.
Palavras-chave: Agricultura urbana; Métodos estatísticos; Sistemas agrícolas alternativos; Bioeconomia; Fertilizante; Mercado de alimentos agrícolas.

Resumen

La recuperación de fertilizantes orgánicos a partir de la orina humana como una de las soluciones para la gestión sostenible de los efluentes y el saneamiento puede ser muy prometedora, mediante la estrategia de reutilización de las aguas residuales urbanas, combinada con el desarrollo de insumos agrícolas. El objetivo de este estudio fue realizar un análisis bibliométrico de las publicaciones disponibles en las bases de datos ScienceDirect y Wiley Online Library sobre el tema de la recuperación de nutrientes de la orina humana para el período comprendido entre 1999 y 2020 para responder si el reciclaje de la orina humana puede mejorar la resiliencia de las ciudades, a través de la gestión de las aguas urbanas tiene el potencial de convertirse en una solución competitiva en el mercado global agroalimentario basado en los hallazgos científicos. El proceso de análisis bibliométrico explorando las bases de datos se dividió en 8 pasos 1) Selección de palabras clave, 2) Selección de períodos, 3) Selección de bases de datos, 4) Exploración de las publicaciones, 5) Eliminación de duplicados, 6) Verificación de las publicaciones, 7) Selección de las publicaciones con mayor adhesión, 8) Clasificación final. Se seleccionaron 985 publicaciones científicas de la Wiley Online Library y 996 de Science Direct. De éstas, sólo 45 fueron seleccionadas por estar potencialmente alineadas con las tecnologías de reciclaje de orina relacionadas con la gestión del agua en una perspectiva mundial. La orina humana como biofertilizante tiene el potencial para el mercado de la agroindustria, basado en el análisis de datos estadísticos, sin embargo, para convertirse en un producto comercializable, especialmente en los países de bajos y medianos ingresos, se necesitan estudios de evaluación de la sostenibilidad de las tecnologías de la orina, integrando los aspectos económicos, sociales y ambientales.
Palabras clave: Agricultura urbana; Métodos estadísticos; Sistemas agrícolas alternativos; Bioeconomía; Fertilizantes; Mercado de alimentos agrícolas.

1. Introduction

The pollution of urban water by the discharge of effluents exposes the population to diseases associated with the quality of the water consumed, such as cholera, typhoid fever, and diarrhea. The World Health Organization (WHO) estimates that approximately 1.5 million people die from diseases resulting from poor water quality and the absence of basic sanitation, and from those 860,000 children under the age of 5 die annually from underweight and malnutrition associated with diarrheal infections or intestinal nematodes (UN, 2019; UN, 2017; WHO, 2019).

Technologies for urban sewage treatment can help to increase the quality of the effluent discharged into water bodies, for example, in Germany, waterless urinals and urine-diverting toilets with flush toilets for the feces compartment allowing urine separation can reduce water consumption and bring a sustainable way to manage urban effluents. It is estimated that the water savings in these systems can reach up to 900 m^3 per year, as well as reducing nutrient loading in wastewater treatment systems (Molina-Sanchéz et al., 2018; Senecal & Vinneräs, 2017; Simha et al., 2018; Marques et al., 2021; Cheng et al., 2018; Langergraber & Muellegger, 2005).

In this context, researchers around the world are studying the potential of producing organic fertilizer out of human urine, once the nutritional contents are equivalent to commercial synthetic fertilizers, nitrogen (N), phosphorus (P) and potassium (K) in the following proportions: N (>10%), P (>1.5%) and K (>5%) (Vinneräs, 2002; Dutta & Vinneräs, 2016; Albertsson, 2008; Salguero-Puerta et al., 2019). Besides the sustainable advantages of this technology, it can be pointed out as advantages the drop of nutrient deficiency in soil and plants (Guzha et al., 2005) and the lower concentration of non-essential heavy metals (Cd, Hg, Pb) in the final product (Wohlsager, 2010; Karak & Bhattacharyya, 2011).

