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Multi-criteria research lines on livestock manure biorefinery development towards a circular economy: From the perspective of a life cycle assessment and business models strategies

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ABSTRACT

Livestock manure (LSM) is a profitable waste if handled sensibly, but simultaneously it imposes several environmental and health impacts if managed improperly. Several approaches have been adopted globally to cartel the problem associated with LSM management and recovery of value-added products, still, technological innovation needs further upgradation in consideration with the environment, energy, and economy. This review delivered a vibrant portrait of manure management, which includes, bioenergy generation and resource recovery strategies, their current scenario, opportunities, challenges, and prospects for future researches along with global regulations and policies. Several bioenergy generation and nutrient recoveries technologies have been discussed in details, still, the major glitches allied with these technologies are its high establishment costs, operational costs, manure assortment, and digestate handling. This review also discussed the techno-economic assessment (TEA) and life cycle assessment (LCA) of LSM management operation in the context of their economical and environmental sustainability. Still, extensive researches needed to build an efficient manure management framework to advance the integrated bioenergy production, nutrients recycling, and digestate utilization with least environmental impacts and maximal economical gain, which has critically discussed in the current review.

1. Introduction

Global population which is projected to be more than 9 billion by 2050. Fulfilling the food demands of population is the key global challenge facing by animal husbandry (Malomo et al., 2018). The globally leading cattle producers' counties include Brazil, India, the United State of America (USA) and China produce ca 218, 186, 94 and 83 million (M) cattle head per year (y^{-1}) (Font–Palma, 2019; Soyer and

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Yilmaz, 2020). The livestock sector provides a livelihood to millions of people, but simultaneously their production imposes numerous environmental challenges such as greenhouse gases (GHGs) emissions, acidification of soil, eutrophication of water bodies, and biodiversity losses (Mottet et al., 2017; Varma et al., 2021). Emission of livestock-associated GHGs, in 2018, Africa, Asia and the America were dominants, with each releasing over 1×10^9 tons (t) carbon dioxide equivalent (CO_2eq) yearly via enteric fermentation and livestock manure (LSM) processing (FAO, 2018).

Consistent with the total global GHGs emission, the larger contributors are methane (CH_4) emitted from enteric fermentation, followed by nitrous oxide (N_2O) emitted from LSM left over on pasture. At global scale, Africa (275 Mt CO_2eq) in comparison to Asia (265 Mt CO_2eq) and the Americas (262 Mt CO_2eq) is the leading contributor in emission of GHGs (FAO, 2018). Since more than 70% of livestock is produced in developing countries and the animal waste is the key source of organic fertilizer, generally recognized as farmyard manure (FYM) or LSM (Al–Suhaibani et al., 2020; Awashti et al., 2022a). The LSM is well-known for their lower carbon to nitrogen ratio (C/N), due to which they decay rapidly and liberate accessible nutrients for plant growth (Thomas et al., 2019; Awasthi et al., 2020b). The well-decayed LSM is usually full of important nutrients, principally nitrogen (N), phosphorus (P), and potassium (K). Liu et al. (2002) described that recycling of 50% organic P from LSM resulting in paying back of nearly 2.5 Mt organic P y^{-1} to agricultural lands. Zhang et al. (2017) estimated, overall N generated from LSM rise from 21.4 Mt y^{-1} in 1860 to 131.0 Mt y^{-1} in 2014 with an inclusive snowballing inclination during 1860–2014 (0.7 Mt y^{-1}, $p < 0.01$). The concentrations of N, phosphorous pentoxide (P_2O_5), and di-potassium oxide (K_2O) in well-decayed LSM may reach up to 0.55%, 0.28%, and 0.52% (Patil et al., 2014). The air and water contamination associated with LSM has gained global attentions. The GHGs emission, nutrient release, ammonia (NH_3) evaporation, and pathogenic microbial contamination are key intimidations which are posed by LSM (Awasthi et al., 2018, 2019a). To overcome this, suitable procedures are required which interlinked the LSM management route, then manure would be able to replace significant quantities of organic and inorganic fertilizers and improve soil productivity (Scarlat et al., 2018; Awasthi et al., 2017, 2019b).

The overexploitation of fossil fuel reserves to meet the contemporary energies directive is presently interlinked with increasing GHGs emission and subsequent climate shift (Adamović et al., 2018; Awasthi et al., 2019c). Rapid depletion of fossil fuels reserves and increasing GHGs emission in the atmosphere propel the research efforts towards proxy energy resources/feedstocks for instance waste to energy (WTE); to overcome the impending energy crisis and associated GHGs emission (Kumar et al., 2018; Kumar and Thakur, 2018; Thakur et al., 2018). These interlinked practices and utilization of LSM as feedstock for production of energy is expected to curtail the emission of GHGs as well as provide alternative resources for generation of renewable energy and organic fertilizer (Burg et al., 2018; Guo et al., 2018).

Anaerobic digestion (AD) and anaerobic co-digestion (AcoD) have been considered as important processes to convert the organic fraction of waste into energy (biogas) and organic fertilizer (Zahedi, 2018; Khoshnevisan et al., 2021), as shown in Fig. 1. The utilization of cow manure in the AD operation leads to the production of biogas and reduces the release of carbon in the atmosphere in the form of CO_2 or CH_4, and simultaneously AD digestates can be used as an organic fertilizer (Purdy et al., 2018 Awasthi et al., 2019d). There are various reports showing that AD has the minimal impact on the environment since its global warming, eutrophication and acidification potency as well as carbon footprint in comparison to composting and incineration is very low (Oldfield et al., 2016; Elkhalifa et al., 2019; Kapoor et al., 2020). AD of LSM offers supplementary paybacks by increasing the manure quality, minimizing odors and suppressing contagious microorganisms (Awasthi et al., 2019e). Recycling and resource recovery methods of LSM have also been considered as attractive approaches along with bioenergy generation via AD (Malomo et al., 2018). In these frameworks, vermicomposting, composting/co-composting, which are often applied typically in low-income countries, are gaining attention due to their effortlessness and cost-effectiveness (Zahedi, 2018; Awasthi et al.,

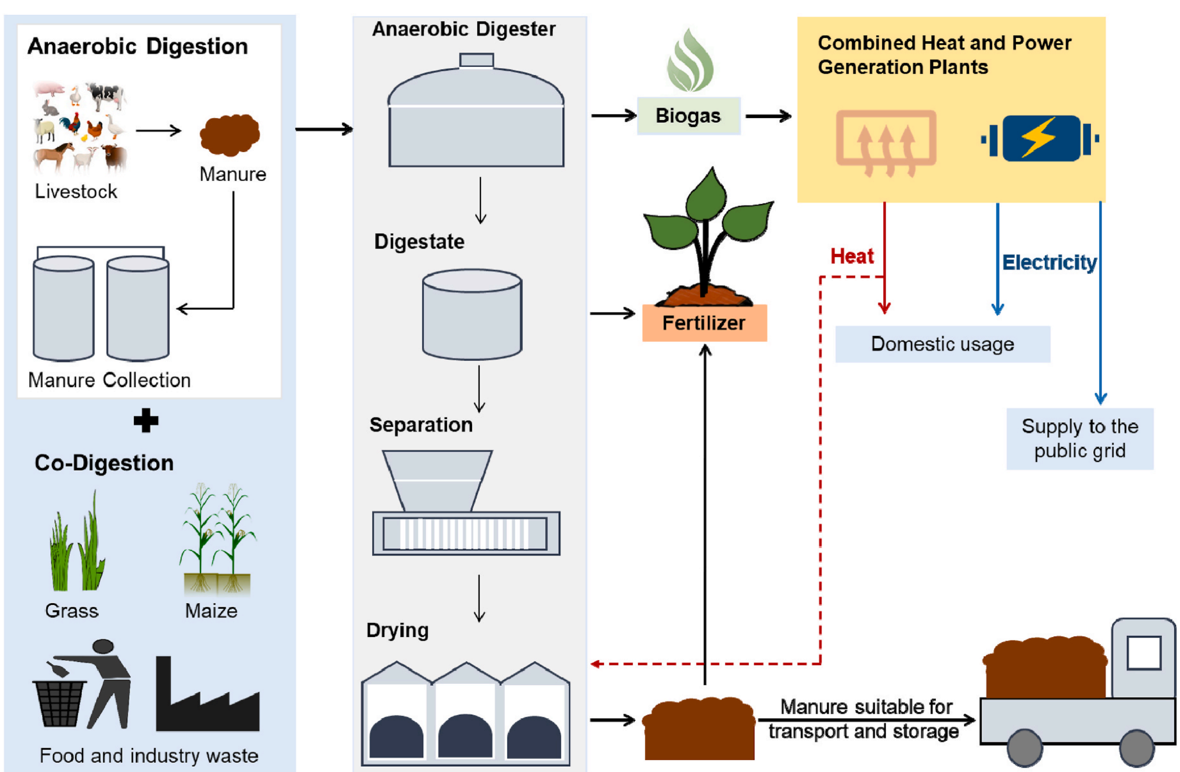

Fig. 1. Schematic representation of anaerobic digestion and co-digestion of LSM and further their application.

2019f). The innovative methods directing on nutrient recapturing have also aroused prodigious attention globally. Overall, LSM should not be considered as a waste, rather than it should be considered as a vital resource that can be further utilized as a soil fertility booster as well as a bioenergy feedstock to curtail GHGs emissions.

Several literatures related to thermochemical conversion (Font–Palma, 2019), bioenergy generation (Burg et al., 2018, 2021; Sefeedpari et al., 2020), resource recovery, and recycling of nutrients from LSM have been published (Awasthi et al., 2020a; Khoshnevisan et al., 2021), as shown in Fig. 2 and Table 1. Awasthi et al. (2020b) has been reviewed the co-digestion technologies applied in the LSM management practices and comprehensively discussed their commercial feasibility along with opportunities and existing challenges. Burg et al. (2018) provided a critical discussion on bio-valorization of the LSM via AD to cartel the GHGs emission and resolve the energy crises. Font–Palma (2019) critically discussed the existing cattle manure management technologies, thermochemical conversion methods, and biological treatment based on their physico-chemical characteristics. Khoshnevisan et al. (2021) provided a comprehensively discussion on various technologies applied in biorefinery of LSM along with persisting challenges and possible solution. Still, a critical discussion on resource recovery and bioenergy generation from the LSM in consideration with environment and economical sustainability is lacking. There is no such review which critically explored, how to maximize recovery of resources from LSM via advance technologies at minimal environmental cost.

