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Review Paper

Review of ecosystem services in a bio-based circular economy and governance mechanisms

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A R T I C L E I N F O

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A B S T R A C T

This paper reviews the literature relating to a type of local bio-based circular economy (BCE) where food waste (FW) is effectively recycled to advanced bio-refineries to produce multiple ecosystem services (ES) including energy, biofertilizer and other value-added products and services. The biofertilizer is applied within urban and peri-urban farms to close the bioresource loop. Such BCE concept has been proposed in several EU countries with varying degree of success in long-term operations. We systematically review the ES of BCE and identify the ES, which are not properly compensated by the market. On this basis, we further review the potential regulatory and supporting mechanisms, which could incentivize the successful implementation of BCE and overcome the market/policy failures. We find that single regulatory instrument at the government and authority level could be compromised by poor governance and practices at other levels, and therefore may not reach its full potential. Instead, we propose a multi-level regulatory and supporting system, which combines the strengths of top-down and bottom-up governances and motivates the self-governance of industry and citizens. We conclude by highlighting a need for multi-level governance research supporting urban sustainable transitions, with a focus on constructing 'policy portfolios' from a systems perspective to better engage government, firms, citizens and other stakeholders.

1. Introduction

As a new economic paradigm, circular economy (CE) views the economic system as a closed-loop resource management system, gradually replacing linear and open-ended, hence waste generating systems (Fig. 1). In the traditional system, the economy has developed with insufficient internal tendency to recycle, treating the environment as a waste reservoir. In the CE landscape, waste generation is prevented and materials are reused or recirculated as valuable resources within emerging product/service systems (Singh and Ordoñez, 2016).

Food Loss (FL) and Waste (FW) are one of the most serious challenges human face today. Around one third of global food produced for human consumption is wasted, which is worth over \$2.6 trillion (FAO, 2020). In EU, about 88 million tons of food are wasted every year, equivalent to 173 kilos per person (Lanfranchi and Giannetto, 2017), most of which are discarded for landfill or incineration (EC, 2020; World Biogas Association, 2018). It is not only a waste of resources but also contributes to climate and environmental change resulting from increasing carbon emissions, natural resource, water and land use (World Biogas Association, 2018). During the past decades, urban farming and food systems have developed rapidly and attracted the attentions of academicians, policymakers and practitioners, both in developing and developed countries as a potential solution towards resilient and resource-saving food production systems (Christensen, 2007). Local food production with urban farming has become an important option for stakeholders to create urban resilience, especially in the light of climate change but also as a measure to increase urban permeability and reduce the risk of flooding. It has been proven that urban farming presents a potential solution to provide food and other benefits within unexploited spaces within the build environment (Clinton et al., 2018; Edmondson et al., 2020). From the sustainability point of view, using unavoidable and inedible FW fractions as feedstock for FW-based biorefineries, which returns renewable energy, affordable nutrients and a range of biobased ecosystem services, is an important environmental innovation and could be a strong driver for sustainable social transition.

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Nomenclature

AD	Anaerobic Digestion
BCE	Bio-based Circular Economy
BMP	BioMethane Potential
CAC	Command and Control
CAP	Common Agricultural Policy
CAS	Civic Amenity Sites
CAT	Cap and Trade
CE	Circular economy
C/N	Carbon to Nitrogen ratio
COD	Chemical Oxygen Demand
DM	Dry matter
EC	European Commission
EIB	European Investment Bank
ES	Ecosystem services
FL	Food Loss
FW	Food Waste
IFEP	Integrated Framework for Encouraging Pro-Environmental Behavior
ISR	Industry Self-Regulation
K	Potassium
KAB	Knowledge-Attitude-Behavior
LAI	Leaf-Area-Index
LE	Linear Economy
MBT	Mechanical-Biological-Treatment
MEA	Millennium Ecosystem Assessment
N	Nitrogen
P	Phosphorus
PAYT	Pay as You Throw
PPP	Public-Private-Partnership
RM	Reward Mechanism
SDG	Sustainable Development Goal
SME	Small and Medium Enterprise
SSF	Solid-State Fermentation
TAN	Total Ammonia Nitrogen
TS	Total Solids
UF	Urban Farm
VFA	Volatile Fatty Acids
VS	Volatile Solids
WTP	Willingness to Pay

Advances in biotechnology have made this type of Bio- based circular economy (BCE) models possible. Anaerobic Digestion (AD) has been proposed as a relatively cost-effective technology for treatment of biomass and organic wastes of high-moisture, producing renewable energy and nutrient-rich residues which can be applied back into farming as biofertilizers if the micro-pollutant content is below specified levels as defined in the new fertilizer regulation (Sheets et al., 2015). Compared to other existing bioenergy technologies, AD can be adapted to a wide range of substrates, even those with high moisture contents ranging from 54 to 87% for food waste (Bhatt and Tao, 2020) and impurities (up to 18% on the weight basis) (Tormo, 2015), although the optimal operation of AD with minimum mechanical problems requires the pretreatment of substrates (Carlsson, 2015). Furthermore, AD can be implemented in both large and small scale digesters and at various geographical locations, which makes it especially promising for treating food waste and providing energy and fertilizers in the urban applications of BCE models as discussed by Appels et al. (2011) and Thiriet et al. (2020).

Although AD is already a relatively mature and widely applied technology in the treatment of biomass and organic waste, e.g. wastewater, sludge, and animal manure, its application in BCE contexts (e.g. adopting AD for FW to support urban and peri-urban farming) still faces technical, economic, and social challenges (Angouria-Tsorochidou and Thomsen, 2021). In the US, only less than 2% of food waste is anaerobically digested, while most of food waste is still incinerated or landfilled (Food Waste Reduction Alliance, 2016). BCE provides many social and environmental benefits in addition to the economic outputs, but most of them are not properly compensated by the current market setting (ING, 2015), which represents a barrier for BCE models to become economically viable in practice. Traditionally, the BCE is focused on technological systems, but it can also benefit from an overall understanding of its connected human-ecological systems (i.e. ecosystems) (Wojtach, 2016). Knowledge of ecosystem services (ES) obtained from BCE could provide stakeholders with more information allowing for this type of nature-based value creation to be included in their decision-making frameworks. Therefore, **our first aim** is to systemically review the ES from BCE model (Fig. 1) with focus on identifying non-market ES, by asking the question 'what are ES from local BCE within the urban areas?'.

