Bulletin of Business and Economics, 13(1), 792-802
https://bbejournal.com
https://doi.org/10.61506/01.00271

A Research Challenging Vision Concerning Waste of Agricultural Management in a Bio-Based Circular Economy: A Review Article

Sehrash Gul[1], Waseem Ahmed[2]

Abstract

Agricultural waste represents an enormous reservoir of underutilized biomass resources, which may even pose environmental and economic risks. Residual resources of this nature can be transformed into bioenergy and bio-based products through cascading conversion processes, thereby fitting the criteria of a circular economy. Significant challenges are examined through a transdisciplinary lens, with an emphasis on the European context. Due to the seasonality, regionality, and complexity of agricultural residue management chains, environmental and economic repercussions are challenging to quantify. It is discussed how to develop multi-criteria decision support instruments that can be implemented in the earliest phases of research. The technological advancement of Anaerobic Digestion (AD), a highly developed conversion technology, is examined in the context of seasonal and geographical variations in refuse feedstock. Utilizing agricultural byproducts to manufacture high-value compounds is a significant challenge that is examined in this article, with innovative cascading conversion processes that are both eco-efficient and cost-effective (bio-refinery concept) taken into consideration. Furthermore, industrial ecology examines the promotion of businesses based on agricultural residues in order to foster local synergy between various industrial and agricultural value chains. In order to optimize the management of materials and knowledge fluxes and facilitate a holistic approach, the connection of stakeholders to encourage resource exchange and cross-sector collaboration at appropriate geographic scales is discussed.

Keywords: transdisciplinary lens, geographic scales, agricultural byproducts, Anaerobic Digestion

1. Introduction

Third, overcome constraints for producing novel building blocks, polymers, and materials from agricultural leftovers. Despite a strong demand to replace petro-derived chemicals and building blocks with competitive sustainable alternatives, only 3% of chemicals and 2% of polymers are bio-based (Fiorentino et al. (2017); Aeschelmann et al. (2017)). Fused Territorial Metabolism (TM) LCA or TM-LCA may be done on areas or territories. LCA and TM outputs, and their combinations, are multifaceted and need to be simplified and streamlined to give key stakeholders (including policymakers) with clear and appropriate recommendations. Multi-criteria decision-making analysis supports a multi-dimensional and multi-actor approach (Njakou Djomo et al., 2015).

FAO (2011) reports that food production and supply chains use 30% of global energy, while bio-energy crops are condemned for competing with food crops and threatening food security and biodiversity. Primary agricultural leftovers will rise proportionally when the global population reaches 9 billion by 2050, requiring more food production. In 2012, these residual resources made up 50% of the fresh weight of harvested crops and had a potential of 90 Million Tons Oil Equivalent (MTOE), far more than round wood production (57 MTOE), municipal and other waste (42 MTOE), and tertiary forest residues (32 MTOE). Economic and environmental difficulties associated to agricultural primary wastes are linked to regional specialization (e.g., infrastructure, waste processing, energy supply technologies, etc.) in animal feed crop or animal production. Animal breeding zones create massive volumes of manure residue, which causes intense smells, microbial contamination, high greenhouse gas (GHG) emissions, and high organic matter and nutrient (e.g. nitrogen) burdens. Meanwhile, vegetable producing areas (e.g. for animal feed) deplete nutrients and organic matter, causing a worldwide imbalance.

Agricultural waste, by-products, and co-products refer to plant or animal wastes that cannot be turned into food or feed, posing environmental and economic challenges in farming and primary processing. Promoting a circular economy strategy is crucial to improving resource efficiency and agricultural waste management in primary agriculture. Most agricultural waste is primary wastes that may be converted into sustainable bio-products including fertilisers, energy, materials, and chemicals via increased convergence processes. This agricultural residue must be converted to promote the decoupling of economic development and human well-being from (primary) resource usage, reducing land pressure, biodiversity

[1] Department of commerce, University of Sargodha, Pakistan, gul.sehri@yahoo.com
[2] waseem.ahmed@cdu.edu.au

loss, and global food security (UNEP, 2011). Our trans-disciplinary publication addresses key challenges to sustainable agricultural residue use and promotes innovative holistic approaches to eco-efficient conversion routes and smart agricultural residue management strategies. The following part will highlight waste management difficulties and their interconnections, followed by in-depth analyses of each. Based on facts and statistics, European situations will be focused on, but the presented principles and difficulties may be applied to Asia.