The current review critically examines the strategies adopted in recovery of resources and by-products from LSM starting with the current global scenario of LSM production, its management approaches, and policies. This review explores the cutting-edge research on the generation of sustainable and clean energy (bioenergy) via various technologies using LSM as feedstock. The life cycle assessment (LCA) and techno-economic assessment (TEA) of the LSM management practices are also discussed, that would be helpful in understanding the environmental impacts imposed by current manure management practices and their economical sustainability. These approaches allow investigators to systematically assess LSM utilization options, their pros and cons as well as several processes involved in recovery of resources from LSM based on the model of sustainable environment and circular economy. At last, this review highlighted the research gaps in the LSM management, recycling, and resource recovery technologies, and their cost-effective viable options to overcome the challenges along with prospects for future researches.

2. Recent trends and strategies of LSM generation, effective utilization and recycling

A significant amount of LSM is contributed by 270 M dairy cows and 677 M pigs head (FAO, 2020; Shahbandeh,). It is key to recognize sustainable livestock and LSM management strategies to circumvent trade-offs between livestock-based industries and adverse environmental effects linked with livestock farming (Hellerstein et al., 2019; Duan et al., 2019a; Awasthi et al., 2020c) (Table 2). LSM management practices and its further utilization is highly governed by its physical states such as solid, semisolid, and liquid. Poultry manure is suitable for composting due to its low water content. Similarly, beef cattle and dairy cattle feces are low in water content which makes them appropriate for composting purposes. In the case of pigs/piggeries, the water content of the manure is very high so its management requires other alternative strategies (Awasthi et al., 2020d), as shown in Fig. 3. LSM has been often applied as an organic fertilizer to improve the soil fertility and boost the

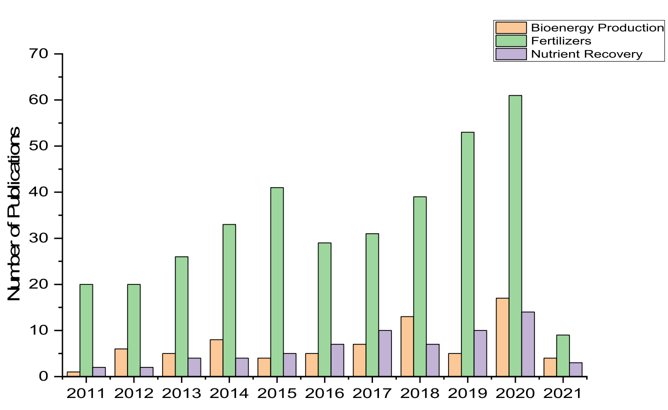

Fig. 2. Publications over the past ten year related to utilization of livestock manure (LSM) in bioenergy production, as fertilizer, and recovery of nutrient.

Table 1
Selected literature works related to LSM management and valorization approaches.

Highlights of the study	Year	Reference
This review work provided an overview on manure management processes, persisting challenges, environmental and economical sustainability, environmental policies/regulations, incentives, along with prospects for future research.	2021	Khoshnevisan et al. (2021)
The key objective of this review work was to validate the viability of electricity generation from LSM via gasification along with plausible technical innovations.	2021	(Sasikumar et al., 2020)
This review article provided a detail discussion on manure valorization in China via AD and AcoD operation, their influencing factors, and the government policies. This work also compiled the economic feasibility, potential challenges associated with LSM management and valorization.	2019	(Awasthi et al., 2019)
This review work provided a critical discussion on enzymatic technologies applied to pretreat the livestock wastewater and LSM; focusing on their usefulness, mechanism, and process parameters.	2020	Cheng et al. (2020)
This review work evaluated the generation of biogas from the LSM in Bangladesh and discussed the potential role of technologies innovation along with the government policies and regulations.	2020	Chowdhury et al. (2020)
This literature review provided an organized discussion on biogas generation scenario at global scale, production processes, and their LCA.	2019	Esteves et al. (2019)
This piece of literature work discussed the current LSM management methods, their diverse physical and chemical properties, along with various thermochemical and biological processes involve in valorization of LSM.	2019	(Font–Palma, 2019)
This review work provided a detail discussion on manure management practices and their importance in elevating the socioeconomic statues of the developing countries.	2019	Parihar et al. (2019)
This piece of literature work provided a critical discussion on bio-valorization of the LSM via AD to cartel the GHGs emission and resolve the energy crises.	2019	Burg et al. (2018)
This literature review provided a comparative discussion on various technologies applied to recover the nutrients from LSM, along with their existing challenges.	2018	Shi et al. (2018)
This reviews work provides detail discussion on the microbiological safety of chicken litter/chicken litter-based organic manures, along with emerging disinfection methods, including physical, chemical, and biological.	2014	Chen and Jiang (2014)
This review work provided a detail discussion on generation of bioenergy and recovery of nutrients from LSM and their current state of the art. This work also critically discussed the environmental and economical feasibility of the ongoing approaches based on LCA and TEA, along with opportunities, challenges and prospects for future research	2021	Present work

Table 2
Selected references for generation of LSM in various countries and their contribution in emission of GHGs.

Country	Manure generation year^{-1}	Dairy and beef cattle	Pigs	Others	CO_2	CH_4	N_2O	GHGs	Reference
USA	110.00 Mt	92.00 Mt	11.00 Mt	7.00 Mt	–	9.4%	–	–	(Cheng et al., 2020; USEPA, 2020a, b)
China	551.30 Mt	174.9 Mt	121.7 Mt	274.7 Mt	–	–	–	–	Jiang et al. (2021)
India	350.00 Mt	–	–	–	–	10.08 Tg y^{-1}	–	–	Parihar et al. (2019)
Bangladesh	155.80 Mt	–	–	–	–	–	–	18%	Khanam et al. (2019)
Japan	79.00 Mt	60%	30%	10%	4.32 Mt y^{-1}	9.68 Mt y^{-1}	9.46 Mt y^{-1}	–	(Awasthi et al., 2020e)
Korea	0.045 Mt	47%	39%	14%	–	–	–	–	Won et al. (2018)
Denmark	35.00 Mt	–	–	–	–	40%	20%		(Foged, 2012; Malomo et al., 2018)
Scotland	12.94 Mt	11.36 Mt	0.57 Mt	1.01 Mt	–	0.29 Tg CO_2-eq y^{-1}	0.23 Tg CO_2-eq y^{-1}	–	(Milne et al., 2014; Smith and Williams, 2016)
Northern Ireland	11.04 Mt	9.87 Mt	0.59 Mt	0.58 Mt	–	0.35 Tg CO_2-eq y^{-1}	0.21 Tg CO_2-eq y^{-1}	–	(Milne et al., 2014; Smith and Williams, 2016)
England	50.46 Mt	38.04 Mt	4.82 Mt	7.6 Mt	–	1.67 Tg CO_2-eq y^{-1}	0.94 Tg CO_2-eq y^{-1}	–	(Milne et al., 2014; Smith and Williams, 2016)
Wales	8.93 Mt	7.80 Mt	0.04 Mt	1.09 Mt	–	0.25 Tg CO_2-eq y^{-1}	0.14 Tg CO_2-eq y^{-1}	–	(Milne et al., 2014; Smith and Williams, 2016)
Finland	16.00 Mt	80%	14%	6%	–	15.20%	13.50%	–	Kaparaju and Rintala (2011)
Netherland	76.2 Mt	62.2 Mt	10.0 Mt	4.00 Mt	–	–	–	–	DMANFQ (2021)
France	120.00 Mt	86.90 Mt	26.23 Mt	6.87 Mt	–	2300 kt y^{-1}	137 kt y^{-1}		Loyon (2018)
Switzerland	24.00 Mt	18.24 Mt	1.44 Mt	4.32 Mt	–	–	–	1194 Kt CO_2-eq y^{-1}	Burg et al. (2021)
Poland	7.56 Mt	6.14 Mt	1.42 Mt	–	–	–	–	–	Sefeedpari et al. (2020)
Turkey	1.30 Mt	–	–	–	–	–	–	–	Soyer and Yilmaz (2020)
Saudi arabia	115.00 Mt	–	–	–	–	–	–	–	(Abdel–Rahman et al., 2020)
Canada	180.00 Mt	90.00 Mt	16.20 Mt	73.80 Mt	–	–	–	–	Statcan (2006)
Australia	10 Mt	–	–	–	–	–	–	3.4 Mt CO_2-eq y^{-1}	ADAFF (2008)

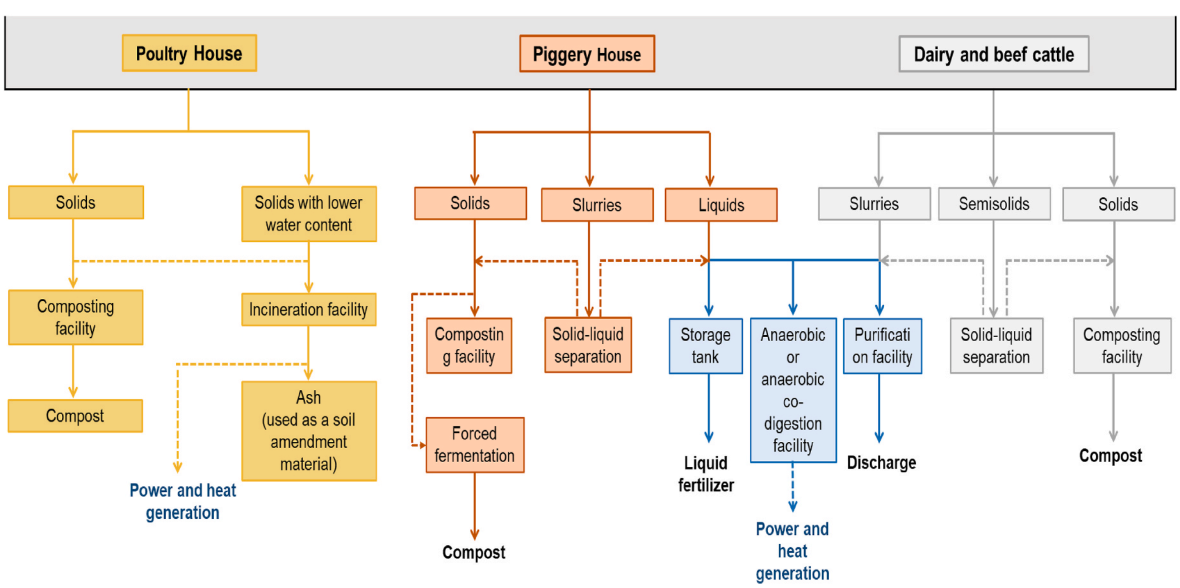

Fig. 3. Schematic representation of LSM management and resource recovery strategies.

crop yield, but at the same time, it is considered as potential contributor of the GHGs in the environment as shown in Table 2. On the basis of the link between LSM utilization and their subsequent environmental consequences, various countries have executed distinct and, in few cases, even stringent rules and guidelines related to the agricultural application of LSM in the form of organic fertilizer (Varma et al., 2021; Duan et al., 2020a).