Although in general CE has shown its superiority in many areas, the

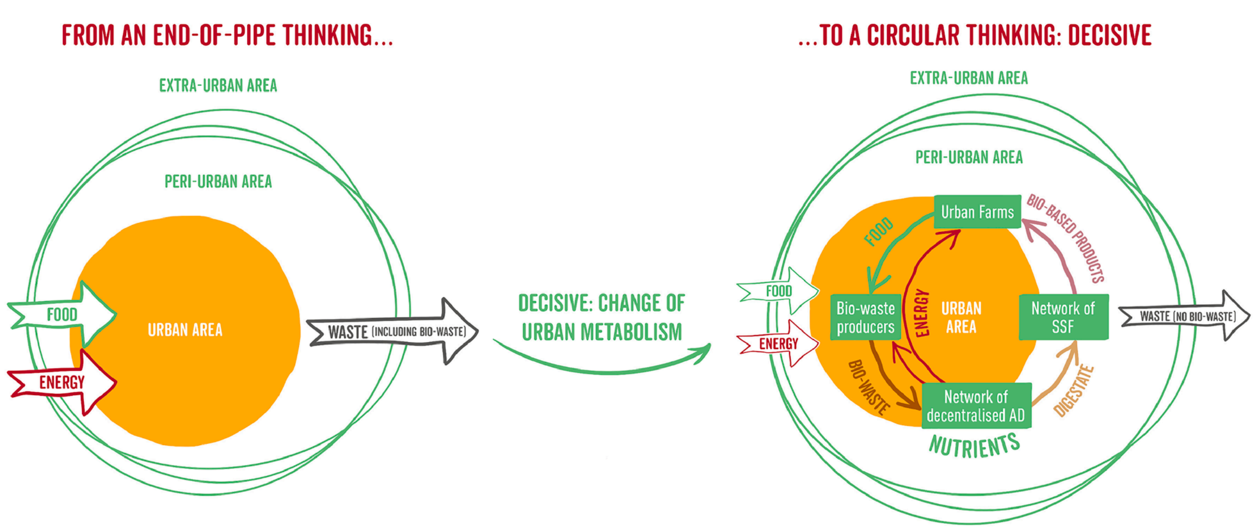

Fig. 1. Transition from end-of-pipe thinking to circular thinking(http://www.decisive2020.eu/the-project/).

Linear Economy (LE) has been the dominant paradigm for decades and still has its competitive advantage in the current market setting. The European Commission (EC) has identified several potential reasons why some economies are still locked into the linear models. At the micro level, it could be still more profitable for companies to pursue the linear model (even if the overall impacts on society are negative). This is due to the following: 1) the negative environmental and social impacts (externalities) of LE operations are not fully penalized in the current market setting (market failure); 2) the impact of cumulative effects of production and consumption in LE (such as resource depletion, pollution, and climate change) are ignored by companies and 3) short-term profits and dividends to shareholders are often prioritized compared to long-term targets such as sustainable development.

In the current market setting, the market failure to incorporate all costs and benefits leads to low competitiveness of products/services in CE compared to in LE. The market failure does neither reflect the resource scarcity and environmental costs nor provide full monetary compensation for all the goods and services of CE. However, LE have been driven by such market failures for a long time, which makes a transition to CE a threat to the long-established market players. Moreover, efforts to establish a CE model through price instruments (such as fees, taxes and subsidies) are seen as a burden to existing dominating markets players, rather than an essential adjustment to the market failure in LE, which could receive many resistances (Houston et al., 2018). In addition to pricing mechanism adjustments pushing a transition to CE, there are also other concerns at different regulatory/supporting levels. For example, during the transition to the CE there are usually skill gaps in the current workforce, which could require public investments in special education. In the CE models, there could be lack of initial capital investment and high interest rates on short payback period (Demichelis et al., 2018), which needs support from both public and private investors. The BCE models especially requires citizens shift their behaviors to effectively reduce and sort FW, which could be achieved by environmental education, information campaigns, and changing social norms (Angouria-Tsorochidou et al., 2021). Therefore, **the second aim of this paper** is to review the existing literature to identify alternative regulatory/supporting instruments to form a multi-level regulatory system, by asking the question 'which policy instruments can best support the transition of BCE in practice?'.

The paper is structured in the following way: in Section 2, we present the methodology used in the literature review, e.g. the period covered, the defined categories and keywords used within each category; we review the ES of BCE within four redefined categories in Section 3; in Section 4, we firstly identify the potential barriers of the BCE transition in reality, and then review the regulatory and supporting instruments at the levels of government, industry and citizens to overcome such barriers. After comparing the cons and pros of instruments at different levels, we propose an integrated multi-level regulatory system, which could be best in supporting BCE transition. In Section 5, we discuss our findings and propose directions for the future research.

2. Methodology

We conducted the literature review in a systematic way to keep the replicability and minimize the potential bias. We searched in the Web of Science database with pre-defined keywords in three categories. The first category contained keywords related to varied parts of BCE. The chosen keywords with logical operator OR were: bio-based circular economy, urban farming, urban agriculture, urban horticulture, urban gardening, urban green infrastructure, peri-urban agriculture, food waste, restaurant food waste, household food waste, waste collection, waste transportation, waste plants, incineration, landfill, anaerobic digestion, solid state fermentation, sustainable transition. The second category contained keywords related to varied ES directly or indirectly from BCE. The chosen keywords with logical operator OR were: ecosystem service, provision service, supporting service, regulating service, social service, cultural service, food waste, local food production, bioenergy, biofertilizers, biopesticides, platform chemicals, habitat, biodiversity, pollination, biological control, nutrient cycling, soil formation, air quality, climate change, water regulation, knowledge sharing, community development, aesthetic values and recreational function. The third category contained keywords related to regulatory instruments and supporting schemes to facilitate the transition of circular economy. The chosen keywords with logical operator OR were: barrier, governance, regulatory instrument, tax, subsidy, grant, loan, self-regulation, agreement, shared financing, economic incentive, waste charge, regulation, tradeable permit, social support, social norms, education, environmental knowledge, environmental awareness, citizen engagement, behavior change. We connect the second and third categories of keywords with the logical operator OR, and connect these two categories and the first category with the logical operator AND to find any articles that contained at least one keyword from category 1 and one keyword from category 2 or 3.