2. Challenge I: Environmental consequences of agricultural residues management strategy: Assessment and early prediction

Agricultural practices degrade soil, air, and water quality, consume scarce resources like land, water, energy, and more, and generate large and diverse waste streams that are not efficiently used. Soil quality is vital to agriculture and food security in a growing global population (Hurni et al., 2015). Agriculture utilizes 70% of worldwide and 36% of European freshwater withdrawals (FAO, 2014; World Bank, 2017) and degrades ecosystem water quality. This effect pattern is mostly caused by conventional agricultural practices such overusing fertilisers to increase yields, irrigation, pesticide usage, and suboptimal animal production (Zia et al., 2013). Common agricultural practices transport intentionally applied contaminants (antibiotics, pesticides, nutrients fertilizers, micro- and nano-particles from plastic materials, various bioactive chemical pathogens from livestock manure, waste water sludge, etc.) from arable land to surface and groundwater. Unintentional water recipient contamination occurs when chemicals and substances are atmospherically deposited on arable land and follow the same emission paths to the aquatic environment as purposefully applied pollutants. Anaerobic digestion (AD) is one of the most effective and mature methods for converting agricultural primary wastes into bioenergy and bioproducts (Merlin & Boileau, 2013). AD in biogas plants may produce digestate slurry from manure and other agricultural leftovers, which can be utilized as biofertilizer. Bio-fertilisers may restore nutrients and organic matter to arable land with low manure potential, making seasonal and territorial fertilising management plans more sustainable. Extended AD treatment of manure increases nitrogen availability by 5-20% (Mo€ller and Mu€ller, 2012). AD might cut mineral fertilizer needs by 10%, reducing GHG emissions by 3–5 Mtons CO_2/year (Mo€ller, Boldrin and Christensen, 2009). Since agriculture uses less nitrogen, surplus nitrogen issues may be reduced. AD digestate bio-fertilisers reduce chemical fertilizer pollution, improving ground water quality (Mo€ller, 2015). Applying AD to agricultural residues (e.g. manure) reduces gaseous emissions by capturing and converting methane, which would otherwise escape into the atmosphere, and by using biogas to replace fossil fuels, which would otherwise be needed to generate energy. However, for economic and supply concerns, biogas facilities frequently use energy crops instead of agricultural leftovers. Dedicated energy crops and underutilization increase agricultural land usage, agrochemical emissions, and soil deterioration on arable land. Given this degradative development, Croxatto Vega et al. (2014) argue that end-users (farmers, industries, policymakers, and other stakeholders) must be informed of all the impacts of different agricultural residue management strategies. The use of petro-based plastics in agriculture (e.g. plastic mulch) and other plastic pollutants (e.g. food packaging) is also a developing environmental problem, with implications that are hard to quantify. These plastic pollutants increase soil erosion, reduce water holding capacity, and affect soil biological metabolisms, diversity, organic matter composition, and stability of arable soils (Steinmetz et al., 2016). Also concerning is the seeping of these toxic compounds into ground water. Micro and nano-plastics have been found in aquatic, terrestrial, and marine environments (Chae and An, 2017). These particles' health risks are unknown. However, the production and use of chemicals (e.g., agro-chemicals) and biodegradable materials (e.g., PHA, lignocellulosic composites) based on agricultural residue resources can affect the replacement of potentially harmful petro-based plastics in soils (Costa et al., 2014) and groundwater micro and nano-particle concentrations. Plastic production and usage in agriculture and elsewhere have skyrocketed since the 1970s. Conventional environmental impact assessment methods do not account for long-term effects like those caused by plastic micro and nano particles, so they cannot address micro and nano-particle contamination issues (Zalasiewicz et al., 2016). Territorial Metabolism (TM), a regional variant of urban metabolism (UM) (Wolman, 1965; Kennedy, Cuddihy and Engel-Yan, 2007), can be used to evaluate the impact of altered agricultural residue utilizations. It quantifies material and energy flows across a specific geographic region. Unlike cities, such areas may be specialized agricultural regions with a different palette of goods, such as Roussillon-Languedoc, which may exist as a patchwork of wine growers cultivating a single grape type (Figure 2). As Goldstein et al. (2013) have shown, urban and regional material flow and energy analyses are limited by the incomparability of material flows (e.g. concrete and steel) and the lack of valid proportionality (Laurent, Olsen, and Hauschild, 2010) between urban/regional flows and environmental impacts. Fusing TM and LCA in urban areas (UM-LCA from Goldstein et al., 2013; Ipsen et al., 2018; Ohms et al., 2018) provides a convenient and powerful method for systemic assessment of the environmental impacts of new waste management schemes at territorial scale. Unlike territorial LCA (LCA applied to a territory, Loiseau et al., 2013, 2018, Mazzi et al. 2017), hybridizing TM with LCA examines a territory's metabolism (changing metabolism caused by a technology). LCA fused metabolic assessments of specific geographic areas can convert material flows into standardised (and thus comparable) sets of environmental impact indicators at various aggregation levels (e.g. mid-point, end-point, and single score), solving material flow assessment issues in “pure” UM and TM. Thus, TM-LCA will provide regional environmental performance evaluation before and after agricultural residue utilisation technology introduction, providing an alternative and indirect means to evaluate novel agricultural residue uses (Sohn et al., 2018). Due to the fused TM-LCA approach's ability to provide a complete and systemic picture of a region's environmental performance potential, including specific agricultural residue systems, optimal agricultural residue management strategies can be implemented at appropriate (regional) scale and complexity levels (Sohn et al., 2018). Since TM-LCA outputs need certain skills to apply, they must be reduced to offer clear instructions to end-users. Cross-disciplinary and multi-criteria evaluation and decision support tools enable stakeholder discussions and provide structure and knowledge for complex decision-making situations like agricultural residue utilisation policy (Sohn et al., 2017). The integrated TM-LCA multi-criteria approach could also be used to simulate and predict the environmental performance of future systems by adding scenario analyses to include regional and seasonal factors, potential product life cycles (and trade-offs), and a wide range of impacts indicators, including undesirable contaminants in circular management. Applying these assessment and interpretation methods to early residual resource management can foster innovation that addresses all three sustainability pillars (Economic, Environmental, and Social) coherently and focus research on eco-design hot/critical points. By upgrading and improving existing methodological frameworks to streamlined integrated strategic environmental assessment (multi-criteria evaluation model supported by geographic information system application), agricultural residue management planning decision-making should be greatly improved.