In the USA, Comprehensive Nutrient Management Planning (CNMP) was launched in 1999, which took part to deal with environmental pollution imposed due to intensive livestock farming. It was expected that the CNMP will function as the keystone of environmental management plans collected by animal feeding processes to discourse federal and state government regulations (Duan et al., 2020b; Zhang et al., 2021). It was compulsory for livestock farmhouses to have a CNMP. The CNMP comprises regulations related to manure storage, their application on agricultural land, nutrient recovery and management which were aimed to help the farmers involved in animal farming and efficient management and utilization of LSM (De et al., 2006). Managing water quality, involving local people and making the process cost-effective, were some of imperative criteria applied to articulate manure management regulations for Western Washington area of the USA (Peterson and Grusenmeyer, 1995; Duan et al., 2019b). In 2011, the United State Environmental Protection Agency (USEPA) renewed the Clean Water Act to check the excessive runoff of LSM nutrients containing water come out from Concentrated Animal Feeding Operations (CAFO) and advised the acceptance of nutrient management strategies and recovery of resources from LSM (USEPA, 2020a,b).

African countries have been instigated several polices for the recovery of nutrients and LSM management strategies. These policies highlight that livestock housing should be covered and their floorings must be waterproofed. Sill, such regulations and monitoring are not thoroughly implemented by the local livestock growers (Ndambi et al., 2019). Several African countries do not have proper waste management system for LSM, but few countries utilize LSM as organic fertilizer (Ndambi et al., 2019). The bulky nature of LSM make them unattractive to be applied as a fertilizer in agricultural fields. Some farmers favor not to apply LSM as a soil amendment and instead use synthetic fertilizers as a substitute. The incentive provided by the government to use organic fertilizers in few countries encourage farmers to use LSM on farmlands (Ketema and Bauer, 2011; Duan et al., 2019c). In few African countries, LSM is considered as a possible hazard to human health rather than a feedstock for valuable by-products (Ndambi et al., 2019).

In European Union (EU), there are tangible and stringent rules to circumvent manure application in agricultural fields. EU Nitrate Directive has fabricated a new regulation which clearly mentions the use of maximum LSM N which was 170 kg-N ha^{-1}. Even then, only France strictly follows this regulation while the remaining EU countries have revised the regulation according to the local availability of LSM and their needs (Khoshnevisan et al., 2021). Each and every European country follows their own set of rules and regulations and strategies to circumvent overuse of LSM which might be able to control the eutrophication of surface waterbodies and ground water contamination. “Zero Eutrophication policy” in Sweden and “Animal Manure Act” and “Feasible Technology for Pollution Control of livestock and Poultry Breeding” in the Netherlands are two illustrations of nation-wide policies and regulation. The above-mentioned policies are initiated in several countries; undoubtedly postulate that LSM are permitted to be used only during the cropping season and far away from waterbodies to circumvent the eutrophication. There are several other regulations/legislations which are implemented in EU related to LSM recycling and pollution control. European council as well as EU parliament has set a benchmark for reduction of gaseous pollutants (SO_2, NOx, volatile organic compounds (VOCs) and NH_3) emission (Goździewicz–Biechońska, 2019). NH_3 is a foremost potent gas generally emitted from cattle husbandry and LSM storage systems; EU countries must reduce NH_3 generation from LSM storage system and their use as soil amendment. In Coordination with EU Nitrate Directive, United Kingdom (UK) also set the “Clean Air Strategy” to reduce the NH_3 release since major contribution of this emission is from LSM (Duan et al., 2019d).

In EU, Switzerland established the ambitious goal to optimize both resource recovery and energy from wastes and its uses for domestic purposes (CORE, 2015). The major decisions are taken at national level and total natural resource estimations cover the entire country. Overall, the theoretical capacity of Swiss biomass resources is 209 PJ (PJ) primary energy y^{-1}, and 50% is contributed by forest wood (108 PJ) and 25% by LSM (49 PJ). Around half of the LSM could be utilized in a more sustainable way (Burg et al., 2018). Utilizing LSM would be extremely advantageous for instigating the energy transition. Undeniably, biogas obtained from AD is a multipurpose energy reserve that can be easily translated into heat energy, electrical, and fuel in both developing and developed nations (Burg et al., 2021). In comparison to other nations, only 954 TJ (TJ) biogas which accounts <6% of the overall assessed exploitable LSM is presently generated by almost 100 biogas energy units in Switzerland (Burg et al., 2018). LSM signifies a huge, generally unexploited, locally accessible resource of bioenergy generation, whose sustainable utilization should be considered. A cohesive strategy of bioenergy generation from LSM is required, where all key parameters such as environmental impact, TEA, technological limitations and public acceptance are considered along with their pros and cons (Burg et al., 2021).

Denmark is another EU country with substantial LSM generation and its application in agriculture fields. The handling of LSM in Denmark is driven by the purpose to circumvent nutrients leaching from LSM and reduce the eutrophication of waterbodies. A regulation was established in 1985 imposing growers to have LSM storage system up to nine months, because the uses of LSM in agriculture fields was only permitted for few months in a year. Danish rule of LSM application in agriculture fields was also regulated according to varying agricultural practices (EPA, 2017). Danish ministry implemented a program in 1985 for LSM based CH_4 production systems. This is principally based on AcoD of LSM with several other categories of feedstock like domestic waste, food wastes (FWs) and agricultural waste (Tonini et al., 2016). The idea of AcoD has been encouraged and all the large-scale centralized biogas systems are converted to AcoD manure-based systems. The centralized AcoD biogas systems are also subsidized to allow a better and more flexible LSM management system among growers (Angelidaki and Ellegaard, 2003; Liu et al., 2021a). Presently, <10% of LSMs are utilized in AD as feedstock. Consistent with the Danish generation and energy recovery policy, by 2025, almost 50% of LSMs should be utilized as a feedstock for generation of bioenergy and digestate to be utilize as an organic fertilizer in agricultural fields (Awasthi et al., 2020i; Khoshnevisan et al., 2021). Germany also developed a bioenergy production technology to apprehend effective LSM utilization and management. The well-known “Renewable Energy Act (2004)” is encouraging the development of bioenergy production process in Germany to appropriately manage and utilize LSM as a feedstock.

In China, LSM management has been reckoned as a key task in the Chinese government’s must-to-do list. More than twenty regulations related to LSM management and resource recovery have been announced since 2004. “Zero Fertilizer Increase Input Policy” and “Recycling of LSM policy” have been launched to improve the LSM utilization in agrarian field which can replace 60–75% synthetic fertilizer and recovery of nutrients from LSM (Chadwick et al., 2020). To replace the synthetic fertilizer by LSM, recovery of nutrients from LSM, and improving the yield of agricultural crops “Agricultural Green Development Program” has also been launched in China (Khoshnevisan et al., 2021). The instigated strategies highlight that all livestock farmhouses should have a well prepared LSM storage and dumping amenities and the direct release of leachable fraction of LSM to the environment must be circumvented. The disposal of the leachable fractions serves as the potential source of contamination of rivers in north, central and south China (Chadwick et al., 2020; Strokal et al., 2016). To prevent air pollution cause by LSM, the “Blue Sky Act” was launched by China in 2018, which set the goal to reduce the SO_2 and NOx concentration by up to 15%, but this act did not cover NH_3 release (Chadwick et al., 2020; Liu et al., 2021b). The bioenergy generation from LSM and its composting technologies in China are on top priority to reduce the environmental contamination linked with LSM mishandling. Still, some bioenergy plants and compost generation practices have faced several problems to gain revenue which demoralized publics/owners involve in these activities. More precisely, non-cost effectiveness of the raw material is an impediment for biogas plant owners to gain an adequate benefit. The scarcity of appropriate assurance mechanism and helpful amenities limits the utilization of end products.

To fulfill the demands of bioenergy, LSM is considered as potential feedstock for generation of renewable energy in Bangladesh (Mostakim et al., 2021 Chowdhury et al., 2020). Bangladesh Government is showing an increasing interest in LSM as they instigated the National Domestic and Manure Program (NDBMP) in 2006 with a goal of publicizing biogas production technology in rural sector where most of the livestock farming are concentrated (Khanam et al., 2019). The Ministry of Power and Energy has taken a decision to utilize biomass to generate 10% of overall needed electricity (around 2000 MW) (Ramos–Suarez et al., 2019; Liu et al., 2021c). The quantities of per year generated LSM in Bangladesh is effective to create at least 4.0 M biogas production plants which could enable the production of 105 $\times$ 10^9 cubic feet of biogas y^{-1}. The latter corresponds to 1.5 Mt kerosene or 3.08 Mt of coal, which is able to fulfill 20% of total national domestic demands (Khanam et al., 2019). More than 2 $\times$ 10^5 t of digestate will be generated from the anticipated biogas production plants, which contains 20–30% nutrients in comparison to conventional organic fertilizer which is appropriate for agricultural practices. Overall, LSM serve the Bangladeshi people with bioenergy, power and organic enrichment (Mostakim et al., 2021). These approaches provide farmers more income than other activities. The revenue generated from side products of biogas plants such as energy trading and digestate as biofertilizer is unified with the enumerated value of human, animal and ecosystem, then the overall economy and community status of cultivator will be increased (Burg et al., 2021; Awasthi et al., 2021a). The release of various GHGs will be curtailed by these approaches, which eventually improves environmental sustainability (Burg et al., 2018).

3. Importance and significance of resource recovery

To manage the environmental waste, recycling, recovery and reuse play key role in fabricating and stabilizing a waste management model (Sarkar et al., 2021). Recovery of resources from waste via advance sustainable approaches may leads to reduce environmental impacts and simultaneously increase the economy of the processes (Rajendran et al., 2021). These approaches are completely based on circular economy model, which encourage efficient economic growth with drastic reduction in ecological and environmental impacts (Kumar et al., 2021b; Rajendran et al., 2021). These approaches not only able to generate more job openings but also enable to transforms waste into wealth, produce green energy and stop material flow from the process.

3.1. *Anaerobic digestion/co-digestion a potential strategy for bioenergy production*

The demands of energy, food and water are increasing rapidly with increase in population and industrialization (Mishra et al., 2020; Kumar et al., 2020b). The food-energy-water nexus needs proper natural resources exploration to meet these demands (Kumar et al., 2021b; Awasthi et al., 2021b). Another significant factor for environmental pollution is the increasing generation of inorganic and organic waste (Bolan et al., 2022; Kumar et al., 2021a). To over comes these issues, efficient utilization of organic environmental wastes must be prioritized. AD, AcoD, and composting are important natural organic waste management processes involving microbial decomposition (Baek et al., 2020; Lin et al., 2018; Li et al., 2021a). AD processes occur naturally in wetlands, marshes and inside ruminants' stomach leads to generation of biogas and digestate (Li et al., 2021b; Bhujbal et al., 2022). These processes have been used in management and recovery of bioenergy and nutrients from LSM, FW and agriculture waste since long back (Khoshnevisan et al., 2021; Kumar et al., 2021b).