We restricted the initial literature search to the period from 1967 to 2020. The search first produced 4381 papers. Then we had a second-step screening to identify research papers targeting our two research requestions: ES from BCE, potential barriers and regulatory instruments for implementing BCE. This screening narrowed down the selection to 129 journal articles. In addition to them, we also added manually 26 publications, which are either report, thesis or book and are found be important complements to the papers in Web of Science database. The final number of publications analyzed was 155.

3. Review of ecosystem services (ES) of BCE

For the convenience of analysis and assessment, it is important to adopt a pragmatic view of ecosystem boundaries and adapt it to our research question. As the guiding principle, a well-defined ecosystem has strong interactions among its components and weak interactions across its boundaries (Alcamo et al., 2003).

The BCE ecosystem is comprised by a network of organizations, including agriculture (food suppliers and FW product (biofertilizer, biopesticide, etc.) users), wholesalers and retailers (food distributors), consumers (FW generators), secondary bioresource treatment plants (AD plants and Solid State Fermentation (SSF)), government agencies, financing companies, citizens, educational and research organizations, and other interested parties. All actors of the network of organizations are involved in the BCE ecosystem through both competition and cooperation (Fig. 2). Each organization in the ecosystem affects and is affected by the others (interactions), and must be flexible and adaptable (decentralized decision-making and self-organization) for itself to survive in the long term, similar to biological systems (Peltoniemi and Vuori, 2004).

In the current LE paradigm, agriculture provides food to different food processors and food distributors, which deliver the food to commercial and private consumers. Post-consumer waste is collected through the municipal waste collection scheme, while the municipalities normally outsource the waste collection service to a company which collects the mixed or source-separated waste including the FW and transports it for landfill, incineration or to centralized composting or biogas plants. Recently, large-scale Mechanical–Biological-Treatment (MBT) plants combining mechanical processes (e.g. shredding, separation and densification) and biological treatment (aerobic and anaerobic degradation), have become a solution for processing mixed waste (Di Lonardo et al., 2012). However, the digestates of MBT systems is not fully suitable for agricultural use, especially the food crop use because of the high levels of contaminations, implying MBT cannot fully solve the problem of nutrient recovery (Banks et al., 2018).

In the emerging BCE paradigm, the urban farms and infrastructure (e.g. horticulture, garden) offer a food supply system with less FL due to short transportation distance, and a number of other beneficial services including increase permeability of the city, recreational and aesthetic

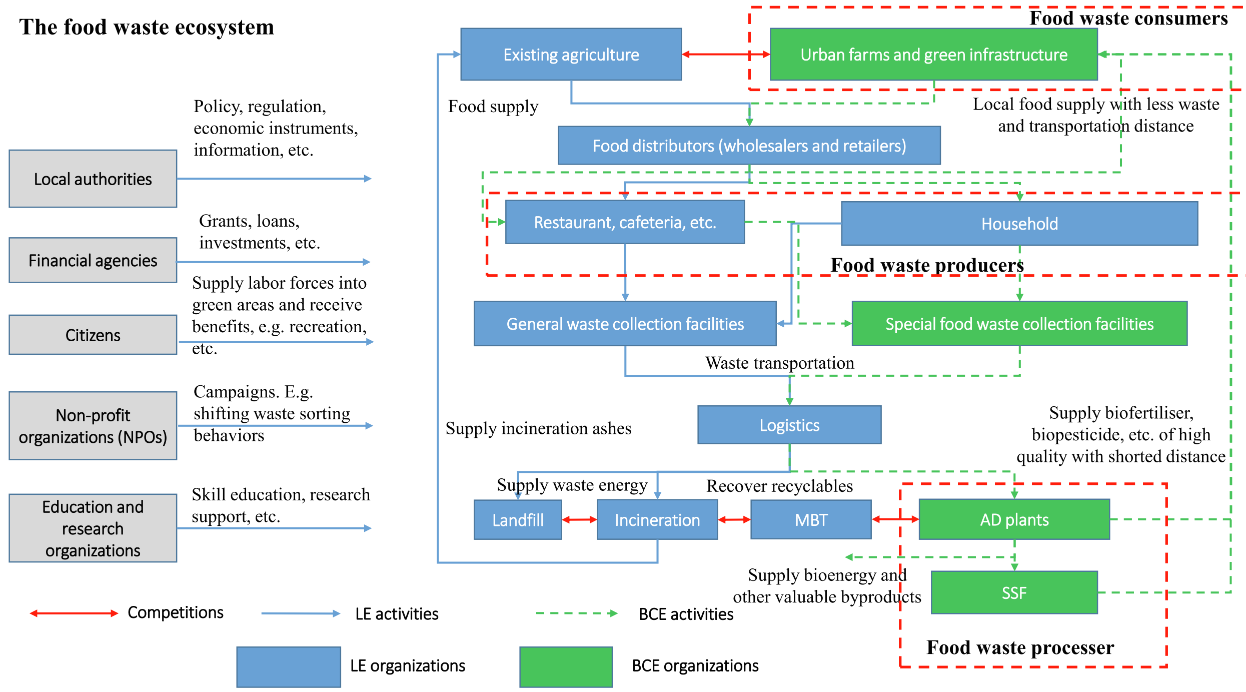

Fig. 2. The metabolism of the BCE ecosystem.

values to the local citizens. A local specialized separate FW collection company, which is a part of the local BCE system, implements a separate FW collection scheme and collects the sorted FW and transports it for valorization at decentralized AD and SSF plants. The FW is then converted to bioenergy, biofertilizer and other high value products such as biopesticides, which deliver biobased products for self-supply within the urban farms and export excess products to peri-urban and rural farms.