3. Challenge II: Converting agricultural residues into biogas and bio-fertiliser: Required upgrading technologies

Anaerobic Digestion (AD) is the most used agricultural residue conversion method. The European Biogas Association (EBA, 2018) reports 17,500 AD plants, most of which are farm-based, with 9.98 GWe of installed capacity and over 65 TWh of biogas-generated power. Europe has about 500 biome-thane plants with 17,264 GWh of output capacity. Although robust, this technology has limitations and weaknesses, including low conversion yields of lignin-rich organic material (Ahring et al., 2015), low economic value, and feedstock supply and digestate handling/storage issues. Feedstock and operating circumstances affect AD recovery yield (Mo€ller, 2015). Lignocel-lulosic-rich waste streams have not been extensively used for AD because complex plant cell walls resist microbial assault, resulting in poor biogas conversion yields. This has been studied using mechanical, chemical, thermal, and biological methods. In actual situations, determining pre-treatment's true benefit is crucial. Pre-treatment capital and operating expenditures frequently exceed biogas production returns (Budde et al., 2016). Mechanical pretreatments like grinding and milling or ultrasonic need a lot of energy to affect methane production. Acid or alkali treatments are low-energy but high-hazard chemical treatments that may contaminate and create inhibitors like furans and phenolics. Ozone pretreatment, although beneficial in labs for lignin breakdown and methane output, raises questions regarding economic and environmental viability (Doman´ski et al., 2017). Hydro-thermal and steam explosions boost biogas production to meet energy needs (Carrere et al., 2016). Wet explosion, which combines steam explosion with oxygen addition, is a potential lignocel-lulosic pretreatment process. This method works with agricultural leftovers and manure fibers in AD procedures (Ahring et al., 2015). Selective enzymatic treatments of agricultural waste improve straw-manure co-digestion at low energy cost (Wang et al., 2016). Rouches et al. (2016) found that wheat straw sprayed with white-rot fungus increased methane production despite organic matter losses. Biological pre-treatments offer intriguing options for cost-benefit analysis. At the anode, "electro-active" microorganisms, or electrotrophes, oxidize organic waste substrates to carbon dioxide utilizing graphite as their ultimate electron acceptor. Electrons from the anodic oxidation process in the external circuit are utilized to (bio)catalyze the synthesis of reduced molecules such H2, CH3COOH, or CH4 (Zhen et al., 2017; Zeppilli et al., 2016a). Waste treatment may be combined with energy carrier and chemical production. A MEC configured for "electromethanogenesis" can combine wastewater treatment (COD) oxygenation in the anode with biogas upgrading to biomethane (Figure 3) (Villano et al., 2013; Blasco-Go´mez et al., 2017). Implementing MEC may reduce energy demand for biogas refining and boost energy efficiency in biomethane production compared to traditional methods like water scrubbing and pressure swing adsorption (Andriani et al., 2014). Due to cathodic chamber alkalinity, MECs also remove CO2 as HCO- (Xu, Wang and Holmes, 2014). This method allows a methane-producing biocathode to create 9 moles of CO2 every mole of CH4 (Zeppilli et al., 2016b). By considering the latter approach, electromethanogenesis might use nearly one order of magnitude less energy. A novel method is to employ two-phase AD processes, which produce biogas with up to 10-20% H2 content, via fermentation and methanization (Micolucci et al., 2014). Dual-phase AD procedures boost conversion yields by 37% (Premier et al., 2013) and produce bio-hythane simultaneously. Bio-hythane (hydrogen-enriched methane) reduces HC, NOx, and GHG emissions, improves combustion (engine power), and may be utilized in traditional natural gas automobiles. HythaneVR fuel is used in numerous countries, including the USA and India, but industrial manufacturing requires energy-intensive catalytic techniques. This technique might achieve 1.5 €/kg hydrogen (yield 10 moles H2/mole glucose, feedstock < 0.05 €/kg) (Bolzonella et al., 2018). Recent research (Zeppilli et al., 2017) found that a pilot-scale two-phase anaerobic digestion AD process could sustain MEC technology using a mixture of effluents from the first (acidogenic fermentate) and second (digestate) stages. Two-stage AD also produces volatile fatty acids (VFAs)-rich residual effluents (Cavinato et al., 2017), which can be converted into bio-based chemicals like polyhydroxyalkanoates (PHAs) and derivatives (Reis et al., 2011), which have many packaging applications as speciality biopolymers. Indeed, PHAs has been identified as a promising potential of the bio- waste bio-refinery (Bugnicourt et al., 2014), especially because: (i) its pro- duction process has the best potential to cope with large heterogeneity of the waste feedstock, in particular because the first production step, i.e. the acidogenic fermentation, is both robust and flexible and provides stable feedstock to the PHA production; (ii) PHA includes a whole family of copolymers with a wide range of tunable properties, so that PHA can be the main constituent of several bioplastics and their biocomposites, with a wide portfolio of applications (Chen, 2010); (iii) PHA is bio-based not only because it is produced from organic biomass, but also because it is pro- duced through a process, which is mostly biological under mild conditions (e.g. no sterile conditions are required); (iv) in comparison with other bio- logical processes, the PHA-producing process does not produce an excess of sludge that needs to be handled, as the polymer makes up to 70% of the biomass (Reis et al., 2011).

4. Challenge III: Converting agricultural residues into innovative building blocks, molecules and materials: Overcoming key bottlenecks

Potential for developing bio-products from agricultural residues is high, but biomass conversion processes need technological improvements, more knowledge of their potential, and environmental, economic, and societal sustainability. Even though global warming and the 7th plastic continent are serious environmental issues, the petro-chemical sector uses mature technology to produce the most widely used chemicals, multi-purpose plastics, and energy in the world. Chemically and biotechnologically, most plastic compounds and building blocks may be manufactured from renewable basic resources.

Mixing PHA with low-cost lignocellulosic fibres may alter its characteristics while retaining biodegradability and lowering costs. Lignocellulosic fibers from agricultural and food sector by-products are cost-effective and ecologically friendly, making them ideal for use in biocomposites (Berthet et al., 2015, 2017) (Figure 5).

Combining dry grinding and sorting may readily create reinforcing fillers from lignocellulosic biomass (Berthet et al., 2017; Lammi et al., 2018). Dry fractionation uses no water or chemicals and produces minimal waste (Lammi et al., 2018). Fibers may also be found in the solid residue left after extracting high-value bioactive molecules like polyphenols from agricultural or food manufacturing byproducts. Finally, this fibrous residue may reinforce polymers (Totaro et al., 2018). If impurities can be removed, lignocellulosic residue biocomposites are promising materials for horticulture, construction, automotive, and packaging (Berthet et al., 2016).

Lastly, White et al. (2004) identified the key sugar-derived building components for polymer production: 1,4-diacids (succinic, fumaric, and malic), 2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/ Due to its ability to form the basis for many high-value replacement products, such as phthalic anhydride, adipic acid, and maleic anhydride, succinic acid (SA) is one of the most competitive bio-based chemicals among these top twelve promising platform chemicals (White et al., 2004; Weastra, 2013). The growing use of SA in industrial (57%), pharmaceutical (16%), food & beverage (13%), and other (14%) applications is driving this market (Sisti et al., 2016). SA is traditionally made from petroleum by oxidizing n-butane, but biomass sugar fermentation may also produce it (Lin et al., 2012). The worldwide bio-based succinic acid market is estimated to reach 710.0 kilo tons by 2020, expanding at 45.6% from 2013 to 2020 (Allied Market Research, 2014). Petrochemical output has been constant for years. The Weastra (2013) market research predicts that bio-based succinic acid will be cheaper than petro-based. Recent developments in fermentation from glucose sources such maize wastes and purifying technology made bio-based SA economically appealing (Sisti et al., 2016).

Although prominent businesses like BioAmber, Reverdia, Myriant, and BASF have erected demonstration bio-SA facilities in North America, Europe, and Asia Pacific, the worldwide market share remains low. Innovative solutions should be developed to reduce bio-based SA raw materials and production cost to reach PEP (Process Economics Program) (Vaswani, 2010)'s 3.0 €/kg bio-SA product value at best case design capacity. SA from agro-wastes might replace several petro-based chemicals, reducing GHG emissions by 94% (Lin et al., 2013). SA fermentation is traditionally batch-based and uses pure substrates, however there are few investigations on mixed agro-waste and designed strains that can metabolise carbohydrate-rich waste (Kiran et al., 2015). Metabolic and evolutionary engineering yeast may enhance yield, concentration, byproducts, and strain adaptation to agro-wastes' carbon sources and inhibitors.