Microorganisms play an imperative part in AD. The organic fraction of waste is converted to multifaceted organic molecules such as carbohydrates, lipids, and proteins by microbial action (Mishra et al., 2021; Gupta et al., 2022). Microorganisms hydrolyze these molecules into monomers which are then converted into volatile fatty acids (VFAs) by acidogenesis (Burg et al., 2018; Liu et al., 2021c). The VFAs are transformed by acetogenesis into acetate, CO_2 and/or hydrogen (H_2). These are used in last step and CH_4 is produced by methanogens (Mao et al., 2015). The AD has been controlled by C/N ratio. The appropriate C/N ratio for AD of the organic matter (OM) is around 20–30 and imbalanced C/N ratio inhibits the proper digestion of the material (Kainthola et al., 2019). In organic materials with imbalanced C/N ratio, AcoD is applied which is a process where two or more than two substrates are simultaneous digested in one unit (de Oliveira Paranhos et al., 2020). Anaerobic microorganisms in waste activated sludge (WAS) have imbalanced carbon source due to low C/N ratio, resulting reduce process efficiency (Luo et al., 2019; Liu et al., 2021d). The activity of the anaerobic organism is also inhibited due to NH_3 accumulation under low C/N ratio (Dai et al., 2017; Awasthi et al., 2021c). To overcome this, AcoD is consider as a better option for utilization of WAS for generation of bioenergy after mixing with other feedstocks having high C/N ratio, such as LSM, lignocellulosic waste, FW, algal biomass etc., (Bohutskyi et al., 2019; de Oliveira Paranhos et al., 2020).

The processes of AcoD are divided into two different stages or phases called as single-phase/stage and two-phase/stage systems (Van et al., 2020; Liu et al., 2020a). Two phase system is considered as much efficient due to controlled production parameters and higher yield of biogas as compared to single phase systems (Dareioti et al., 2021). There are several crop wastes and LSM utilized efficiently in a synergistic manner to generate CH_4 from AcoD process (Baek et al., 2020; Aboudi et al., 2015). Mei et al. (2016) investigated the impact of the loading rate on performance of anaerobic mesophilic AcoD of rice straw (RS) with chicken manure (CM). This approach resulted in the highest CH_4 yield of 250.3 ± 8.8 L kg VS^{-1} at VS ratio of 1:1 (RS/CM) and a C/N value of 17.8 (Mei et al., 2016). Aboudi et al. (2015) used sugar beet cossettes with pig manure and optimizes the hydraulic retention times (HRT) from 20 to 5 days (d). This finding revealed that the maximum system efficiency was attained at an organic loading rate (OLR) of 11.2 g VS d^{-1} (6 d-HRT) with a CH_4 generation rate (2.91 L CH_4 d^{-1}) and VS reduction of 2.91 57.5%. Shen et al. (2019) evaluated the performance of the co-digestion of durian shell (DS) with pig manure (PM), chicken manure (CM) and dairy manure (DM). The pig manure (PM) has positive effect on the generation of the CH_4 production in comparison to the mono-digestion with highest cumulative methane yield (CMY) of 224.8 mL g VS^{-1} and biodegradability of 48.3%. The CM and DM were not found appropriate for co-digestion with DS (Shen et al., 2019; Awashti et al., 2022a). The outcomes of this work established that the AcoD of PM and DS was an efficient method which not only attain the bioconversion of biowaste into bioenergy but also provide a broad prospective for their upcoming commercial application.

Utilization of the microalgal biomass as co-substrate in AcoD of the environmental wastes is gaining attentions (Kumar et al., 2020a; Bohutskyi et al., 2019). The microalgae biomasses are efficiently utilized for extraction/production of secondary metabolites for pharmaceutical, nutraceutical and cosmeceutical uses (Kumar et al., 2020a; Nie et al., 2020). This process generates a large amount of the microalgae residue which creates an environmental burden. The residual microalgae biomass has been utilized efficient and economical way for production of renewable bioenergy (Dębowski et al., 2020). Another major environmental and economic benefit is mobilization of micronutrients (N and P) and reutilization of CO_2 for microalgal biomass production (González–González et al., 2018; Duan et al., 2021). The unprocessed microalgae have high content of the lipid which can adversely inhibit the production of biogas during AD (Milledge et al., 2019). Experiments have shown that approximately 40–73% biogas conversion from algal biomass can be achieved with *Chlorella sorokiniana* and *Chlorella vulgaris* (Polakovičová et al., 2012). The dried and milled algal biomass was used and a higher CH_4 yield was obtained (Ayala–Parra et al., 2017; Saratale et al., 2018). The two genera of cyanobacteria, *Arthrospira* (*Spirulina*) and *Anabaena* with protein as main biochemical component have been well studied and suited for bio-methanation process.

González–Fernández et al. (2019) evaluated CH_4 production along with other parameters like OM removal, VFAs production and N-mineralization with *Spirulina platensis*. This study found the yield of CH_4 at 107 mL CH_4 g VS^{-1} along with 42% COD removal in mesophilic condition. The microalgae with low C/N ratio have been studied for co-digestion with other substrates with highly biodegradable carbon-rich organic wastes like switch grass, crop waste, straws, waste paper and beet silage for efficient production of biogas (Saratale et al., 2018; Awasthi et al., 2020b). The above discussed studies demonstrate the important of algal biomass in AcoD of organic fraction of the environmental wastes.

3.2. Composting/co-composting

The composting and/or co-composting are waste management strategies which are considered as environment friendly techniques for waste management (Lin et al., 2018; Guo et al., 2020). The organic waste management with controlled decomposition under aerobic conditions is referred to as "composting" (Vázquez et al., 2015; Liu et al., 2020c). When two or more than two organic waste materials are composed to improve the performance of composting, the process is called co-composting (Qdais and Al–Widyan, 2016). The compost from livestock waste is considered as "clean bio-waste,'' as it increases fertility and act as a soil conditioner too (Awasthi et al., 2019a; Chen et al., 2020c,d). There are several gaseous pollutants such as NH_3, CH_4, NO_x, N_2O and VOCs emitted during composting process (Tsai et al., 2008). The co-composting is a technique where waste with low C/N ratio is mixed with high C/N ratio to improve the compost quality (Şevik et al., 2018; Zhou et al., 2021a). The sewage sludge (SS) has low C/N ratio and high moisture content which hinders its application in composting. To overcome this issue, various types of bulking agents has been applied, such as green forest waste (Guo et al., 2020; Awasthi et al., 2022c), woodchip and sawdust (Golbaz et al., 2020), DM and tomato stalks (Şevik et al., 2018), FW (Chen et al., 2021), and chicken manure and rice husk (Luo et al., 2019).

Zhou et al. (2015) showed the effect of inoculation time, composting material and inoculants types on the co-composting of dairy manure with rice straw. Prior to start the fermentation process, the inoculum of *Thermoactinomyces* sp. GF1 and GF2 were used to diminish the pathogenic microbial community at high temperature. The second inoculum (*Coprinus cinerea* and *Coprinus comatus*) was used after thermophilic phase to increase the process of biodegradation. In third phase, to promote degradation of cellulose, *Trichoderma harzianum* and *Rhizopus oryzae* were used. The study found increased compost stability/maturity and decrease in the C/N ratio in inoculated pile (Zhou et al., 2015; Chen et al., 2018, 2020a). Zhang et al. (2017) used SS and agriculture waste for co-composting along with silver nanoparticles as an additive. They observed less OM loss, while using silver nanoparticles in comparison to control. Meng et al. (2017) utilize the spent mushroom substrate (SMS) contains a cocktail of organic waste degrading enzymes along with wheat straw (WS) having low moisture content and high C/N ratio. These substrates were tested for co-composting with SS. The co-composting revealed that combined composting of SMS and WS with SS is more effective than individual composting (Meng et al., 2017; Liu et al., 2020d; Awasthi et al., 2022d). The composting effect of wood sawdust with co-composting of SS and WS was assessed by Kebibeche et al. (2019). They reported positive effect of co-composting by decreasing the phytotoxicity of SS and increasing the seed germination when compost was applied in the soil. Li et al. (2020) investigated the effects of the additives on the co-composting at laboratory scale set-up for 30 d. Swine manure and corn straw were chosen along with the phosphate, calcium bentonite and biochar as additives. This study proposed that phosphate concentration and biochar as an additive were the key factors in this process and the decomposition rate of aliphatic carbon was found higher than aromatic carbon (Li et al., 2020a; Chen et al., 2020b; Qin et al., 2021a).

3.3. Nutrient recovery from manure

LSM is an important resource of biologically important nutrients for plants growth. The most common method used by the farmers for LSM management and land fertility improvement is application of manure as bio-fertilizer (Khanal et al., 2020; Bolan et al., 2021). In some cases, its direct application in certain occasions has been found unsafe for the environment (Vázquez et al., 2015; Lakshmi et al., 2021). Various finding observed that an increase in concentration of NO_3^- in surface and groundwater, when LSM was applied in agricultural field (Sahoo et al., 2016; Torres–Martínez et al., 2021). To avoid this problem, composting and AD are found to be better, economical and environment friendly approaches. The composting converts the OM with low water into a safe and stable fertilizer (Li et al., 2021a). AD is considered as a better technology for generation of bioenergy in the form of CH_4 along with other advantages like reduction in pathogens, odor elimination, less GHGs emissions as discussed in previous subsections. The AD digestate is found more effective in increasing land fertility as it contains most of the nutrients (Dennehy et al., 2017; Shi et al., 2018; Qin et al., 2021b).

The animal feeding pattern, animal health and manure storage conditions are certain parameters which play a vital role in the nutrient compositions/qualities of the digestate (Van Weelden et al., 2016; Suhartini et al., 2019; Zhou et al., 2021b). N is a major nutrient required for the biosynthesis of amino acids for proper growth and development of the plants which majorly liberated during the process of AD. It is estimated that more than 70% of the total N present in the manure is mineralized to ammonium (NH_4^+) and free NH_3 during AD process (Brienza et al., 2020; Costamagna et al., 2020). Costamagna et al. (2020) demonstrated the NH_3 removal and ammonium sulphate production at pilot scale via AD process. Pilot scale study showed the feasibility of the process after recovery of ammonium sulphate upon feeding 4.1 g N–NH_4 kg^{-1} of sludge for 180 d (Costamagna et al., 2020).