It has been estimated that an average family of four persons would require 6 kg of fresh alkaline media per month, to produce approximately 10 kg of urine bio-fertilizer containing >10% N and >2% P, suitable for storage. Such technologies,

based on transformation of waste into resources like water, nutrients, biofertilizer and energy are the most promising solutions in the sanitation and agricultural sector (Bisnella, et al. 2015).

Many bibliometric studies about human urine were conducted in the past years, however most of them are health-care facilities-related (Bin et al., 2021; Enre et al., 2020; Soudabeh et al., 2020) pollutant removal from the water bodies, highlighting different scenarios from clinical studies to trace drugs intoxication (Sa'ed et al., 2017), circular economy and life cycle sustainability in wastewater treatment (Furness et al., 2021). No studies were found regarding the regarding the potential of human urine recycling to decrease pollution in urban areas and expansion of sustainable agricultural crops.

In this paper, we explored recycling human urine technologies trends in Agri-Food sector and forecasts by means of bibliometric analysis from 1999 to 2020, to elucidate whether it has the potential to become a competitive solution in the global Agri-Food market based on scientific findings.

2. Methodology

Bibliometric Analysis

The process of bibliometric analysis exploring databases can be described in 8 steps; 1) Keyword selection, 2) Period selection, 3) Database selection, 4) Scanning the publications, 5) Removal of duplicates, 6) Verification of publications, 7) Selection of the publications with the highest adherence, 8) Final classification.

Keyword Definition

The keyword search was performed in English.

Table 1: Criteria for the exploration of the article base.

Criteria	Definition
Database	ScienceDirect Wiley Online Library.
Documents Type	Book Chapter and Article
Key-words	*<nutrient* AND recycling*>, <human* AND urine*>, <water* AND management*>, <fertilizer*>.*
Academic field	Resources Orientated Sanitation
Publication Period	1990 to 2020
Research Institution	No restrictions
Language	No restrictions

Source: Authors.

From each publication, the following information were extracted: (1) year of publication, (2) distribution of the articles as to representativeness relate to the central theme of the research, (3) area of knowledge, and (4) country. The search period was delimited to the years 1990 to 2020. The databases evaluated were ScienceDirect (worldwide) and Wiley Online Library (worldwide) (Table 1). The scanning process in the indexed publication databases was performed between November 20-25, 2020 for the following keyword combinations: <nutrient* AND recycling*>, <human* AND urine*>, <water* AND management*>, <fertili*er>.

3. Results

A total of 985 scientific publications were selected from the Wiley Online Library and 996 from Science Direct, based on the keywords divided according to Table 2. The list of selected papers allowed a screening to identify and remove repeated publications in the databases.

Table 2: Gross portfolio of total studies selected of the database.

Key-words	ScienceDirect	Wiley Online	Total
nutrient AND recycling*, human* AND urine*, water* AND management*, water* AND*	996	985	1.981

Source: Authors.

There were two situations that generated duplicity: (i) replicated in the same journal base; (ii) available in more than one base - when the journal is indexed in different bases. After identifying and excluding the duplicate studies, the filtered portfolio resulted in 1,750 publications, from this number of publications the following components were checked: (i) title and subtitle; (ii) abstract; and (iii) keywords. The purpose of this scanning was to exclude publications unrelated to the objectives of this study, remaining 91 publications for the fully reading process of each publication. Out of 91 studies, 45 were selected due to strong topic alignment, consequently, were submitted to the bibliometric analysis process.

3. Discussion

The first publication identified was evaluate as medium adherence to the research according to the criteria previously established entitled "Exergy Analysis: A Comparison of Source Separation Systems and Conventional Treatment Systems" (Hellström, 2005) whose scope was based on the influence of physical factors such as: system size, concentration of collected human urine and type of agricultural crop, concluding that the total exergy consumption is lower in systems with waste separation.