5. Challenge IV: Promoting agriculture residue business in a circular bio-economy context

Frosch and Gallopoulos (1989) presented industrial ecology in eco-industrial parks in the 1990s. Such a system uses "wastes from one industrial process as raw materials for another, reducing industry's environmental impact". Eco-industrial parks are communities of manufacturing and service enterprises that collaborate to manage energy, water, and materials to improve environmental and economic performance. By cooperating, the community of businesses seeks a collective gain higher than the sum of the individual advantages each firm would have obtained by optimising its interests (Lowe, Moren and Holmes, 1996). Current eco-industrial parks focus on inter-company cooperation to optimize resource efficiency, dubbed industrial symbiosis. Danish “Kalundborg” is the most renowned example (http://www.symbiosis.dk/en). Few research identify success factors and constraints to eco-industrial park implementation worldwide (Massard, Jacquat and Zu€rcher, 2014). Industrial Ecology demands a new view of customer-supplier interactions, new organizational forms, and new business models at the intersection of value chains, making implementation challenging.
Eco-industrial parks often focus on petrochemical, chemical, or diversified industries, with few projects and research using farm leftovers for cross-chain valorisation. One agro-industrial ecosystem in France (Bazancourt-Pomacle Biorefinery, Schieb et al., 2015) and a state-owned conglomerate operating China's largest sugar refinery with over 3,800 workers and 14,700 ha land to cultivate and use all sugar cane byproducts since more than four decades are completed projects.

The bio-economy has yet to completely integrate the agro-food industry. R&D, business modeling, and framework conditions must favor such integration and allow a complete conversion, similar to a petro-chemical refinery, of the full fresh weight of harvested crops (food plus agriculture residue mass) into food/feed, bio-energy, and bio-products to increase agricultural biomass without affecting land uses or plant productivity. Developing a cross-sectorial vision that reviews the entire value of the agriculture residue chain is needed to bridge the gap between innovative agriculture residue upgrading technologies and business opportunities for better environmental benefit and added value.

For each case study cross-sectoral value chain, a focused investigation of eco-innovative business models and a robust business model generating process may provide a few business model possibilities. This may also help identify and address important hurdles via framework changes (new rules, incentives) or marketing and communication to demonstrate advantages and increase market adoption. Technological and scientific advances, including territorial approach, will show which options benefit from local or regional proximity and fit in locally designed agro-parks promoting bio-economy and industrial symbiosis in food, feed, energy, and bio-products sectors. Better understanding of agriculture residue molecular complexity and heterogeneity and optimal streams (mostly organic and conventional) management can help diversify energy feedstocks like biogas, materials and commodities like agro-chemicals, polymers, and others. Innovative locally adaptive solutions for converting agricultural waste into biogas and bio-products, or intermediate chemical building blocks, should be deployed at full scale and their expertise shared. This strategy may double biogas output by 2020 to reach 1.5% of the EU's primary energy supply and 5% of its natural gas consumption, according to the National Renewable Energy Action Plans (European Commission, 2018). It may help achieve 2030 EU waste objectives, including €600 billion in net savings for EU enterprises, 30% increase in resource productivity, 1% GDP growth, and 2 million job creation. To promote circular economy, European and national waste policies should prioritize defined targets and eco-efficiency initiatives, including industrial symbiosis (materials, water, energy, and heat).

6. Challenge V: Connecting stakeholders and sharing knowledge about agriculture residue management

Due to lags in agricultural growth in many EU nations, environmental and socio-economic challenges are exacerbated in certain regions/supply chains. As said (Challenge I), arable areas without animals have soil nutrient depletion, yet livestock rearing zones have abundant nutrients, odorous compounds, methane emissions, and infections. However, metropolitan areas import a lot of food and have serious ecological repercussions from wastewater and sewage sludge organic nutrient load (Buckwell, Heissenhuber and Blum, 2014). Most farm residue conversion procedures don't meet territorial environmental and economic goals, which hinders their growth. Dedicated crops frequently replace agricultural leftovers for economic and supply reasons, such as biogas feedstock fodder maize taking up a substantial proportion of biomass cropping land in Germany. Addressing these obstacles requires increasing stakeholder awareness and interaction across sectors. The production stage is highly organized at national and European levels by winery, cattle, and cereal producers and farmers' groups. However, smart agriculture residue chains clearly require cross-sector dialogue and the addition of other actors (e.g. converters, end-users, waste management, CSO representatives, knowledge providers, regional and national policy makers, etc.) to properly address sustainability challenges and market opportunities, both in terms of resources and end-products, according to possible territorial scales determined by several factors. However, agriculture residue valorisation interacts with energy, raw material, pollutants, and pathogens systems (Mo€ller, 2015). Spatial data infrastructures and databases on agricultural residues are required for territorial and socio-economic land planning strategies and optimum resource use, considering the INSPIRE Directive 2007/2/EC (European Commission, 2007a) as an umbrella resource. GIS technology supports spatial/territorial analysis of waste production streams, collection, trans-port facilities, treatment plant availability, specific soil needs and water quality issues, substitutable product flow, population and economic growth, and job creation (Josimovic et al., 2015). Co-generation of electricity and heat with block power plants makes biogas production sensible. District heating or long-distance heating for individual residences or business are the greatest ways to sell heat. Most agricultural wastes are found distant from metropolitan areas, and husbandry farms are established far from individual homes to reduce noise and smell disturbances. Thus, biogas-generated heat is hard to valorize unless it is utilized to locally dry agricultural goods.