The Millennium Ecosystem Assessment (MEA) report defines Ecosystem Services (ES) (in ecology) as the benefits people obtain from ecosystems and distinguishes between four categories of ecosystem services: 1) supporting services; 2) provisioning services; 3) regulating services; 4) cultural services (Alcamo et al., 2003). Because our BCE ecosystem can be viewed as an analogy to natural ecosystems, we redefine the concepts of four categories of ES at the beginning of each of following subsections to fit into the BCE ecosystem, from the perspectives of three main actors (urban farms, FW generators and FW processers).

3.1. *Provision services*

Provision services are the physical goods provided by BCE, such as local fresh food, bioenergy, biofertilizers, biopesticides and platform chemicals.

3.1.1. *FW generators*

The FW is mainly produced by commercial (e.g. restaurants and cafeterias) and private (e.g. households) food waste producers. In the LE, FW is usually mixed with other waste, which is a barrier for efficient recycling and valorization of the biomolecules and nutrients contained in the FW. In the BCE, commercial and private FW generators are encouraged to sort their waste into separate fraction resulting in high quality FW, which serves as feedstock at AD and SSF plants.

The FW quality can be characterized into four categories: 1) physiochemical characteristics, e.g. pH, Dry Matter (DM), Volatile Solids (VS), Chemical Oxygen Demand (COD) and BioMethane Potential (BMP); 2) elementary composition, such as C, H, O and N content (%), C/N ratio; 3) biochemical characteristics referring to e.g. carbohydrates, protein and fats proportions; 4) nutritional elements, such as N, P and K; 5) heavy metals, for example, Cd, Cu, Hg and Pb (Fisgativa et al., 2016). The FW quality is primarily affected by its composition, e.g. FW consisting of rice and vegetables is high in carbohydrates while FW of meat and eggs is rich in proteins and lipids (Paritosh et al., 2017).

Fisgativa et al. did a literature review from 70 papers and found that FW quality is very variable and 24% of such variations may be due to the geographical origin, the type of collection source and collection seasons (Fisgativa et al., 2016). They found that FW from Asia and North America has lower DM content than EU while FW from Asia has lower TAN (Total Ammonia Nitrogen) value than EU and North America, which could be driven by the cultural and socio-economic reasons. Developed countries such as USA and UK could substantially increase food waste because of their culture favoring fresh produced food, while in developing countries FW could generated during social activities, e.g. the “La Tomatina” festival in Spain (Phasha et al., 2020). Ho and Chu studied FW from different sources and they found that FW from household kitchen waste and Chinese restaurant has high crude protein content and amount of minerals; while FW from pre-consumption and wet market has favorable C/N ratios and crude fat content (Ho and Chu, 2019). It is also found that during monsoon and summer reasons, more FW may be generated due to the food preferences related to the weather (Jadoon et al., 2014).

In addition to this, numerous studies have examined the role of waste sorting behaviors in FW quality and factors affecting human waste sorting behaviors. Rousta argued that the waste sorting at source is crucial (Rousta, 2018) which is confirmed by a review of Angouria-Tsorochidou and Thomsen (Angouria-Tsorochidou and Thomsen, 2021). The influential factors of waste sorting behaviors can be generally categorized into five aspects: social demographics (Matsumoto, 2011), attitudes (Babaei et al., 2015), subject norms (Zhang et al., 2015), knowledge (Echegaray and Hansstein, 2017) and perception (Briguglio, 2016). Steg et al. proposed an integrated theoretical framework, IFEP (Integrated Framework for Encouraging Pro-Environmental Behavior) which comprises a limited number of key influential factors (values, situational cues, and goals) and key processes through which effective pro-environmental behavior change may take place (Steg et al., 2014).

They argued that pro-environmental behaviors (such as waste sorting) may make people feel good and enhance their status, if the right situation factors are triggered. In addition to these, Rousta found that socio-technological design of convenient collection points and new information communication channels can significantly reduce the proportions of miss-sorted FW (Rousta et al., 2015).

3.1.2. FW processers

The AD digesters can produce methane as renewable energy from FW, although the methane production could vary between the different types of FW (e.g. fruit waste and dairy waste) and even within the same type of food waste, depending on total solid (TS) content and organic content (VS/TS ratio, VS: volatile solids), C/N ratio, pH, protein content, etc. (Meng et al., 2015). In addition to energy, the digestate produced during the digestion process contains most of the nutrients from FW and can be applied back to urban farms as biofertilizer. The biofertilizer has high agronomic values due to its availability of nutrients, stability of organic matter and biosecurity, and could keep or increase even up to 40% crop yields compared to mineral fertilizer (Rigby and Smith, 2014). Biofertilizer can also improve the soil structure and microbiology due to its rich nutrient content and its introduction of organic matter to soils. However, there are also some uncertainties regarding to the effects of biofertilizer application, e.g. some studies have reported 10–25% lower crop yields with FW digestates compared to mineral fertilizers (Odlare et al., 2008; Svensson et al., 2004) because FW digestates could have lower plant-available N concentrations than the mineral fertilizers. Instead of competing, the digestate produced from FW could be used to supplement mineral fertilizer to form optimal nutrient ratios for meeting the crop nutrient demand (Nicoletto et al., 2014). In addition to these, the AD digesters can also produce other valuable product, e.g. enzymes, bioplastics, and biopesticides (Tumaševičiūtė and Ignatavičius, 2019).

SSF is the biodegradation of solid organics into value products such as enzymes, biosurfactants or bioplastics, which provides alternative usage for digestates from AD process. SSF uses solid substrates with low level of water, reduced energy requirements, high productivity and less inhibitory effects for enzyme production, which outperforms the conventional submerged fermentation technologies (Cerda et al., 2019).