The phosphate rocks are a major source of the elemental P used for fertilizer production but slowly this source will be depleted (Chen and Graedel, 2016; Qin et al., 2021c). The recovery of this essential element from anaerobic digestate is crucial and provide a viable opportunity (Huang et al., 2018). The digestate application provides P in a readily stabilized and available form with impact on P loss to the environment when applied directly (Li et al., 2020b). The maximum portion of the P in digestate is precipitated with metals (Shi et al., 2018; Wainaina et al., 2019). The positive ion concentration and pH are important factors for the P transformation in the AD systems (Cerrillo et al., 2015; Wilfert et al., 2018). The sludge is usually considered as a waste but sludge with metals can be efficiently utilized for the production of sludge-based fertilizers (Pradel et al., 2020). This approach of sludge utilization will increase the value of both the liquid phase of anaerobic digestate and the sludge (Pradel et al., 2016; Wainaina et al., 2020a). Wang et al. (2020) utilized biochar synthesized from iron-rich sludge for efficient recovery of P from anaerobic digestate. The study also found efficient utilization of *Pseudomonas aeruginosa* in release of P from iron hydrogen phosphate (Singh et al., 2019; Wang et al., 2020). Shi et al. (2018) reviewed and discussed different types of nutrient recovery approached such as NH_3 stripping, chemical precipitation, pressure-driven membrane technologies, non-pressure membrane technologies, thermal treatments, ion exchange and adsorption, therefore, we are not covering these technologies in the present review.

3.4. Centralized and de-centralized models for resource recovery

Food and energy requirements are increasing with increase in population imposing strain on agriculture and natural resources (Mishra et al., 2020; Prabha et al., 2021). The resource recovery from LSM offers a potential platform (Wainaina et al., 2020b; Khoshnevisan et al., 2021). The adequate technological development for the efficient use of LSM can be a better option for the efficient recovery of the P and N (Bora et al., 2020; Chadwick et al., 2020). To overcome these issues, manure management has received specific attention and various research provided context specific approaches for LSM management (Cheng et al., 2020; de Oliveira Paranhos et al., 2020). Cheng et al. (2020) provided detail discussion on enzymatic bioprocessing of animal manure in to value-added products. Similarly, de Oliveira Paranhos et al. (2020) provided a kinetic and energy assessment study on co-digestion process of lignocellulosic biomass and poultry manure for generation of CH_4.

In developing countries, a number of domestic biogas plants are running but large-scale bio-methanation plants are still lacking (Khanam et al., 2019; Wang et al., 2021). Setting up the bio-methanation plants will be beneficial as it will reduce emission of GHGs (Milne et al., 2014; Xu et al., 2020). The other benefits will be solid and liquid waste management along with reduction in use of the nonrenewable source of energy like coal, gas and diesel (Torres–Martínez et al., 2021; Wang et al., 2022). Different countries have different policies regarding economical support to setting up the biogas plants using LSM as a feedstock has been comprehensively discussed in section 2. Total productions of the biogas from the manure differ drastically among agriculture-based countries. In Brazil, 12.01% biogas is produced from animal waste while co-digestion accounting only 6.07% (Yao et al., 2020). In India, 17538 MW power is generated through biomass. Indian government has thrust area for the generation of electricity from renewable sources like biomass in the rural areas. Setting up the biogas plants for the electricity generation will be also added to the rural economy (Kaur et al., 2017; Yang et al., 2020). Transportation of feedstock become one of the major cost factors in the economy of the biogas plants (Zetterholm et al., 2020). The centralized AD plants use transport facility for the collection of large amounts of organic waste. In the rural areas, decentralized biogas plants are more beneficial as the transportation cost will be negligible (Mittal et al., 2018). A decentralized biogas plant utilizes farm and household organic waste locally. The electricity, heat or fuel have been produced from generated biogas, while the digestate have applied as an organic fertilizers in the farm land (Buragohain et al., 2010; Singh et al., 2020).

The regulatory framework needs revamping to increase the incentive-based programs for setting up the decentralized digestion system (Andoni et al., 2019). Framing such type of policy, rural economy will increase with benefit of the utilization of organic fertilizers (Mittal et al., 2018; Yuvaraj et al., 2020). This cycle will reduce the strain on the nonrenewable sources of N and P fertilizers. Scientific studies are required to strengthen the claims that decentralized AD will increase the sustainability with integrating the economic, social and environmental pillars. If economic and environment pillars of the sustainability are benefitted, the social awareness about the biofertilizers or use of the organic fertilizers will change the agricultural perception (Vaneeckhaute et al., 2018).

4. Energy matters and economic feasibility

The efficient use of LSM as a feedstock for production of bioenergy not only fulfill the demand of clean energy, but it also minimizes the environmental impacts associated with LSM mismanagement (Zhou et al., 2019; Yuvaraj et al., 2021). AD process is a well-established bio-valorization pathway of LSM. The LSM treatment capacity of AD has been grown all over the EU from 1×10^5 t y^{-1} in 1990 to 46×10^6 t y^{-1} in 2016 (Ecoprog, 2017; EBA, 2017). Nevertheless, the low biomethane yield of AD using LSM as feedstock make the process non-commercial. Imeni et al. (2019) performed a TEA of AD operation using dairy manure as a feedstock. The outcome of this study revealed that, a medium-size cattle farmhouse having 250 adult cattle heads, the profits gained by the AD operation are even not sufficient to counterbalance the initial expenditure. The bioenergy generated from 1 t of dry LSM is equivalent to the energy generated by burning of 0.375 t fossil fuel (Wu et al., 2018), which makes LSM as a potential solid fuel instead of AD feedstock. There are few drawbacks appear in direct burning of LSM such as lower heating value (HV) (14–16 MJ kg^{-1}), higher moisture content (60–90%), and inefficient dewaterability and grindability (Tavasoli et al., 2018; Gao et al., 2018), which reduces energy efficiency of the operation and make it non-economical (Lang et al., 2019a). These grave hindrances can be nullified by applying advanced environmental management technologies, like thermochemical conversion, which arose as potential methods for recovery of resources from LSM integrated with waste volume reduction, elimination of pollutants and pathogens (Cao et al., 2019; Huang et al., 2018).

Hydrothermal carbonization (HTC) is evolving thermochemical methods, gained specific consideration for the valorization of LSM as they did not require feedstock pre-drying (Lang et al., 2019b). The end product obtained from HTC is a slurry which can be further converted in to hydrochar via mechanical compression (Lang et al., 2019a). The hydrochar obtained in this process provide an extra value due to its comparable energy yield like lignite-coal. Marin–Batista et al. (2020) demonstrated that HTC operation of dairy manure led to generation of higher energy than the traditional AD operation (4.1 MJ kg^{-1}). The energy generated via AD integrated with the hydrochar energy content (13.7 MJ kg^{-1}) obtained during process, counted nearly 85% of the total energy content of the feedstock, providing a possible dairy manure valorization route (Marin–Batista et al., 2020). Shanableh et al. (2021) performed an AD operation using dromedary manure as feedstock and found generation of 129 mL and 160 mL of CH_4 g VS^{-1}. This study also demonstrated that AD manure management system can reduce GHG emissions; with a unit emission of 0.52 kg kWh^{-1} of CO_2eq compared to 0.61–0.91 kg kWh^{-1} of CO_2eq emitted from conventional fuel burning. The comparative results between incineration and AD operation revealed that; incineration is a more viable approach to manage the dromedary manure in consideration with energy recovery and revenue generation (Shanableh et al., 2021).

In the near future, energy sectors and entrepreneurs can continue with the new approaches for production of electricity through integrated technologies (Sasikumar et al., 2020). The combination of hydro-thermal liquefaction (HTL) and the solar thermal imaging has shown significant potential in reducing energy costs and making HTL technology economically viable (Khoshnevisan et al., 2021). Pyrolysis of poultry manure is being investigated to find out an ongoing platform to dispose the poultry manure while gaining energy in the form of syngas (Lee et al., 2017). Syngas which is a mixture of CO and H_2 serves as a potential fuel in the internal combustion engines (Thakur et al., 2018). The improved generation of syngas at higher temperatures (500 °C) was achieved due to the warm behavior of VOCs resulting from pyrolysis of chicken manure. The calcite present in the chicken manure also contributed in improved generation of syngas, which make this process economically viable (Lee et al., 2017). Jeswani et al. (2019) evaluated the energy requirement for producing 1 kWh of energy by using poultry waste as a feedstock is 42 g CO_2eq kWh^{-1} and 0.14 MJ kWh^{-1}. The effective use of LSM as a bioenergy feedstock not only eliminates the pressure to provide clean energy but also reduces the environmental impacts of herd manure management (Marin–Batista et al., 2020). Overall, the major drivers for the selection of appropriate conditions for manure treatment will include the market demand for highly refined products (compared to separated or concentrated products), as well as the need of renewable energy (De et al., 2018).

de Oliveira Paranhos et al. (2020) utilized six different types of lignocellulosic feedstock such as peanut shell, sawdust, rice straw, coffee husk, corn cob, and sugarcane bagasse along with poultry manure to estimate the yield of CH_4 via AcoD. The results showed that the highest CH_4 generation is found in corn cob and poultry (126.02 Nm^3 CH_4 t^{-1} residue) using an inoculums dietary supplement of 0.5, which reduced fatty acid accumulation. In this case, the production of thermal energy (1.73 MJ kg^{-1} live chicken) will be able to compensate 53.2% of energy demand (de Oliveira Paranhos et al., 2020), which showed the potential of chicken manure biorefinery. Furfural is considered a potential feedstock for biofuels and biopolymers (Cao et al., 2018). Extraction of furfural from goat excreta (3.2 g L^{-1}) by acid-catalyzed dehydration was performed by Kim et al. (2019) and further its application in bioenergy generation. To increase renewable energy from goat manure by pyrolysis, CO_2 is recruited as an active component in place of N_2 (Kim et al., 2019). This study demonstrated the role of CO_2 in changing pyrolytic fuels to pyrolytic gas, thereby improving CO production. Based on the results of the experiment, it is suggested that goat feces could be a promising feedstock for the generation of bioenergy.

Overall, the management of LSM (solid and liquid) within the biological framework appears to be an essential solution to achieve the goal of sustainable development and circular economy (Khoshnevisan et al., 2021). Still, further researches are needed to establish a structured framework based on regional needs to improve the integration of manure recycling planning and manure management with minimal environmental risk and high profitability.