7. Conclusions

This paper aims to provide a transdisciplinary and holistic view of how to coherently address key research challenges in agricultural residues management, including existing and missing scientific knowledge and technological, social, economic, and environmental impacts. Each challenge's major findings and suggestions are below. A suitable evaluation strategy that addresses seasonality, regionality, and complexity of agricultural resource management chains is still needed. Thus, bioconversion technologies need cross-disciplinary, multi-criteria, multi-scale, and multi-actor environmental and economic performance evaluation methodologies (really multi-criteria decision tools). These tactics should enable bench-scale eco-design from the start of research and development. To assess the full potential of substantial bioconversion technology investments, indirect effects of future technical breakthroughs on society must be evaluated. Based on geographical and seasonal AD waste feed streams and digestate nutrients distribution, and by investigating new technological options to extend AD applicability (especially regarding lignocellulosic feedstock digestibility) and increase eco-efficiency, end-products (energy, nutrients, and bio-polymers) safety, and economic value, conventional AD performance must be improved.

References

Aeschelmann, F., Carus, M., Baltus, W., Carrez, D., Guzman, D., K€ab, H., … Ravenstijn, J. (2017). Bio-based building blocks and polymers: global capacities and trends 2016–2021. Nova Institute GmbH and Europeans Bioplastics Association.

Ahring, B. K., Biswas, R., Ahamed, A., Teller, P. J., & Uellendahl, H. (2015). Making lignin accessible for anaerobic digestion by wet-explosion pretreatment. *Bioresource Technology*, *175*, 182–188.

Alizadeh, H., Teymouri, F., Gilbert, T. I., & Dale, B. E. (2005). Pretreatment of switchgrass by ammonia fiber explosion (AFEX). *Applied Biochemistry and Biotechnology*, *124*(1–3), 1133–1134.

Allied Market Research. (2014). *Bio Succinic Acid Market by Application (1-Butanediol,4- Butanediol (BDO), Polyester Polyols, PBS, Plasticizers, Solvents & lubricants, Alkyd Resins, Resins, coatings, pigments, De-icer solutions): Global Opportunity Analysis and Industry Forecast, 2013–2020.*

Al-Oqla, F., Sapuan, M. S., Ishak, M. R., & Aziz, N. A. (2014). Combined Multi-criteria evaluation stage technique as an agro waste evaluation indicator for polymeric compo- sites: date palm fibers as a case study. *BioResources*, *9*(3), 4608–4621.

Andriani, D., Wresta, A., Atmaja, T. D., & Saepudin, A. (2014). A review on optimization production and upgrading biogas through CO_2 removal using various techniques. *Applied Biochemistry and Biotechnology*, *172*(4), 1909–1928.

Angelidaki, I., Treu, L., Tsapekos, P., Luo, G., Campanaro, S., Wenzel, H., & Kougias, P. G. (2018). Biogas upgrading and utilization: Current status and perspectives. *Biotechnology Advances*, *36*(2), 452–466.

Aouf, C., Benyahya, S., Esnouf, A., Caillol, S., Boutevin, B., & Fulcrand, H. (2014). Tara tannins as phenolic precursors of thermosetting epoxy resins. *European Polymer Journal*, *55*, 186–198.

Avadi, A., Nitschelm, L., Corson, M., & Vert`es, F. (2016). Data strategy for environmental assessment of agricultural regions via LCA: Case study of a French catchment. *The International Journal of Life Cycle Assessment*, *21*(4), 476–491.

Barakat, A., de Vries, H., & Rouau, X. (2013). Dry fractionation process as an important step in current and future lignocellulose biorefineries: a review. *Bioresource Technology*, *134*, 362–373.

Battini, F., Agostini, A., Boulamanti, A. K., Giuntoli, J., & Amaducci, S. (2014). Mitigating the environmental impacts of milk production via anaerobic digestion of manure: Case study of a dairy farm in the Po Valley. *The Science of the Total Environment*, *481*, 196–208.

Bellarby, J., Tirado, R., Leip, A., Weiss, F., Lesschen, J. P., & Smith, P. (2013). Livestock greenhouse gas emissions and mitigation potential in Europe. *Global Change Biology*, *19*(1), 3–18.

Berthet, M. A., Angellier-Coussy, H., Guillard, V., & Gontard, N. (2016). Vegetal fibre- based biocomposites: Which stakes for food packaging applications? *Journal of Applied Polymer Science*, *133*(2).

Berthet, M. A., Coussy, H., Chea, V., Guillard, V., Gastaldi, E., & Gontard, N. (2015). Sustainable food packaging: Valorising wheat straw fibres for tuning PHBV-based com- posites properties. *Composites Part A: Applied Science and Manufacturing*, *72*, 139–147.

Berthet, M. A., Mayer-Laigle, C., Rouau, X., Gontard, N., & Angellier-Coussy, H. (2017). Sorting natural fibres: A way to better understand the role of fibre size polydispersity on the mechanical properties of biocomposites. *Composites: Part A*, *95*, 12–21.

Blasco-Go´mez, R., Batlle-Vilanova, P., Villano, M., Balaguer, M., Colprim, J., & Puig, S. (2017). On the edge of research and technological application: a critical review of elec- tromethanogenesis. *International Journal of Molecular Sciences*, *18*(4), 874.

Bolzonella, D., Gottardo, M., Fatone, F., & Frison, N. (2017). Nutrients recovery from anaerobic digestate of agro-waste: techno-economic assessment of full scale applications. *Journal of Environmental Management*, *216*, 111–119.

Bolzonella, D., Battista, F., Cavinato, C., Gottardo, M., Micolucci, F., Lyberatos, G., & Pavan, P. (2018). Recent developments in biohythane production from household food wastes: A review. *Bioresource Technology*, *257*, 311–319.

Buckwell, A., Heissenhuber, A., & Blum, W. (2014). The *sustainable intensification of euro- pean agriculture*. A Review Sponsored by the RISE Foundation.Budde, J., Prochnow, A., Plo€chl, M., Su´arez Quinones, T., & Heiermann, M. (2016). Energy balance, greenhouse gas emissions, and profitability of thermobarical pretreatment of cat- tle waste in anaerobic digestion. *Waste Management*, *49*, 390–410.

Bugnicourt, E., Cinelli, P., Lazzeri, A., & Alvarez, V. (2014). Polyhydroxyalkanoate (PHA): Review of synthesis, characteristics, processing and potential applications in packaging. *Express Polymer Letters*, *8*(11), 791–808.

Bundhoo, Z. M. A., & Mohee, R. (2018). Ultrasound-assisted biological conversion of bio- mass and waste materials to biofuels: A review. *Ultrasonics - Sonochemistry, 40*, 298–313. Carrere, H., Antonopoulou, G., Affes, R., Passos, F., Battimelli, A., Lyberatos, G., & Ferrer, I. (2016). Review of feedstock pretreatment strategies for improved anaerobic digestion: From lab-scale research to full-scale application. *Bioresource Technology*, *199*, 386–397.