From the beginning of the new century until 2005, there were no publications regarding the link between sanitation focused on resources and agriculture that reinforce the minimization of the problems developed by the increase in population, especially in low-middle income countries. The study (Guzha et al., 2005) entitled "An assessment of the effect of human faeces and urine on maize production and water productivity" developed in Zimbabwe-Sweden cooperation, initiates the search for sustainable solutions in the area of sanitation for underdeveloped and developing countries. For the following years 2006-2008, no publications adhering to water management and human waste recycling for agri purposes have been found, however, from 2009-2010, 4 publications were found, 3 were developed in the European continent, Sweden (2), Germany (1) and one in North America. The study considered most relevant in this analysis was entitled "Urine - A Valuable Fertilizer with Low Risk after Storage in the Tropics" (Wohlsager, S. 2010), whose contribution consists of the development of urine storage method to reduce contaminants and use as a supplement to commercial mineral fertilizers.

During 2011 and 2014, 2 publications were released in Africa and Asia, in cooperation with European countries, thus the discussion about the viability of human urine as a realistic solution for alternative methods of agricultural fertilization for countries in exponential demographic expansion, such as India, gained prominence, on the study entitled "Human urine as a source of alternative natural fertilizer in agriculture: A flight of fancy or an achievable reality" (Karak & Bhattacharyya, 2011).

It is also noted that in 2015 occurred the first significant increase in the number of publications, being approximately 8 during 2015-2016. The study "Evaluation of new alternatives in wastewater treatment plants based on dynamic modelling and life cycle assessment (DM-LCA)" developed in France (Bisinella et al., 2015) based on the comparison of scenarios of wastewater treatment plants (WWTPs) found out that urine source-separation had a positive effect on the effluent quality and the reduction of energy consumption in WWTP, also it was considered to be the least environmental impact scenario, however the socio-cultural acceptance of this type of scenario were not much analyzed which brings a research gap on this thematic.

Nowadays, Europe has experienced population growth, especially in metropolitan cities areas, as Paris, Amsterdam and others, for this reason researchers are seeking for sustainable solutions to maintain the structural standard of water and sewage with the lowest possible environmental impact, which made terms as urban agriculture, sustainable sanitation, circular economy and resource reuse gain more prominence.

In 2017, a study was released about the concept of sustainable food systems linked to sanitation in Netherlands, the highlight of new methodologies and technologies for the reuse of wastewater to expand the commercialization on small scales, was discussed in the publication "Assessment of environmental impacts and operational costs of the implementation of an innovative source-separated urine treatment" (Igos et al., 2017), based on the coupling of process simulation tools with LCA and operational cost evaluation showed that significant benefits could be achieved whether a pre-treating of urine from the sewage were made, by decreasing chemicals and electricity consumption, lower gas emissions and saving water through the reduction of toilet flushing.

In the subsequent year, a study entitled "Harvest to harvest: Recovering nutrients with New Sanitation systems for reuse in Urban Agriculture" (Rosanne et al. 2018). In the last three years (2018-2020) BRICS countries (Brazil, Russia, India, China, and South Africa) are receiving financial and political stimulus to develop innovative solutions to improve water access and quality to create good living conditions for urban population as was mentioned in "Urine: The liquid gold of wastewater" (Randall et al., 2018) publication in South Africa, in addition to attesting to the numerous advantages of nutrient recovery through human urine.

It is important to understand human urine as a product capable of being marketed and integrated in terms of the evolution of sustainable urban-rural agriculture, for this reason field experiments in different agricultural crops are fundamental to test the viability as a fertilizer, for instance in South Africa researchers were evaluating the indices of productivity, leaf coverage, size, color and firmness entitled as "Evaluating the feasibility of human excreta-derived material for the production of hydroponically grown tomato plants - Part II: Growth and yield" (Magwaza et al., 2020).

The bibliometric analysis results provided the identification of 21 studies with strong adherence, 14 with medium adherence, and 10 low alignments, once the final classification resulted in 45 articles. (Table 3).

Table 3: Research Publication Year.

Adherence	Quantity	%
Strong	21	46,7
Medium	14	31,1
Low	10	22,2
Total	45	100

Source: Authors.

The use of chemical fertilizers became more popular in Europe and North America, but from the 1980s and, in Europe, decreased due to environmental policies in Central European countries and the removal of subsidies on synthetic fertilizers, even in Union of Soviet Socialist Republics (USSR) in the 1990s. By that time, there was an increase in recycling

nutrients from animal manures and decreasing on synthetic fertilizer requirement. Recent studies indicate that for the next few decades there might have a significant drop in the demand of NPK synthetic fertilizer in the EU countries may. Asia, from 80s on, became the largest user with the largest area of cropland and population, due to high food demand. In Africa, fertilizer use is still low, mainly because of market and infrastructure constraints (Rosanne et al., 2018).