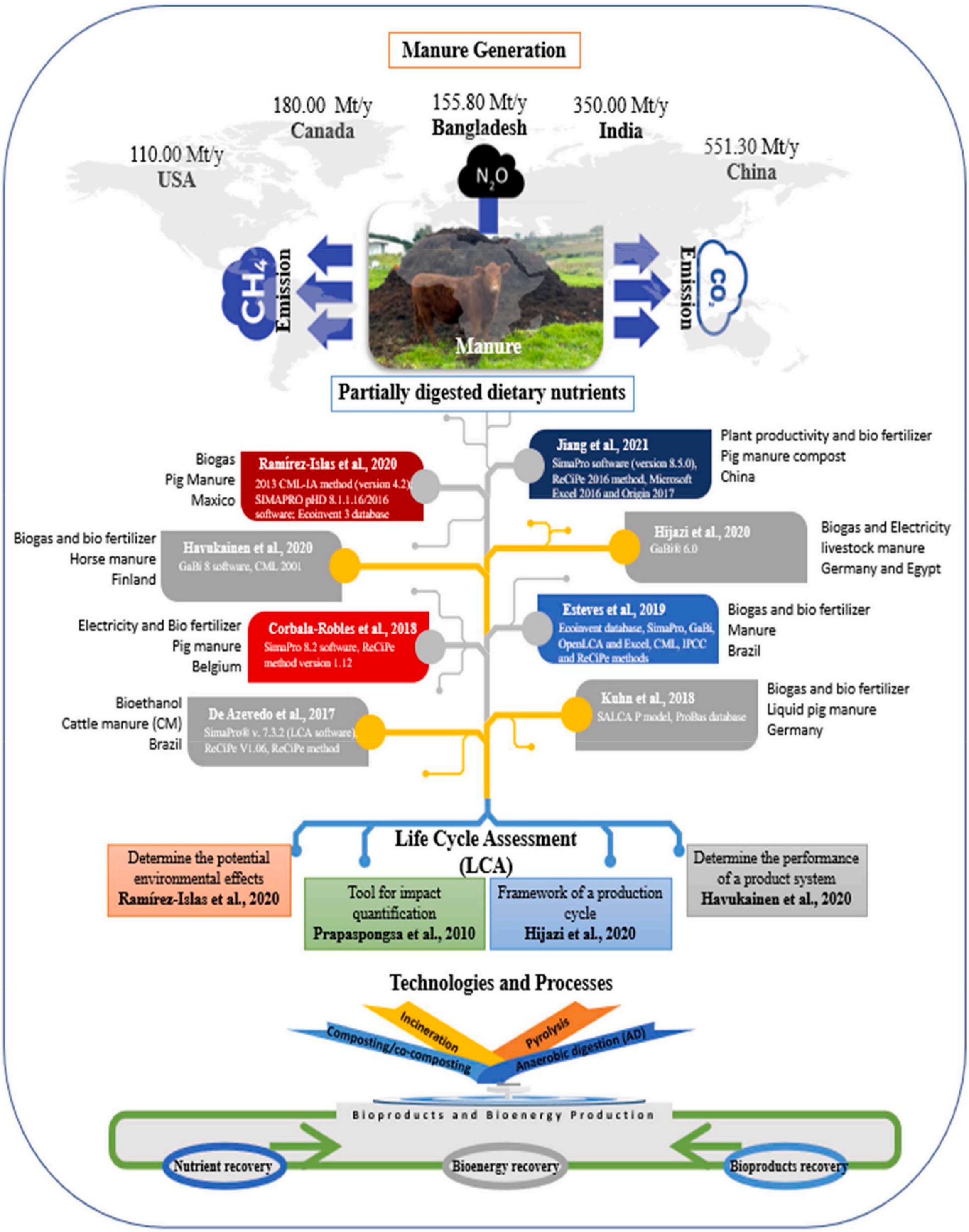

Fig. 4. Life cycle assessment system boundary for sustainable manure management.

5. LCA of effective LSM management systems

LCA is considered as potential impact measurement tool to demonstrate the environmental impact of the overall process (Ramírez–Islas et al., 2020). LCA is a complete method used for a single examination exploring the environmental impacts of the applied technologies and novel products (Hiloidhari and Kumari, 2021a). LCA can be used as a tool for predicting GHG emissions of different processes in the production cycle framework (Ramírez–Islas et al., 2020). In LCA, a functional unit defines the average performance of a product system to be used as a reference unit. In a comparative LCA, all sub-comparisons systems should have the same operating unit (Havukainen et al., 2020). Many LCA studies evaluate over-fertilization management in livestock production systems, including the use of composting techniques (Kuhn et al., 2018) as shown in Fig. 4 and Table 3.

To calculate the environmental impacts of various categories,

Table 3
Life cycle assessment process, tools/software's published data for manure management sustainability.

Year	Region	Feedstock's	LCA process	LCA tools/software's	Sustainability LCA Application and uses	Products recovery	References
2021	China	Pig manure compost	Wheat production uses four fertilizer strategies to test its environmental performance using LCA	SimaPro software (version 8.5.0), (Awasthi, 2022) method, (Awasthi et al., 2020f,g) and Origin 2017	Based on a comparison of the LCA results of the three fertilizer strategies, MCB5 with a low biochar supplement rate of 5% is recommended as a viable wheat production strategy due to its low environmental impact.	Plant productivity and bio fertilizer	Jiang et al. (2021)
2020	Mexico	Pig manure	Anaerobic digestion at medium-scale based on the Life Cycle Assessment	2013 CML-IA method (version 4.2); SIMAPRO pHD8.1.1.16/2016 software; Ecoinvent 3 database	Determine potential environmental effects on energy production and products; proves significant environmental benefits from climate change, photochemical oxidation, and depletion of fossil fuels	Biogas	(Ramírez–Islas et al., 2020)
2020	Germany and Egypt	Livestock manure	The impact of biogas systems on global warming using the equivalent of CO_2 (base) for a period of 100 years of global warming (GWP)	GaBi® 6.0	The addition of Co NP has been shown to have a negative impact on the environment in terms of acidification (1.499×10^{-5} kg SO_2 MJ^{-1} elect.), Eutrophication (6.1×10^{-6} kg Peq MJ^{-1} elect.) And human toxicity (0.00218 kg DCBeq MJ^{-1} elect.)	Biogas and electricity	Abdelsalam et al. (2020)
2020	Finland	Horse manure	Global warming power (GWP), eutrophication (EP), and acidification (AP) for various horse manure management chains using LCA	GaBi 8 software, (Liu et al., 2020b)	Combustion is the most favorable option for saw dustmanure for all the studied impact categories, whereas anaerobic digestion is the most favorable for GWP reduction, and combustion is the best option for EP and AP reduction for peat manure	Biogas and bio fertilizer	Havukainen et al. (2020)
2019	Brazil	Manure	'LCA of mono-digestion of manure biogas', 'LCA of co-digestion of manure biogas', 'LCA of anaerobic digestion of manure biogas production', 'LCA of combined heat and power (CHP) productionfrom manure biogas', 'case study of LCA biogas production	Ecoinventdatabase, SimaPro, GaBi, OpenLCAand Excel, CML, IPCC and ReCiPe methods	Assessment of critical points and environmental impacts, and as a result to help develop regional sustainability strategies for the production of biogas from manure	Biogas and bio-fertilizer	Esteves et al. (2019)
2018	Belgium	Pig manure	The natural effectiveness of the pig manure treatment system (centrifugation and subsequent removal of biological nitrogen from liquid part and solid compost) tested using a life cycle test (LCA) and ReCiPe method	SimaPro 8.2 software, ReCiPe method version 1.12	The key areas that govern the environmental impact of manure treatment have been identified using a life cycle assessment: field use of compost, field use of pollution, electricity use	Electricity and bio-fertilizer	(Corbala–Robles et al., 2018)
2018	Germany	Liquid pig manure	Quantify the emissions and resourceconsumption of a product along its whole life cycle	SALCA Pmodel, ProBasdatabase	Potential trade and combined benefits between separate releases and end resources associated with manure have been identified	Biogas and bio-fertilizer	Kuhn et al. (2018)
2017	Brazil	Cattle manure (CM)	Life cycle assessment (LCA) of bioethanol production from cattle manure (CM)	SimaPro® v. 7.3.2 (LCA software), ReCiPe V1.06, ReCiPe method	The production of cow manure bioethanol eliminates the need for composting and uses the last residue in biofuel production, thus fighting the environmental impacts of the bioethanol process.	bioethanol	De Azevedo et al. (2017)

Ecoinvent database-related programs or spreadsheets have been used such as SimaPro, GaBi, Open LCA and Excel. There are many LCA methods available to assess different areas of impact. In various studies, CML, IPCC and ReCiPe methods are the most widely used (Hiloidhari et al., 2021b; Esteves et al., 2019). The standard LCA procedure is performed using the GaBi® 6.0 tool (think step AG, Germany) (Abdelsalam et al., 2020). LCA have highlighted that mono-digested compost is more environmentally friendly option than other feedstocks, because it protects the normal storage and management directly applied to the soil (Esteves et al., 2019). The LCA was conducted at a moderate level using the 2013 CML-IA method (version 4.2), developed by the Center for Environmental Sciences, the University of Leiden, Netherlands. LCA was applied using SIMAPRO pHD software 8.1.1.16/2016. Electricity, diesel and water inputs are available in the Ecoinvent 3 database (Ramírez–Islas et al., 2020). Havukainen et al. (2020) developed the LCA for a variety of horse manure management methods and concluded that, anaerobic treatment is an effective alternative in view of GHGs reduction.

LCA is implemented by SimaPro 8.2 software and only the compulsory elements of LCA in accordance with ISO 14040 (selection of impact categories, category indicators and modeling models, classification, and editing) need to be applied. The ReCiPe 1.12 method is used to quantify the environmental impact at Midpoint (MP) and Endpoint (EP) levels from a better perspective (Corbala–Robles et al., 2018). In the mathematical experiments, the imitation of Monte Carlo is performed with SimaPro® v. 7.3.2 (version 7.3.2), which allows the spread of uncertainty across all the parameters. The details of the founding phase are interpreted based on the sections of the ReCiPe definition method (De Azevedo et al., 2017). De Azevedo et al. (2017) described the use of cow manure in bioethanol production; eliminates the need for waste treatment and the use of synthetic raw material, thereby combating the environmental impacts of bioethanol production. The conditions and impact assessments are measured and calculated with the OpenLCA software tool (Green Delta, Berlin, Germany) using the ReCiPe midpoint (hierarchist version) impact assessment method. The ReCiPe life cycle impact assessment method is based on 18 different phases to assess the environmental impact of products and services (Hasler et al., 2015).

Pexas et al. (2020) modified the CML-IA Baseline approach (version 3.05) to focus on five intermediate impact categories as proposed by FAO guidelines for environmental impact assessments on pig supply chains. The LCA demonstrates the effects of interactions between various components of the pig production system that can affects its environmental impact. Improved environmental and economic use of LCA is also found in plant products using MC compared to CF or MC compared to untreated compost. The SimaPro software (version 8.5.0) was used to measure the impact of environmental sustainability on wheat production through various fertilizer strategies using the ReCiPe 2016 method, which determines the indicators at the intermediate level. The results of the LCA suggest that the environmental performance of wheat production can be significantly improved by converting the standard CF strategy into manure fertilizers (especially biochar-amended manure fertilizers) (Jiang et al., 2021).