Carvalho, G., Oehmen, A., Albuquerque, M. G. E., & Reis, M. A. M. (2014). The relation- ship between mixed microbial culture composition and PHA production performance from fermented molasses. *New Biotechnology*, *31*(4), 257–263.

Cavinato, C., Da Ros, C., Pavan, P., & Bolzonella, D. (2017). Influence of temperature and hydraulic retention on the production of volatile fatty acids during anaerobic fermenta- tion of cow manure and maize silage. *Bioresource Technology*, *223*, 59–64.

Chae, Y., & An, Y. J. (2017). Effects of micro- and nanoplastics on aquatic ecosystems: Current research trends and perspectives. *Marine Pollution Bulletin*, *124*(2), 624–632.

Chen, G. Q. (2009). A microbial polyhydroxyalkanoates (PHA) based bio- and materials industry. *Chemical Society Reviews*, *38*(8), 2434.

Chen, G. Q. (2010). Industrial production of PHA. In G. Q. Chen, (Ed.), *Plastics from bac- teria. microbiology monographs* (vol. 14). Heidelberg, Germany: Springer.

Choi, J., & Lee, S. Y. (1999). Factors affecting the economics of polyhydroxyalkaonoate pro- duction by bacterial fermentation. *Applied Microbiology and Biotechnology*, *51*(1), 13–21.

Corona, A., Parajuli, R., Ambye-Jensen, M., Hauschild, M. Z., & Birkved, M. (2018). Environmental screening of potential biomass for green biorefinery conversion. *Journal of Cleaner Production*, *189*, 344–357.

Costa, R., Saraiva, A., Carvalho, L., & Duarte, E. (2014). The use of biodegradable mulch films on strawberry crop in Portugal. *Scientia Horticulturae*, *173*, 65–70.

Croxatto Vega, G. C., Hoeve, M., Birkved, M., Sommer, S. G., & Bruun, S. (2014). Choosing co-substrates to supplement biogas production from animal slurry: A life cycle assessment of the environmental consequences. *Bioresource Technology*, *171*, 410–420.

Deepa, A. K., & Dhepe, P. L. (2015). Lignin depolymerization into aromatic monomers over solid acid catalysts. *ACS Catalysis*, *5*(1), 365–379.

Domański, J., Marchut-Mikołajczyk, O., Polewczyk, A., & Januszewicz, B. (2017). Ozonolysis of straw from *Secale cereale* L. for anaerobic digestion. *Bioresource Technology*, *245*, 394–400.

Dugmore, T. I. J., Clark, J. H., Bustamante, J., Houghton, J. A., & Matharu, A. S. (2017). Valorisation of biowastes for the production of green materials using chemical methods. *Topics in Current Chemistry*, *375*(2), 46.

Dumas, C., Silva, G., Damasceno, G., Barakat, A., Carr`ere, H., Steyer, J. P., & Rouau, X. (2015). Effects of grinding processes on anaerobic digestion of wheat straw. *Industrial Crops and Products*, *74*, 450–445.

Durham, E., Baker, H., Smith, M., Moore, E., & Morgan, V. (2014). *The BiodivERsA stake- holder engagement handbook*. Paris: BiodivERsA .

EBA. (2018). Statistical Report of the European Biogas Association (EBA). 7th edition.

EEC. (1991). Council Directive 91/676/EEC of 12 December 1991 concerning the protec- tion of waters against pollution caused by nitrates from agricultural sources. *Official Journal of the European Communities*, No. L 375/1, 31.12.1991.

Eerhart, A. J. J. E., Faaij, A. P. C., & Patel, M. K. (2012). Replacing fossil based PET with biobased PEF; process analysis, energy and GHG balance. *Energy & Environmental Science*, *5*(4, 6407.

Elbersen, B., Startisky, I., Hengeveld, G., Schelhaas, M. J., & Naeff, H. (2012). *Atlas of EU biomass potentials*. Biomass Futures Project Project Deliverable 3.3.

European Commission. (2007a). Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). Official Journal of the European Union, No. L108/125.4.2007.

European Commission. (2007b). Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91.*Official Journal of the European Union*, 189 20.7.2007, 1.

European Commission (2008). Commission Regulation (EC) No 889/2008 of 5 September 2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control. Official Journal of the European Union, No. L 250/ 118.9.2008.