Although AD is a relatively mature and widely applied technology in the treatment of sludge, wastewater and manures, AD for FW management still faces technical, socio-economic challenges, implying AD alone could still not be a viable option for all countries (Xu et al., 2018). Technically, mono-digestion of FW often cause digester instability because of the accumulation of VFAs (volatile fatty acids) and ammonia inhibition, especially with a high loading rate and thermophilic conditions (Banks et al., 2011). Co-digestion of FW with other biomass, e.g. manure or sewage sludge, could be a beneficial solution due to enhanced of nutrients and synergy effects of microorganism (Zhang et al., 2014). From the economic perspective, AD systems are cost intensive regarding the feedstock transportation, digester construction and operation, while their revenues are mainly from gate fees of FW collection and sales of electricity and methane (Cong and Termansen, 2016; Lin et al., 2013). Integrating AD with other FW based biorefineries for the production of other value-added products might be a desirable solution. One example is using hydrothermal liquefaction (HTL) to convert FW into oil, and a carbon-rich hydrothermal aqueous phase which can be converted into biomethane via AD. This HTL-AD system can increase the recovery of energy products from FW and provide an option to choose between oil and biomethane production (Posmanik et al., 2017).

3.1.3. Urban farms

With biofertilizers and biopesticides from FW processers as inputs, urban farms (UFs) in turn produce local fresh food, in particular vegetables, fruits, and herbs (Madaleno, 2000). Because there are concerns regarding to pollution and infectious diseases (e.g. Salmonella), livestock is much less frequently raised in UF and not considered in this paper. The role of UFs within the total urban food supply could be, however, limited. A variety of urban farm scenarios has been analyzed for cities in US, which found UF can typically contribute between 3 and 18% of urban food consumption depending on proportions of vacant lots and rooftop used, production methods, etc. (Grewal and Grewal, 2012; McClintock et al., 2013). Although existing quantitative studies are still scarce and show high variability, the current evidence suggests that in industrialized countries, UFs may only make a limited contribution (ca 10% of the global food production) in improving food self-sufficiency at the city scale (Clinton et al., 2018).

3.2. Supporting services

Supporting services refer to those necessary for the production or the maintenance of all other ES. They differ from provisioning, regulating, and cultural services in that their impacts on people are either indirect or occur over a very long term, whereas changes in the other categories have relatively direct short-term impacts on people. In the context of BCE, supporting services include not only nutrient cycling and soil formation due to the application of biofertilizer and biopesticide from AD and SSF plants to land, but also habitat provision from UFs and green infrastructure to increase biodiversity. Furthermore, the indirect benefits of BCE due to the linkages between economic sectors are included in this category.

3.2.1. Urban farms functioning as habitats and contributing to biodiversity

Typically, urban areas are characterized by highly simplified landscapes, intensively developed ecosystems with low levels of biodiversity. However, UFs can bring diverse green infrastructure back into the urban system (Lin and Fuller, 2013). Vegetative structural complexity in UFs provides extra biodiversity conservation to the urban environment (Tscharntke et al., 2012). UFs can not only support biodiversity within the farm sites, but also nearby areas due to the 'spillover' effects of energy, resources, and organisms across habitats. Such spillover effects are very important processes for the survival of wildlife populations in human-dominated landscapes because they allow for wildlife resource acquisition and recolonization processes. The contribution of UFs to biodiversity is affected by, e.g. the farm size, spatial location of farms and management practice. For example, pesticide application, extensive pruning, frequent mowing and other disturbances, could limit the capacity of UFs to maintain sensitive insect species (Matteson and Langellotto, 2011).

The biodiversity produced by urban farm system can further provide a suite of ES, which further support other ecosystems. UFs can potentially provide supporting ESs, such as pollination and biological control, to the broader urban landscape. Urban green infrastructure and floral strips can support abundance and diversity of bees and butterflies, which could benefit the relevant crop and fruit production (Cong et al., 2014; Winfree and Kremen, 2009) through pollination. Biological control (or biocontrol) is a method of controlling pests (e.g. insects, weeds and diseases) using other organisms. Biocontrol could enable crop production in cities without chemical pesticides, which is especially important in urban areas where human is more vulnerable to toxins (Robbins et al., 2001). The biological controllers include parasitoids, below-ground invertebrates and microbes, birds and spiders, which usually benefit from increased availability of green areas and decreased impervious cover in the surrounding landscape, similar to pollinators (Bennett and Gratton, 2012).

3.2.2. Integrated urban farming and FW-based biorefineries for nutrient recycling

In both of landfill and incineration systems of LE, nutrients leave farms as a part of the harvest and are never returned. Instead, they enter the atmosphere, groundwater and freshwater and marine ecosystems. Using anaerobic processes for stabilization of the organic matter, the FW that contains high amounts of organic matter and nutrients can be recycled in terms of bioenergy, biofertilizer and biopesticide in urban farms to close nutrients cycles and make cities more sustainable (Van Veenhuizen, 2006). The heavy metals concentrations and other contaminants in digestate of AD plants could be a concern, especially when the FW is not sorted properly (Amusan et al., 2005). The major plant nutrients Nitrogen (N), Phosphorus (P) and Potassium (K) are generally regarded as being conserved in anaerobic digestion: the feedstock characteristics can thus be used to predict nutrient content of digestate (Angouria-Tsorochidou and Thomsen, 2021). The efficiency of nutrient recycling are also dependent on other factors, such as soil type, crop type, climate, surficial geology, management methods, etc. (Di and Cameron, 2002).

Biofertilizers can improve soil formation through improved soil biodiversity, resulting in increased nutrient cycling via nitrogen fixation, phosphate and potassium mineralization, release of plant growth regulating substances, production of antibiotics and biodegradation of organic matter in the soil. High quality biofertilizers are environmental friendly and do not cause pollution at the level of inorganic fertilizers (Knobeloch et al., 2009). Bio-fertilizers have long lasting effects due to their slow and steady nutrient release for more than one season. As a result, long-term use of bio-fertilizer leads to the buildup of nutrients in the soil, thereby increasing the overall soil fertility. In addition, biofertilizers have been found to be helpful for control of plant diseases.