The results of the LCA detect potential trade and the combined benefits between the various emissions and the depletion of resources associated with composting. Still, measuring conflicting environmental impacts via LCA are challenging due to uncertainty in LCA results and, from a policy perspective, framing appropriate policies are difficult (Kuhn et al., 2018). LCA is not developed enough to present a clear conclusion so far. Further research is needed to improve the LCA performance to encourage the social and economic trade. The main focus should be obtained accurate extraction of NH_3 and CH_4 during the storage of crude fertilizers to obtain the most accurate results of the LCA system boundary and usually the time limit should be reduced to lower down these outputs in the surface water needs to be done and considered in future studies (Corbala–Robles et al., 2018).

6. Techno-economic assessment of LSM treatment technologies

The enactment of large-scale collective LSM treatment technologies must require TEA. Considering a technological viewpoint, it is imperative to validate both the accurate running of every management and treatment technologies and their outputs that turn out to be an input for consequent treatment methods. In consideration with TEA, a treatment technology could be only viable and appropriate if the cost–benefit analysis is heightened (Finzi et al., 2020). An expensive treatment method such as microbial aerobic treatment turn out to be commercial if coupled with AD that generates bioenergy which add extra income via this process. Carefully allied to energy generation, economical constraints are key because they decide the salability potential of the products.

6.1. Economics of nutrient recovery and energy generation from LSM

The gradual intensification of livestock farming systems implies an increase in the availability of LSM for nutrient recovery (Shi et al., 2018) and energy production (Soyer and Yilmaz, 2020). A detailed description of such LSM resource recovery technologies has been provided in the above sections. Selection of optimal technology for resource recovery and proper management of LSM from livestock facilities, an efficient techno-economic decision toolset is required (Awasthi et al., 2019). TEA is necessary in the early decision stage to identify the critical factors influencing the process economics and guide technological improvements for a sustainable process scale-up (Patria et al., 2021). The toolset for LSM treatment encompasses several components which include following: (i) livestock facility data; the type and number of animals in the facility which in turn dictates the type, generation rate and characteristics of LSM produced from the facility (De Vrieze et al., 2019), (ii) techno-economic modules incorporating equipment selection such as manure solid-liquid separation, AD stage, biogas valorization process (electricity, CH_4), nutrient recovery systems such as struvite-based, calcium precipitation-based, physical separation systems and (iii) economic parameters including the discount rate, electricity and CH_4 price, C and P credits, and capital cost incentives (Struhs et al., 2020). The feasibility of any LSM treatment technology depends on its capital costs, operation and maintenance costs as well as the transportation costs of substrates (raw materials, co-substrates) and products (Bora et al., 2020). The decision-making further involves the size of the treatment system, the required levels of nutrient recovery and/or energy generation in addition to the costs incurred from installation and operation of the system. This essentially means that the selection of a suitable technological strategy is very specific and has to be adapted to the local condition (Finzi et al., 2020), as shown in Fig. 5.

In consideration with the reference of any biorefinery scheme, the integration of several treatment technologies is often considered to be more effective in achieving higher overall efficiencies than using a single strategy. Similar to LSM management, a new approach has been investigated by few researchers which is called integrated treatment system (De et al., 2018; De Vrieze et al., 2019). The implementation of such a

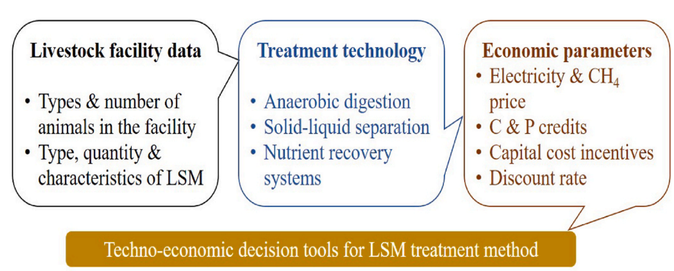

Fig. 5. Selection criteria for LSM treatment technology based on techno-economic assessment.

system also requires the selection of the right combination of technologies which are suited to a specific situation and the decision for system design relies on the magnitude of LSM-derived nutrient surplus at both farm and regional scales (Asai et al., 2014). A solid-liquid separation system for slurry processing can be incorporated to transport the solid fraction more economically to farther sites. When the surplus is too large to not be effectively managed by relocation, the solid-liquid separation could be used as a pre-treatment step for subsequent nutrient recovery (by struvite-based, calcium precipitation method) following the AD treatment step.

Another type of classification of treatment systems based on economics is individual and collective-based management system (Finzi et al., 2020). This is primarily based on the size of the farms and their capacity to manage the generated LSM. In case, the nutrient surpluses exist at a regional scale such as an intensive livestock production area with small or medium sized farms, a centralized or a collective-based system can be adopted (Zemo and Termansen, 2018). This allows an easy access of treatment systems for multiple farms to manage their LSM. In consideration with economic perspective, the setting up of a collective system should importantly consider the total amount of LSM generated in the area and the location of various farms from the centralized treatment system to allow economical transfers.

6.2. Factors influencing the economic viability of LSM treatment technologies

Considering the aspects of economic balance, assessment of the treatment technologies includes the expenses associated with the treatment plant unit such as AD, solid-liquid separation and the costs incurred during the transport of materials to and from the plant are required. The treatment plants, mainly generated incomes in the from of electricity and/or renewable natural gas and nutrient-rich solid fraction (De Vrieze et al., 2019). The CAPEX i.e., the capital expenditure or expenses is obtained from the manufacturers and it depends on the size of the farm and the quantities of LSM that need to be treated (Kassem et al., 2020). The application suitability for a specific treatment system like solid-liquid separation is based on the N-surplus generated and whether it can be effectively managed by relocation, as discussed above. Considering the case of AD, several factors govern its economics including the equipment installation cost (Finzi et al., 2020). The most critical is the farm size which makes it a feasible technology only for medium to large scale farms. This is mainly because the revenues from AD energy in small scale farms are not able to offset the CAPEX costs. Another important factor is the co-substrate added along with LSM to the digester in a co-digestion process (Imeni et al., 2019). The later has been investigated as a higher CH_4 yielding process as compared to LSM mono-digestion which can increase AD process efficiency and profitability. Imeni et al. (2020) analyzed on-site production of the co-substrates used in the AD is more profitable than buying them from an external provider. Here again, the quantity of co-substrates produced on-site i.e., ha^{-1} y^{-1} to suffice AD needs also requires adequate consideration. For example, wheat straw, a common co-substrate with LSM, is produced at 4.7 t ha^{-1} y^{-1} (Chau et al., 2009). This might be a limiting factor for small/medium farms which do not have sufficient cultivation of wheat to provide it for use in AD. Other expenses include the electricity consumption, buffering agents, antifoaming agents required for AD operation, maintenance costs and salaries of employees (Kassem et al., 2020). The solid fraction recovered from LSM, the cost of fuel consumption resulting from its transport to outside the farms also affects the process economics.

Generation of revenue from LSM resource recovery, the products from AD such as CH_4 and its conversion to electricity fall under the category of renewably generated products and their production is benefitted from public subsidies established in various countries (Kamalimeera and Kirubakaran, 2021). A study by Kassem et al. (2020) showed that the production of electricity from CH_4 and selling it to the grid would only be economically profitable if a considerable support from the government was available. The provision of programs such as the US federal renewable fuel standard could provide greater incentives and increase the value of CH_4 production, thereby greatly enhancing the process viability. Imeni et al. (2020) reached a similar conclusion and further demonstrated that the selling price of electricity was a critical variable influencing the process economics. The authors reported that a minimum selling price of €0.11 KWh^{-1} made the AD system operating at an organic loading rate of 2 kg VS m^{-3} d^{-1} profitable.

6.3. Business models for economically viable LSM treatment approaches in a circular economy

The economic viability of the treatment approach to be adopted for LSM is assessed on the basis of the expenses incurred and revenues generated. To make the business model profitable, a net positive revenue is required which is dependent on the process efficiency in terms of nutrient recovery and/or energy generation from the treated LSM (Kamalimeera and Kirubakaran, 2021). The technological model of AD has been extensively investigated for LSM management. Mono-digestion of LSM and its co-digestion with other substrates has been studied from an economic perspective. Imeni et al. (2019) provided a detailed comparison of cattle manure mono-digestion and its co-digestion with cheese whey. The study showed that the revenue generated from the mono-digestion of manure from a 250-herd farm was incapable to offset the initial required investment. Co-digestion with 30% cheese whey made the process economically viable at an internal rate of return $>$11% and a return of investment in $<$10 years. The authors also showed that the process was feasible even for small farms with a minimum size of 115 cattle heads. Imeni et al. (2020) performed a co-digestion study of cattle manure with raw and pre-treated wheat straw. The technology was shown to be profitable over mono-digestion due to the possibility of operating the AD digester at a high OLR which maximized the digester usage and resulted in significantly higher specific biogas production per volume of digester.

AD is a useful technology as it generates a revenue source in the form of bioenergy while also producing an effluent (digestate) that can be used to recover nutrients and/or other economically useful products (Sasikumar et al., 2020; Milledge et al., 2019). In this model, AD is integrated with other downstream technologies to recover additional products. Imeni et al. (2020) studied the TEA of an integrated LSM treatment system involving AD, a solid-liquid separation system and a biological N-removal process using nitrification-denitrification (NDN). In this treatment scheme, a co-digestion was performed at mesophilic temperature and the digested slurry was passed through a solid-liquid separator. The solid fraction was sold to the nearby horticultural farms while the liquid fraction was subject to N-removal by the NDN process. Feeding of 105,931 Mt y^{-1}, a 4364 Mt y^{-1} biogas was produced by AD. The solid-liquid separation step was a key component of this process since it allowed the removal of coarse solids which could be transported more economically to the farms outside which also increasing the amenability of the remaining liquid fraction to be processes by NDN. The overall treatment process resulted in an economic profit of €1.61 Mt^{-1} of treated feedstock. A treatment removal efficiency of 40% total Kjeldahl N and 41% total P was obtained which was useful to remove the nutrient surpluses at the livestock production area. To further increase the economic profitability, the replacement of nutrient removal process with a nutrient recovery process could be attempted.