European Commission. (2018). European Commission Renewable Energy National Action Plans.
European Union. (2013). Regulation (EU) N° 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No. 1698/2005. Official Journal of the European Union, No. L 347/487, 2012. 2013.
Eurostat. (2015). *Consumption of inorganic fertilizers*.
Fabbri, D., & Torri, C. (2016). Linking pyrolysis and anaerobic digestion (Py-AD) for the conversion of lignocellulosic biomass. *Current Opinion in Biotechnology*, *38*, 167–173.
FAO (2011). "*Energy-smart*" *food for people and climate*. Issue Paper. Food and Agriculture Organization of the United Nations.
FAO. (2014). AQUASTAT Website.
Fava, F., Totaro, G., Diels, L., Reis, M., Duarte, J., Beserra Carioca, O., … Sommer Ferreira, B. (2015). Biowaste biorefinery in Europe: opportunities and research & development needs. *New Biotechnology*, *32*(1), 100–108.
Feng, Q., & Lin, Y. (2017). Integrated processes of anaerobic digestion and pyrolysis for higher bioenergy recovery from lignocellulosic biomass: A brief review. *Renewable and Sustainable Energy Reviews*, *77*, 1272–1287.
Fiorentino, G., Ripa, M., & Ulgiati, S. (2017). Chemicals from biomass: technological versus environmental feasibility: A review. *Biofuels, Bioproducts and Biorefining*, *11*(1), 195–214.
Foged, H. L., Flotats, X., Blasi, A. B., Palatsi, J., Magri, A., & Schelde, K. M. (2011). Inventory of manure processing activities in Europe. Technical Report No. I concerning "Manure Processing Activities in Europe" to the European Commission, Directorate General Environment; 138p.
FPA (2017). *U.S. flexible packaging: State of the industry report 2017*. Flexible Packaging Association.
Fradinho, J. C., Oehmen, A., & Reis, M. A. M. (2014). Photosynthetic mixed culture poly-hydroxyalkanoate (PHA) production from individual and mixed volatile fatty acids (VFAs): Substrate preferences and co-substrate uptake. *Journal of Biotechnology*, *185*, 19–27.Fritsch, C., Staebler, A., Happel, A., Cubero-M´arquez, M. A., Aguilo´-Aguayo, I., Abadias, M., … Belotti, G. (2017). Processing, valorization and application of bio-waste derived compounds from potato, tomato, olive and cereals: A review. *Sustainability*, *9*(8), 1492.
Frosch, D., & Gallopoulos, N. (1989). Strategies for manufacturing. *Scientific American*, *261*(3), 144–102.
Galloway, T. S. (2015). Micro- and nano-plastics and Human Health. In M. Bergmann, L. Gutow, & M. Klages, (Eds.), *Marine anthropogenic litter*. New York: Springer International Publishing.
Gioia, C., Banella, M. B., Marchese, P., Vannini, M., Colonna, M., & Celli, A. (2016). Advances in the synthesis of bio-based aromatic polyesters: novel copolymers derived from vanillic acid and e-caprolactone. *Polymer Chemistry*, *7*(34), 5396–5406.
Goldstein, B., Birkved, M., Quitzau, M. B., & Hauschild, M. (2013). Quantification of urban metabolism through coupling with the life cycle assessment framework: concept development and case study. *Environmental Research Letters*, *8*(3), 035024.
Grand View Research. (2016). Polyphenols market analysis by product (Grape seed, green tea, apple), By application (Functional food, functional beverages, dietary supplements) and segment forecasts to 2024. Market research report.
Harmsen, P. F. H., Hackmann, M. M., & Bos, H. L. (2014). Green building blocks for bio- based plastics. *Biofuels, Bioproducts and Biorefining*, *8*(3), 306–324.
Hendriks, A. T. W. M., & Zeeman, G. (2009). Pretreatments to enhance the digestibility of lignocellulosic biomass. *Bioresource Technology*, *100*(1), 10–18.
Hilliou, L., Machado, D., Oliveira, C. S. S., Gouveia, A. R., Reis, M. A. M., Campanari, S., … Majone, M. (2016). Impact of fermentation residues on the thermal, structural, and rheological properties of polyhydroxy(butyrate-co-valerate) produced from cheese whey and olive oil mill wastewater. *Journal of Applied Polymer Science*, *133*(2), 42818.
Hilliou, L., Teixeira, P. F., Machado, D., Covas, J. A., Oliveira, C. S. S., Duque, A. F., & Reis, M. A. M. (2016). Effects of fermentation residues on the melt processability and thermomechanical degradation of PHBV produced from cheese whey using mixed microbial cultures. *Polymer Degradation and Stability*, *128*, 269–277.
Hospido, A., Davis, J., Berlin, J., & Sonesson, U. (2010). A review of methodological issues affecting LCA of novel food products. *The International Journal of Life Cycle Assessment*, *15*(1), 44–52.

Hűbner, T., & Mumme, J. (2015). Integration of pyrolysis and anaerobic digestion: Use of aqueous liquor from digestate pyrolysis for biogas production. *Bioresource Technology*, *183*, 86–92.
Hurni, H., Giger, M., Liniger, H., Studer, R. M., Messerli, P., Portner, B., … Breu, T. (2015). Soils, agriculture and food security: the interplay between ecosystem functioning and human well-being. *Current Opinion in Environmental Sustainability*, *15*, 25–34.
Ipsen, K., L., Zimmermann, R., K., Nielsen, P., S., & Birkved, M. (2018). Environmental assessment of Smart City Solutions using a coupled urban metabolism—life cycle impact assessment approach. *International Journal of Life Cycle Assessment*.
ISO 14040. (2006). ISO 14040:2006 Environmental management-Life cycle assessment: Principles and framework.
Jang, Y. S., Kim, B., Shin, J. H., Choi, Y. J., Choi, S., Song, C. W., … Lee, S. Y. (2012). Bio-Based Production of C2–C6 platform chemicals. *Biotechnology and Bioengineering*, *109*(10), 2437–2459.
Josimovic, B., Maric, I., & Milijic, S. (2015). Multi-criteria evaluation in strategic environ- mental assessment for waste management plan: a case study. *Waste Management Journal*, *36*, 331–342.
Kennedy, C., Cuddihy, J., & Engel-Yan, J. (2007). The changing metabolism of cities. *Journal of Industrial Ecology*, *11*(2), 43–59.
Khan, I. U., Othman, M. H. D., Hashim, H., Matsuura, T., Ismail, A. F., Rezaei- DashtArzhandi, M., & Wan Azelee, I. (2017). Biogas as a renewable energy fuel: A review of biogas upgrading, utilisation and storage. *Energy Conversion and Management*, *150*, 277–294.
Kim, B. S. (2000). Production of poly(3-hydroxybutyrate) from inexpensive substrates. *Enzyme Microb. Technol*, *27*(10), 774–777.
Kiran, E. U., Trzcinski, A. P., & Liu, Y. (2015). Platform chemical production from food wastes using a biorefinery concept. *Journal of Chemical Technology & Biotechnology*, *90*(8), 1364–1379.
Kirschweng, B., T´atraaljai, D., F€oldes, E., & Puk´anszky, B. (2017). Natural antioxidants as stabilizers for polymers. *Polymer Degradation and Stability*, *145*, 25–40.
Kourmentza, C., Pl´acido, J., Venetsaneas, N., Burniol-Figols, A., Varrone, C., Gavala, H. N., & Reis, M. A. M. (2017). Recent advances and challenges towards sustainable polyhy- droxyalkanoate (PHA) production. *Bioengineering*, *4*(4), 55.
Lammi, S., Barakat, A., Mayer-Laigle, C., Djenane, D., Gontard, N., & Angellier-Coussy, H. (2018). Dry fractionation as a sustainable process to produce fillers from olive pomace for biocomposites. *Powder Technology*, *326*, 44–53.
Laurent, A., Olsen, S. I., & Hauschild, M. Z. (2010). Carbon footprint as environmental performance indicator for the manufacturing industry. *CIRP Annals – Manufacturing Technology*, *59*(1), 37–40.
Lin, C. S. K., Luque, R., Clark, J. H., Webb, C., & Du, C. (2012). Wheat-based biorefining strategy for fermentative production and chemical transformations of succinic acid. *Biofuels, Bioproducts and Biorefining*, *6*(1), 88–104.
Lin, C. S. K., Pfaltzgraff, L. A., Herrero-Davila, L., Mubofu, E. B., Abderrahim, S., Clark, J. H., … Luque, R. (2013). Food waste as a valuable resource for the production of chem- icals, materials and fuels. Current situation and global perspective. *Energy and Energy & Environmental Science*, *6*(2), 426–464.
Loiseau, E., Roux, P., Junqua, G., Maurel, P., & Bellon-Maurel, V. (2013). Adapting the LCA framework to environmental assessment in land planning. *The International Journal of Life Cycle Assessment*, *18*(8), 1533–1548.
Loiseau, E., Aissani, L., Le F´eon, S., Laurent, F., Cerceau, J., Sala, S., & Roux, P. (2018). Territorial Life Cycle Assessment (LCA): What exactly is it about? A proposal towards using a common terminology and a research agenda. *Journal of Cleaner Production*, *176*, 474–485.
Lowe, E. A., Moren, S. R., & Holmes, D. B. (1996). *Fieldbook for the Development of Eco- Industrial Parks*. Final Report. U.S. Environmental Protection Agency.
Markets and Markets. (2015). *Antimicrobial Plastic Market by Type (Commodity Plastic, Engineering Plastic, and High Performance Plastic*) by Application (Healthcare, Packaging, Consumer Goods, Automotive, Construction, and Others) & by Region: Global Forecast to 2020.
Massard, G., Jacquat, O., & Zűrcher, D. (2014). *International survey on ecoinnovation parks. Learning from experiences on the spatial dimension of eco-innovation*. Federal Office for the Environment (FOEN) and the ERANET ECO-INNOVERA, Bern. Environmental studies no. 1402; 310p.