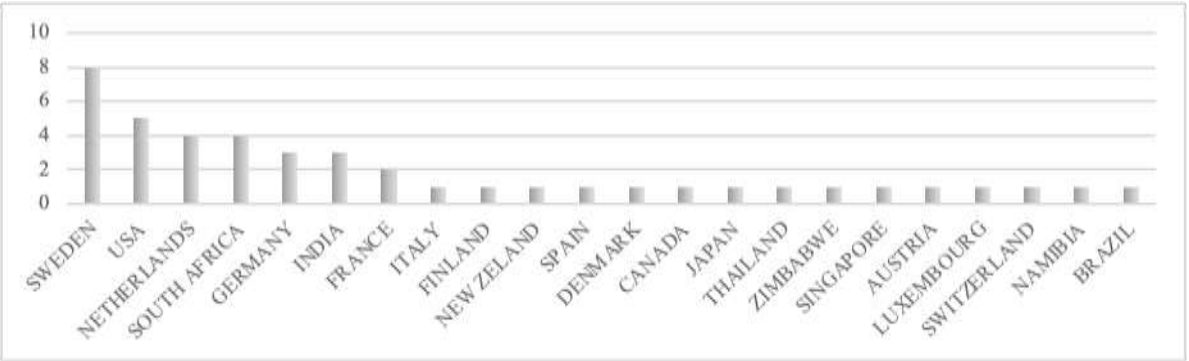
These finding lead to the follow country perspective (Figures 1 and 2), which shows c that 75% of the studies, regarding the thematic, were found in high income countries. For instance, Sweden held the highest number of publication on water management and bio-fertilizer recycling through human waste. The reason could be due to the reduction of energy dependence on oil, extreme climate conditions that require new sources of resources and the popularization of environmental activists from mid-2017.

It is also highlighted that some low-middle income countries were developing technologies or tool on this topic with Swedish partnership, which grew the country visibility in nutrient recycling out of human urine. Sweden performs very well in many sustainable areas, despite of being interested in cooperation researchers with other countries to improve their resilience towards food-water security, the country itself is highly motivated to boost the internal agricultural chain through the new fertilizer option at the market.

Other countries for instance, Brazil, Italy, Austria, Luxembourg, Canada, Switzerland and Singapore the studies are more into new technologies or models to bring the treatment to the urban wastewater, consequently the reduction of human urine in these systems. However, the link between the new sources develop to the Agri-Food sector as a tool to boost the food supply is not yet emphasized.

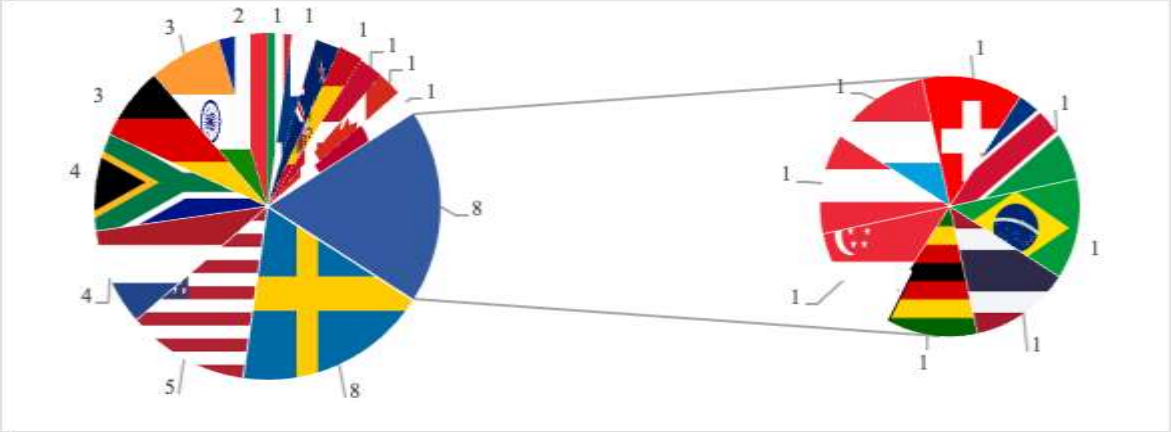
Regarding African countries, such as South Africa, Zimbabwe and Namibia, most of the studies mentioned in this paper were done in the frame of cooperation with European countries, which brought representativeness on this topic to these countries, main focus of the studies was to enhance the food-hydro-energy security of the continent due to high number of vulnerable people.