3.2.3. Indirect and induced effects of BCE in the regional economy

Direct economic outputs in terms of revenues and employment from business in BCE are defined as direct effects, while the results of business-to-business transactions in terms of purchase of inputs to the BCE are indirect effects. Induced effects are the results of increased personal income caused by both the direct and indirect effects of BCE. The indirect effects on the economy mainly fall into three categories: 1) impacts on the value chain: BCE business purchases inputs from different sectors and sells products and service through different market channels; 2) trade substitution effect: BCE provides local food production and may reduce the import of foods from other regions; 3) BCE could potentially change citizens' consumption patterns (e.g. adapting to local organic food, choosing local tourism instead of travelling abroad) which may impact other sectors (Rizos et al., 2017). Although all of these changes could have significant economic, environmental and social implications, currently the quantitative analysis of such effects are not sufficient. Best et al. (2018) highlight the importance of understanding the indirect effects of the transition to CE. Cong et al. (2017b) found the multiplier effects of gross production, i.e. the total increase in gross production divided by the direct effects in transition to CE could be about 1.7–1.8, implying the indirect effects could be equivalent to 70–80% of the direct effects. However, there is a risk of the 'rebounding' effect in BCE transition (Zink and Geyer, 2017). For BCE, the unfolding of rebound effect depends on whether local food production actually reduce, or "displace," existing food production. If so, the original promise of BCE could be achieved; if not, e.g. higher food consumption could be incurred due to increased income, and the environmental benefits of BCE could be overturned.

3.3. Regulating services

Regulating services are the services that ecosystems provide by acting as regulators, e.g. regulating the quality of air and soil or by providing flood and disease control. In this study, we focus on the regulatory benefits of BCE at the city scale. We will view city as a whole unit and investigate the added regulating services by BCE to its functionality.

3.3.1. Air quality, local climate and water regulation services of UFs

UFs and green infrastructure have great potential to help cities mitigate and adapt to climate change and environmental pollutions (Gaffin et al., 2012), through its regulating services which include air quality regulation, local climate regulation and water regulation (Pataki et al., 2011). Air quality regulation of UFs and green infrastructures depends primarily on design of such green structures and the ability of plants to absorb particles and pollutants, described as leaf-area-index (LAI). Because the vegetables produced in urban farms will be consumed by human, there could be some health risks associated to air pollution, through atmospheric deposition of heavy metals and other toxic compounds (Nabulo et al., 2012). UFs and green infrastructure are expected to be effective in mitigating the heat island effect of cities and controlling peak water flows. An integrated design of inedible green infrastructures separating the urban farms from the gray infrastructure may function as a pollution-preventive filter between polluting activities (traffic) and UFs.

3.3.2. Global climate regulation services of urban farms

Global climate regulation through carbon sequestration could very limited in crops of UFs. Nevertheless, urban farms may have an impact on global climate through the reduction of the environmental impact of global food trade and transportation. The average transportation distance of the conventional food chain is very long compared to local food produced by UFs (Grewal and Grewal, 2012). Conventional food also needs packaging and storage, and suffers considerable food losses in the transportation process (Parfitt et al., 2010). Reducing such losses and transport distances by producing food locally can reduce overall carbon emissions of food production.

However, reduction of transport distances and losses might not always result in a net climate change benefit over the complete life cycle of UFs' products (Edwards-Jones, 2010). Studies in the UK and China have shown that the direct emissions of agricultural practices are by far the largest share of the footprint of food production (Vermeulen et al., 2012). Therefore, reducing emissions through shortening food transportation distances could have its limitations. Reduced unit yields, additional inputs (e.g. containers and artificial soil) and reduced scale-effects may even cause higher greenhouse gas emissions in BCE urban farming system than in the conventional farming systems (Kulak et al., 2013). Urban farming can potentially shift consumer diets towards low-carbon foods (vegetable and fruits) implying that it may also have an indirect reduction effect on the household carbon footprint (Jones and Kammen, 2011). UFs usually follow organic farming principles, e.g. minimum soil disturbance, regenerative crop rotation and application of biofertilizer and biopesticide produced from AD and SFF plants. All of these agricultural practices are beneficial for improving soil structure, fertility and biodiversity and reducing indirect emissions (e.g. process emissions from mineral fertilizer and pesticide production). Moreover, the increased permeability of UFs could reduce the impacts of flooding. The multifunctional services of UF has been valorized to $160 billion at global scale (Clinton et al., 2018).

3.4. Social and cultural services

Traditionally, cultural services refer to the non-material benefits people obtain from ecosystems. In our study, they include aesthetic inspiration, cultural identity, recreational values, tourist and spiritual experience related to the urban environment created by BCE (Van Leeuwen et al., 2010). In addition, being closely connected with human society, BCE can also provide non-material social benefits, including job creation from BCE, improved public environmental awareness and public health level (Lovell, 2010). In this category, we review both the social non-material and cultural benefits from BCE.

3.4.1. Social services from urban farms

UFs and green infrastructure provide public space, where people have the opportunity to meet each other. Because of the improved communication between social groups and generations, UFs and in particular community gardening, may play an important role in sharing knowledge and environmental awareness (Barthel et al., 2010). The contribution of urban farming to environmental education is also important. Educational workshops on urban agricultural practices could be organized for vulnerable people who lack job, e.g. women and young people in general. Urban agriculture, therefore, could enhance gender equality and provide opportunities for reducing poverty, especially in developing countries (Hovorka, 2006; Orsini et al., 2013). People can use UFs to establish social networks and obtain a sense of security, which could be beneficial for community development (Slater, 2001). The evaluation of 29 local food programme projects in the UK showed that capacity building of UF (increasing social cohesion, education promotion, changing to healthy diets, etc.) is important for sustainable development of local communities (Kirwan et al., 2013).