Mazzi, A., Toniolo, S., Catto, S., De Lorenzi, V., & Scipioni, A. (2017). The combination of an environmental management system and life cycle assessment at the territorial level. *Environmental Impact Assessment Review*, *63*, 59–71.

Merlin, G., & Boileau, H. (2013). Anaerobic digestion of agricultural waste: state of the art and future trends. In A. Torres, (Ed.), *Anaerobic digestion: types, processes and environ- mental impact*. New York: Nova Science Publishers, Inc.

Mialon, L., Pemba, A. G., & Miller, S. A. (2010). Biorenewable polyethylene terephthalate mimics derived from lignin and acetic acid. *Green Chemistry*, *12*(10), 1704–1706.

Michałowicz, J. (2014). Bisphenol A-sources, toxicity and biotransformation. *Environmental Toxicology and Pharmacology*, *37*(2), 738–758.

Micolucci, F., Gottardo, M., Bolzonella, D., & Pavan, P. (2014). Automatic process control for stable bio-hythane production in two-phase thermophilic anaerobic digestion of food waste. *International Journal of Hydrogen Energy*, *39*(31), 17563–17572.

Mo€ller, J., Boldrin, A., & Christensen, T. H. (2009). Anaerobic digestion and digestate use: Accounting of greenhouse gases and global warming contribution. *Waste Management & Research*, *27*(8), 813–824.

Mo€ller, K. (2015). Effects of anaerobic digestion on soil carbon and nitrogen turnover, N emissions, and soil biological activity. A review. *Agronomy for Sustainable Development*, *35*(3), 1021–1041.

Mo€ller, K., & Müller, T. (2012). Effects of anaerobic digestion on digestate nutrient availability and crop growth: A review. *Engineering in Life Sciences*, *12*(3), 242–257.

Monlau, F., Barakat, A., Trably, E., Dumas, C., Steyer, J., & Carr`ere, H. (2013). Lignocellulosic materials into biohydrogen and biomethane: Impact of structural features and pretreatment. *Critical Reviews in Environmental Science and Technology*, *43*(3), 260–322.

Monlau, F., Sambusiti, C., Antoniou, N., Barakat, A., & Zabaniotou, A. (2015). A new con- cept for enhancing energy recovery from agricultural residues by coupling anaerobic digestion and pyrolysis process. *Applied Energy*, *148*, 32–38.

Njakou Djomo, S., Witters, N., Van Dael, M., Gabrielle, B., & Ceulemans, R. (2015). Impact of feedstock, land use change, and soil organic carbon on energy and greenhouse gas performance of biomass cogeneration technologies. *Applied Energy*, *154*, 122–130.

Totaro, G., Sisti, L., Vannini, M., Marchese, P., Tassoni, A., Lenucci, M. S., … Celli, A. (2018). A new route of valorization of rice endosperm by-product: Production of poly- meric biocomposites. *Composites Part B: Engineering*, *139*, 195–202.

UNEP. (2011). *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication*.

van Es, D. S. (2013). Rigid biobased building blocks. *Journal of Renewable Materials*, *1*(1), 61–72.

Vaswani, S. (2010). P. E. P., & Review, *2010*1. Bio-Based Succinic Acid. SRI Consulting.

Villano, M., Scardala, S., Aulenta, F., & Majone, M. (2013). Carbon and nitrogen removal and enhanced methane production in a microbial electrolysis cell. *Bioresource Technology*, *130*, 366–371.

Wang, X., Li, Z., Zhou, X., Wang, Q., Wu, Y., Saino, M., & Bai, X. (2016). Study on the bio-methane yield and microbial community structure in enzyme enhanced anaerobic co-digestion of cow manure and corn straw. *Bioresource Technology*, *219*, 150–157.

Weastra. (2013). Determination of market potential for selected platform chemicals: Itaconic acid, Succinic acid, 2,5-Furandicarboxylic acid. WP8.1 FP7 BioConSept Project.

Weiss, F., & Leip, A. (2012). Greenhouse gas emissions from the EU livestock sector: a life cycle assessment carried out with the CAPRI model. *Agriculture, Ecosystems and Environment*, *149*, 124–134.

White, J. F., Werpy, T., & Holladay, J. E. (2004). Top Value Added Chemicals from Biomass: Results of screening for potential candidates from sugars and synthesis gas, Volume 1. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

Wolman, A. (1965). The metabolism of cities. *Scientific American*, *213*, 179–190.

Xu, H., Wang, K., & Holmes, D. E. (2014). Bioelectrochemical removal of carbon dioxide (CO_2): An innovative method for biogas upgrading. *Bioresource Technology*, *173*, 392–398.