Figure 1: Countries (a).



Source: Authors.

Figure 2: Countries (b).



Source: Authors.

Regarding the fields of knowledge, it was observed that those with the largest number of publications correspond to Environmental Sciences (26.6%), Energy (22.2%) and Engineering (24.4%). This multidisciplinary approach on the management of water resources, sustainable sanitation and food production promotes the concept of circular economy. The human waste separation and recycling, especially yellow wastewater can be a sustainable solution to reduce the synthetic fertilizer dependence in agricultural crops and a tool for urban water management, considering that the excreta of approximately 4.4 billion people are not safely managed and the nutritional content in human urine as NPK can improve food security around the world.

However, for the model of smart/resilient cities, it is essential the development of decentralized urban sanitation systems, which tend to reduce the volume of the residues and the environmental impact, and can subsidize innovations in food systems (Emre et al., 2020). However, most of the authors highlighted that to achieve urban resilience, solutions should be sought according to each country scenario to their specific condition, such as climatic, economic and social, once there is no single solution for all situations.

Besides the studies selected in this bibliometric analysis (Table 4), which the main view was the development of human urine technologies as a resource to expand agricultural production, there was a landmark article for future space missions, towards urine recycling in space shuttles to provide food to the astronauts, once the urine-derived nutrient solution can provide a higher demand of nitrogen and potassium (Simha et al., 2020).

It is important to emphasize that most of nutrients from crop residues, animal manures, and wastes are often not use in agriculture because of the unknown availability of the nutrients, while the ratio of the nutrient elements in the supply most of the time does not match with the nutrient elements demanded by the crop. Besides, wastes in general are often voluminous and expensive to store, transport, and land application.

Furthermore, the production on farms is often too large to be utilized and the possibility of presence of pollutants, pathogens, and so on turns the transport, handling, and use less attractive or even prohibitive. In some countries, it is even a barrier for recycling.

A range of possible techniques and technologies are available to process, treat and recover the nutrients in a way that allows much more effective utilization. Thus, the input via mineral fertilizers, and hence the fertilizer cost to farmers, may decrease, and the nutrient losses to the wider environment may also decrease. This is the main perspective underlying the processing and treatment of human urine waste product.

Table 4: Publication List.