3.4.2. Cultural services from urban farms

UFs and green infrastructure usually provide recreation opportunities and aesthetic appeal to the local residents and tourists. The practice of growing food and gardening reconnects people with land and nature, alleviates citizen stress, and contributes to healthier diets (Kortright and Wakefield, 2011). Walking and playing sports in urban green areas is not only a good form of physical exercise but also lets people relax. The role that urban green areas plays in maintaining mental and physical health is increasingly being recognized, despite difficulties of measurement (Tzoulas et al., 2007).

As urban areas are characterized with numerous historic, natural and cultural attractions, it is common that tourism spreads in conjunction and combined with urban farming activities. Urban and peri-urban farms and green infrastructure can also bring tourism values combined with the provision of facilities and services for tourists (e.g. food, accommodation, guided tours, and horse riding), which is called as 'urban agro-tourism business' and leads to a considerable increase in neighboring real estate values, e.g. through hedonic prices (Van Leeuwen et al., 2010).

4. Potential barriers and regulatory instruments in implementing BCE into the real world

4.1. Potential barriers in implementing BCE in reality

Although the BCE paradigm has shown its potentials regarding the environmental sustainability and efficient resource utilization, there are still several barriers existing that could impede the widespread application of this paradigm: 1) cultural barriers such as residents could be reluctant to sort food waste or purchase BCE products; 2) market barriers where economic feasibility of BCE highly depends on the policy support; 3) technological barriers e.g. infrastructural challenges and transportation

4.1.1. Cultural barriers

Cultural barriers, particularly barriers regarding biofertilizer/biopesticide consumers (urban and peri-urban farmers) and FW producers (e.g. households and restaurants), can be important factors limiting the market penetration of BCE. Despite having potentials in improving soil structure and increasing crop yields, biofertilizers have not yet gained popularity among farmers for adequate acceptance (Misra et al., 2020). Farmers are not fully aware of biofertilizers' usefulness in increasing crop yields sustainably. They may lack of knowledge about the efficacy and application method of biofertilizers compared to the long-standing conventional and inorganic fertilizers, which could be an important cultural barrier for widespread application of biofertilizers (Mayanglambam et al., 2020). On the other hand, FW generators, such as restaurants and households, could have insufficient incentives to sort food waste. Moreover, sorting FW is considered by some citizens to be time consuming and boring activity, which they would try to avoid without economic incentives. The non-sorting behavior can be negatively related to economic development but also impacted by local social culture and people's values and attitudes towards environmental responsibility, which could be a crucial factor affecting the food waste quality and limiting the penetration of BCE (Minelgaitė and Liobikienė, 2019).

4.1.2. Market barriers

Access to suitable sources of finance and becoming economically viable are key factors for firms in successful transition to BCE. Specifically, the market barriers have three-fold meanings: 1) high investment costs; 2) competitive LE product prices; 3) insufficient compensations for social and environmental benefits. In most cases, the banks could be hesitated to grant loans to private investors because of the uncertainties within this new market. The lack of price competitiveness of BCE products, e.g. chemical fertilizer is usually cheaper than biofertilizer for the same level of nutrients, which would thus undermine the affordability of the BCE products. The low prices of LE products are also related to the identified cultural barriers. If LE product prices were higher, affordable BCE products could spur consumer interest and awareness since consumers are usually price-sensitive when making their purchasing decisions (Rizos et al., 2015).

Currently, there are insufficient compensations for socio-environmental benefits from BCE. The socio-environmental benefits are usually non-market goods, which means that they are not traded (and priced) in markets. Compensation such non-market goods are usually from transfer payments from governments (such as subsidy and tax) and volunteer payment by consumers. Although there are many studies investigating the willingness to pay (WTP) of consumers for such socio-environmental benefits (Dagnew et al., 2012; Yuan and Yabe, 2014), such valuation methods are questioned because consumers are usually context-sensitive, i.e. a consumer's WTP for a product or service depends on context. There could be also large discrepancy between WTP and their real actions (Ajzen et al., 2004), implying there could be challenges for WTP implementation in BCE. The uncertainty in measurements, such as WTP, also creates challenges for efficient design of tax scheme, especially when there are big difference in socio-demographic characteristics of the total population (Kotchen et al., 2013).

4.1.3. Technological barriers

One of the crucial technological barriers is the infrastructural challenge. Although in EU there are clear waste separation rules (e.g. hazardous household waste will have to be collected separately by 2022, bio-waste by 2023 and textiles by 2025). In some developing countries (e.g. Nepal, Iran), poor waste infrastructure and management, e.g. limited access to classified garbage bins, make it difficult for residents to sort FW (Babazadeh et al., 2018; Oduro-Appiah and Aggrey, 2013).

Widespread implementation of biogas upgrading and refueling infrastructure could be more expensive than for liquid fuels, which could limit the demand of biogas from AD plants in BCE business. The lack of underground pipelines and connections to the national grid, as well as other technological challenges such as control variation in composition of biofertilizer and efficient removal of heavy-metal contaminants, create difficulties for BCE business expansion (Cong et al., 2017a). Because more than 70% of FW is water, there could be inadequate incentives for waste transportation due to low profitability, which increases the risk of FW supply disruption (Nevzorova and Kutcherov, 2019).

4.2. Multi-level regulatory systems for the successful implementation of BCE

While BCE definitely shows its role in the future sustainable development, it still relies on the joint efforts of governments, BCE business partners and citizens to create the necessary framework of regulatory instruments and supporting schemes to thrive (Angouria-Tsorochidou et al., 2021). The regulatory systems at different levels have their own objectives, and should be coordinated harmoniously. In the following sections, we outline the current situations of regulatory and supporting systems at different levels, summarize their strength and weakness and discuss the potential improvement, concluding with a reflection of an integrated multi-level regulatory and supporting system.

4.2.1. Regulatory instruments of governments and authorities

For governments and authorities, there are three types of instruments available for them to compensate externalities of BCE and correct potential market failures: namely 1) financial instruments; 2) regulations and 3) cap and trade (CAP). The first two instruments are prominent in the BCE and will be described in the following sections. The CAP is attracting more and more attentions in the application of BCE and will be discussed in Section 4.2.4 as an alternative instrument.