In another TEA, the integration of AD, HTL and bio-methanation was investigated (Chau et al., 2009). HTL is a thermo-chemical treatment process for organic wastes in which fast hydrolysis is performed using supercritical water (Deng et al., 2020). This is followed by dehydration and condensation of lipids, sugars and proteins. HTL produces multiple products such as hydrochar, bio-crude oil and an aqueous phase which can be used for nutrient recovery (Posmanik et al., 2017). All these products along with CH_4 contribute to the revenue model in this treatment system (Khoshnevisan et al., 2021). The study involved the Concentrated Animal Feed Operation (CAFO) farms comprising 397,000 dairy cows and producing nearly 17 Mt of manure per year. The system generated a significantly high amount of 22 MMJ of renewable natural gas per year. The economic viability of the system was found to be critically dependent on the selling price of renewable natural gas which was governed by the C-credit pricing mechanisms imposed by the government. The system was profitable at a $\$7 \times 10^9$ net present value in 20 years if the federal renewable fuel standards were applied. This also highlighted the significance of government policies to monetize the environmental benefits of renewable fuels and provide price incentives for LSM treatment and conversion.

7. Practical implications, opportunities, challenges, and prospects

Various challenges encounters during the process of recycling and managements of LSM; among them, odors and GHGs emission are crucial. LSM contains high NH_3 concentration (12 g N kg^{-1} TS), resulting instant odor emission when it is used for composting (Aboudi et al., 2015). Emission of odor is a persistent challenge associated with various processes involve in the management and recycling of LSM. The application of fly larvae in composting of LSM releases heat, a large quantity of VOCs, and noxious gases imposed adverse impact on the human health and the environment (Čičková et al., 2015). Vermicomposting and composting methods are also considered as responsible sources of secondary pollution due to the release of GHGs, which lessening the environmental gain of LSM recycling (Lim et al., 2016). This limitation can be nullified by mixing organic fraction of waste with LSM and carbonaceous agents such as biochar and activated carbon (Rasapoor et al., 2020; Lim et al., 2016). These carbonaceous agents have inherent properties such as high specific surface area, improved pore size, surface functional groups (Kumar et al., 2020b, 2020c), which facilitate the immobilize/entrapment of the organic and inorganic contaminants (Bolan et al., 2021; Awasthi, 2022). Appropriate LSM management techniques can be helpful in mitigating the release of GHGs such as CH_4 and N_2O. Modifying the animal food with less N-intake, reducing the LSM storage duration and temperature, along with utilizing semi permeable covers could be a plausible strategy to overcome the issues related to GHGs emission and odors (Khoshnevisan et al., 2021). AD is the most evolving approach which can apprehend CH_4 generation from LSM and translate it into renewable bioenergy. Nevertheless, application of AD is inadequate in cold climatic region as it cannot be operated below 15 °C and for that it requires external heat/energy supply (Awasthi et al., 2019), which increase the operation cost.

The contemporary animal husbandry process led to overindulgences of antibiotics, heavy metals (HMs), emerging pollutants, and hormonal concentration in LSM resulting impaired microbial growth when they applied in agricultural field (Zhang et al., 2020). Antibiotics concentration in LSM are a foremost apprehension, as their release in the environment posed detrimental impact on living organisms; even it can induce the antibiotic resistant genes in microorganism due to continuous enrichment (Zhou et al., 2022). The composting of LSM assists to alleviate/terminate emerging pollutants as well as suppress the expression of antibiotic resistant genes by the increasing composting temperature (Ezzariai et al., 2018). LSM is identified to have infective microorganism, and their contagious nature during recycling of manure is also challenging. The poultry manure comprises diverse pathogenic bacteria such as *E. coli*, *Salmonella*, *Clostridium*, *Campylobacter*, *Streptococcus*, *Listeria* etc. (Chen et al., 2014). Elevated temperature operation of AD and composting process is helpful in bringing down the number of several groups of pathogenic microbes to a benign level. Integrated treatment like pasteurization is also applied to remove the pathogenic microbes from LSM. The thermo-chemical operation also produces remnants with a lower content of HMs and is free from pathogenic microbes (Bloem et al., 2017). These processes incurred extra cost on LSM management and recycling which lower down the profit of LSM management operation. Environmental guidelines control the application of recycled-LSM that has HMs, antibiotics, and pathogenic microbes above a benign limit. For example, roxarsone utilize in boiler poultry farm led to arsenic (As) contamination in the surrounding environment. To manage this issue, Maryland authorities excluded As additives excluding nitarsone in poultry farm industry (Fisher et al., 2015).

Public participation in LSM recycling and management is also important as well as challenging. Farmers and linked neighboring groups should be aware about the environmental, economic, and societal gains of LSM management, recycling and resource recovery. The local population have common perception against the setting up a resource recovery and manure recycling plants due to emission of odor. They are suspicious about the spread of contagious microorganism and emission of GHGs along with other environmental related issues. To increase the understanding among local population, the governments should prioritize public safety by applying stringent environmental and health guidelines along with additional regulations related to LSM recycling plant (Lin et al., 2018; Liu et al., 2020b).

Certain groups of communities have a wrong insight about the goods obtained from LSM recycling, resulting decrease in their sales and values. Negative public perception related to LSM recycling could be resolve by involving and convincing public with appropriate scientific cognitive. Scale-up the process of LSM recycling is a big task too, that is related with each technology. The application of fly larvae in recycling of LSM at large scale is vulnerable due to limited knowledge about fly larvae mechanism, as well as the need of a big space for this operation (Diener et al., 2011). Generally, fly larvae only dig up to 7.5–10 cm; the operation will require high quantity trays or basins, which limits the total volume of recyclable LSM. To resolve this issue, technological inventions are desirable to cut out the recycling cost of LSM (Čičková et al., 2015). The government guidelines regulating the application of LSM as fertilizer cannot continually gratify the public globally. The rules for quality check such as uniform nutrient content and removal of pathogenic microorganism can helpful in creating a uniform marketing strategy of LSM. If some guidelines adherence to environmental rules needs a further management step, which might be increase the operational cost (Westerman and Bicudo, 2005). This extra environmental cost burden on farmers should be subsidized by governments via incentives. Stabilizing centralized supportive and government-run big recycling systems can help in assisting the generation of bioenergy and valuable products with even quality.

As it is a well-known fact that, population growth economic development has led to amplified LSM production. LSM recycling and management approaches are ineffective in managing the large quantities of LSM. Livestock growers and the common public are oblivious having detrimental impacts due to unmanaged livestock waste. LSM storage, its transportation, and further its utilization in agricultural field's prerequisite to be accomplished well to discourse the environmental damage. Leaching of nutrients from LSM is still a potential jeopardy for the environment under existing LSM management practices, mainly in developing nations. Bringing LSM management approaches in the biorefinery model linked with bioenergy generation, nutrient recovery and recycling would hasten one step frontward toward circular economy model with least environmental impacts and maximal economical gain.

The government authorities must take appropriate steps to familiarize the concerned communities regarding LSM management. Scientific responsiveness also requires to be generated among the concern communities regarding the management and recycling of LSM. Stabilizing cooperatives and an equal public-private corporation model for recycling and LSM management technology are also desirable. The formulation of a firm and booming market and supply link for LSM-recycled goods is also imperative for boosting the profit. Technological development is one sector that is missing in current LSM recycling system. Scale-up, proper monitoring, even product, performance require upgradation with continuous research and development. The government should also boost private enterprise in the LSM recycling occupational. The technological progression should not be restricted up to LSM recycling, bioenergy and nutrient recovery, and its application as soil amendment, but it should be also emphasized to generate range of value-added products. Assumed the environmental apprehensions and economic profits that are linked to LSM recycling, this sector will be considered in future.

Innovative technology is necessary to grow unified FW pretreatment capacity via a successive progression such as extraction, separation, and fragmentation of FW. The AcoD method is applied to enhance the energy generation from LSM along with FW or other environmental waste in appropriate quantity (Baek et al., 2020; Awasthi et al., 2020h). This type of approach would conceivably, improve the overall profits of waste water treatment plants (WWTPs) along with valorization of FW and LSM. In nearby future, the AcoD approaches become an innovative technology to generate bioenergy from wastes. Still, additional scientific investigations are required to build such an economically viable technology. Several biological approaches are scrutinized for production of CH_4 such as, pre-operated methods, reformed container strategies via bioaugmentation and individual- or dual-stage digester. Several investigators applied the micro-aeration, pre-management, bio-augmentation, nutrients enrichment and electron transfer strategies to enrich the microbial communities and elevated the bio-CH_4 and bio-H_2 generation (Chen et al., 2021; Maddalwar et al., 2021). The thermophilic approach and continuous reactor system has resulted enhanced CH_4 generation and simultaneously management of waste, but still economic of the process is challenging. It is imperative to discourse such research gaps in consideration with additional effort in the near future.

8. Conclusions

The bulky nature of LSM, release of GHGs and odors along with labor intensiveness, make them unappealing to be use in agricultural fields. LSM management will resolve these issues with some extra gain in the form of bioenergy, nutrients, and enable to replace 60–75% synthetic fertilizer. Few LSM management and valorization technologies such as AD, AcoD, composting, and co-composting are well established and showing promising results in attending the environmental and economical sustainability. LSM management and its valorization is highly governed by its physical states such as solid, semisolid, and liquid. Poultry, beef cattle and dairy cattle manure are appropriate for composting due to its low moisture content. In the case of pigs/piggeries manure, the moisture content is very high which make it suitable for AD instead of composting. Antibiotics concentration in LSM is key concern in consideration with the health of the environment and human well-being. The composting and AD of LSM assists to alleviate emerging contaminants as well as suppress the expression of antibiotic resistant genes by the increasing process temperature. These methods are well established for management of LSM, but simultaneously these processes releases GHGs and secondary pollutants which reduces the environmental gain. These limitations can be overcome by using carbonaceous materials such as biochars and activated carbon as an additive. LSM management, bioenergy generation and resource recovery are an interdisciplinary approach, hence, not every associated parameter have been covered in this review. Future investigations are still needed to build an efficient skeleton to assure the real implementation of LSM management and its valorization based on TEA and LCA.

CRediT authorship contribution statement

Sanjeev Kumar Awasthi: Writing-original draft, editing, validation, and visualization. **Manish Kumar:** Writing-original draft, editing, validation, and visualization. **Surendra Sarsaiya:** Writing-original draft validation, and editing. **Vivek Ahluwalia:** Writing-original draft validation, and editing. **Hongyu Chen:** Writing-original draft validation, and editing. **Guneet Kaur:** Writing-original draft validation, and editing. **Ranjna Sirohi:** Writing-original draft validation, and editing. **Raveendran Sindhu:** Writing-original draft validation, and editing. **Parameswaran Binod:** Writing-original draft validation, and editing. **Ashok Pandey:** Writing-original draft, Investigation, validation, and editing. **Rashmi Rathour:** Writing-original draft validation, and editing. **Sunil Kumar:** Writing-original draft validation, and editing. **Lal Singh:** Writing-original draft validation, and editing. **Zengqiang Zhang, Mohammad J. Taherzadeh and Mukesh Kumar Awasthi**: Conceptualization, writing-original draft, editing, validation, visualization, supervision, fund acquisition, and project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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