Publications		
Strong	Medium	Low
”Exergy Analysis: A comparison of Source Separation Systems and Conventional Treatment Systems”	“Taking the water out of “wastewater”: An ineluctable oxymoron for urban water cycle sustainability”	“Anthropogenic global shifts in biospheric N and P concentrations and ratios and their impacts on biodiversity, ecosystem productivity, food security and human health”
“An assessment of the effect of human faeces and urine on maize production and water productivity”	“Global and regional potential of wastewater as a water, nutrient and energy source”	“Global N and P in urban wastewater for the period 1970 to 2050”
“Urine – A valuable fertilizer with low risk after storage in the Tropics”	“Efficiently treated sewage sludge supplemented with Nitrogen and Potassium is a good fertilizer for Cereals”	“Environmental Life Cycle Costing and Sustainability: Insights from pollution abatement and resource recovery in Wastewater treatment”
“Human urine as a source of alternative natural fertilizer in agriculture: A flight of fancy or an achievable reality”	“Struvite recovered from various types of wastewaters: Characteristics, soil leaching behavior, and plant growth”	“Source-separation: Challenges & opportunities for transition in the Swedish wastewater sector”
“Evaluation of new alternatives in wastewater treatment plants based on dynamic modelling and life cycle assessment (DM-LCA)”	“Sanitation of faeces from source-separating dry toilets using urea”	“A comparison of different scenarios for on-site reuse of blackwater and kitchen waste using the Life Cycle Assessment methodology”
“Harvest to harvest: Recovering nutrients with New Sanitation systems for reuse in Urban Agriculture”	“Wastewater treatment by greywater separation: Outline for a biologically based grewater purification plant in Sweden”	“Recovery of nutrients and transformations of municipal/domestic food waste”
“Assessment of environmental impacts and operational costs of the implementation of an innovative source-separated urine treatment”	“Product and cost perspectives of phosphorus recovery from human urine using solid waste ash and sea salt addition – A case of Thailand”	“Pilot-scale investigations on Phosphorus recovery from municipal wastewater”
“Urine: The liquid gold of wastewater”	“Low-grade rock phosphate enriched human urine as novel fertilizer for sustaining and improving agricultural productivity of *Cicer arientinum*”	“Hydroeconomic modelling of resource recovery from wastewater: Implications for water quality and quantity management”
“Evaluating the feasibility of human excreta-derived material for the production of hydroponically grown tomato plants – Part II: Growth and yield”	“Global potential of Phosphorus recovery from human urine and feces”	“Municipal water reuse for urban agriculture in Namibia: Modelling nutrient and salt flows as impacted by sanitation user behavior”
“Yield of dwarf tomatoes grown with a nutrient solution based on recycled synthetic urine”	“Nitrate leaching and pasture yields following the application of dairy shed effluent or ammonium fertilizer under spray or flood irrigation: results of a lysimeter study”	“Cost, energy, global warming, eutrophication and local human health impacts of community water and sanitation service options”

"Investigating the feasibility and logistics of a decentralized urine treatment and resource recovery system"	"Integrated nutrient recovery from source-separated domestic wastewaters for application as fertilisers"	
"Environmental Impact Assessment on the Production and use of biobased fertilizers"	"Phosphorus recovery from municipal wastewater treatment: Critical review of challenges and opportunities for developing countries"	
"Sustainable use of Phosphorus through bio-based recycling"	"Emerging challenges and opportunities for the food-energy-water nexus in urban systems"	
"Global nutrient flows and cycling in food systems"	"Towards sustainable urban basic services in low-income countries: A technological innovation system analysis of sanitation value chains in Nairobi"	
"Ecological Sanitation and nutrient recovery from human urine: How far have we come? A review"		
"The biogeochemical imprint of human metabolism in Paris Megacity: A regionalized analysis of a water-agro-food system"		
"Resource recovery from wastewater: A new approach with Alkaline dehydration of urine at source"		
"Environmental impact of recycling nutrients in human excreta to agriculture compared with enhanced wastewater treatment"		
"The effects of urine and urine-separated plant nutrient sources on growth and dry matter production of perennial ryegrass (*Lolium perenne* L.)"		
"Turning waste into value: Using human urine to enrich soils for sustainable food production in Uganda"		
"Application of hydroponic systems for the treatment of source-separated human urine"		

Source: Authors.

4. Conclusion

Analysis that covers the development of Bio-fertilizer Market can help to set innovation strategies to manufacture this end product, human urine fertilizer, consequently find an innovative way to increase food production. Based on the results, this paper offers a bibliometric overview of urine recycling to the Agri-Food sector purposes aimed to facilitate entrepreneurs and stakeholders to drive Agricultural Marketing Trend Analysis and provide ease of use available resources to farmers and enable them to take informed decisions.

According to the findings, the number of published studies has risen steadily from 1999 to 2020, with a peak in 2017, especially in high income countries. The rise on publications in this topic indicate the recognition of urine recycling as a

growing research field, it brings an important discussion of the urine based fertilizer scientific research in a worldwide perspective, suggesting a great potential to the agribusiness market, based on statistical data analysis.

However, to become a marketable product, especially in low-middle income countries, sustainability assessment of available urine technologies, integrating economic, social and environmental aspects to these countries are much needed, otherwise it would take longer to popularize and became a trend reality in Agri-Food sector.

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