4.2.1.1. Financial instruments (economic incentives). There are two primary types of financial instruments for BCE business: 1) financing the public service of BCE through tax, charges or subsidy; 2) financing the BCE investments through different investment models.

a) Financing the public ES of BCE through tax and charges (the case of waste management)

Typical financial charges and tax for waste management are waste charge and landfill tax. The typical cost of processing urban waste is the gate fee, which represents a unit (usually measured as per ton) payment made by the local authority to the waste processing facility for their waste management services to citizens (Nghiem et al., 2017). The gate fee usually covers the cost of opening, maintaining and eventually closing the facility along with any profits and final disposal costs of any unusable residues. The gate fee is primarily financed by local taxes, household service charge, and industrial user charge (Rand et al., 2000). It may also include any landfill tax, which is applicable in the case of a landfill.

Currently, the waste charge is either one-component or multi-component system. The one-component system represents the simplest charge model. It has only one type of basic fee, which is charged either flat, or according to specific criteria, e.g. the area of the real estate, and independently of both the quantity and quality of the actually generated waste. This system does not provide any incentives to reduce the amount of generated waste or improve waste sorting activities. The multi-component system includes a basic fee and some variable fees paid by each user (household or industry). These variable components are related to the collection service actually provided (known as pay as you throw, PAYT), for instance based on the bin volume, collection frequency, weight and collected volume (Dahlén and Lagerkvist, 2010). Multi-component waste charge models conform to the polluter pay principle to some extents (Jean-Jacques, 2014). However, in most countries the waste charges (either the one-component or multiple-components) are not differentiated based on the quality of the waste, e.g. if the waste is sorted or not, which gives insufficient incentives for residents' sorting behaviors (Wadehra and Mishra, 2018). There are some studies about using the financial instruments as a reward mechanism to enhance residents' waste sorting behaviors, such as reward mechanism (RM) which gives out rewards to residents if their delivered waste is satisfactory (Timlett and Williams, 2008). However, such instruments are not widely applied due to the high monitoring costs.

b) Financing the public ES of BCE through subsidy (the case of urban farm)

The most relevant subsidy for farming activities in EU is common agricultural policy (CAP), which constitutes about one third of the total EU budget (Greer, 2013). According to the definition of first pillar of CAP (direct payment), CAP supports farmers and agriculture within EU - including urban and peri-urban farmers. However, the size of the agricultural area is most likely to exclude urban farmers from being eligible beneficiaries of the CAP. This is because one of the minimum requirements for receiving direct payments of CAP is that the agricultural area which they apply with is at least one hectare. The minimum eligible size of the holding is a barrier to urban farmers who are often confined to very small spaces.

Urban farm is also literally excluded from the second pillar (rural development) of CAP, which is targeted towards to rural areas. It is understandable that supporting food production in rural areas only, is dictated by the fact that there are very few other income possibilities outside of large town and cities, and therefore the CAP's contributions have a wider social effect in those less developed regions. However, urban agricultural production has many environmental and social functions the same as in rural areas. From this point of view, it could be argued that the limitations of the CAP regarding urban farms represents a barrier for transforming EU cities with environmental, socially and economically viable urban landscape (Ricciardi et al., 2018).

c) Financing the public ES of BCE through investment models (the case of biorefineries and urban farms)

There are primarily two types of investment models related to BCE: 1) grant/loan financing; 2) shared financing. Government and authorities may provide investment grants and low interest loans with long repay period to BCE business in cooperation with private and public financial institutions (e.g. banks, business funds) (Whicher et al., 2018). For example, the Danish government has set the Biogas Action Programme which provided such financing support to constructions of biogas plants. In China, Shanghai municipality provides large subsidies to investments of equipment and infrastructure as well as urban farming activities (Cabannes, 2012). The European Investment Bank (EIB) offers medium- and long-term loans for large-scale circular economy projects and indirect financing through local banks and other agents for small projects (Lamia and Glimina, 2020). In many cases, SMEs (Small and Medium Enterprise) and especially very young small business face difficulties in obtaining collateral required by the banks and therefore have very limited access to the loans needed to initiate the BCE projects in the small scale (Rizos et al., 2015).

Another business model related to the investment of BCE is sharing financing models, where the public bodies create partnerships with private sectors in BCE business, the so-called Public-Private-Partnership (PPP) model. The PPP model is interesting for governments and authorities because it can save public budget in parallel with private investments and utilize the expertise of private enterprises. PPP model could attract private investors' interest as well because it could secure long-term relationship with public bodies and relative stable remuneration (Bao et al., 2019). The sharing financing models are not new at construction of public infrastructure, but they might be innovative to construction of decentralized biorefineries and management of urban farms in the BCE business (Awasthi et al., 2019). PPP is also suffering some serious problems. For example, it requires a long negotiation time to define the services scope, pondering the risks, and discussing the price. Once the PPP contract is signed, there is insufficient flexibility, even there is a need to change the public sector's service requirements. The delivery is often in the private sector's hand without sufficient transparency and private sector could charge a high-risk premium, implying the service of PPP could be expensive. A pros and cons analysis of PPP can be found in the case of waste management in Suzhou, China (Bao et al., 2019).

4.2.1.2. Regulations (command and control). Compared to incentive-based financial instruments, regulation is a type of command and control (CAC) system which allows public authorities to specifically mandate a specific behavior that is socially desirable in the law and use enforcement mechanisms (courts, fines, inspections, etc.) to get people to obey it. The regulations can be implemented at the international (e.g. EU), national and local levels.

On the international level, the EU commission has established the Waste Framework Directive 2008/98/EC and identified good practice for waste management. Sorting waste at source is one of the key levers to improve the quality of recycled materials. In Article 22(1): it stated “member states shall ensure that bio-waste is either separated and recycled at source, or is collected separately” (Maarten et al., 2020). Separate collection is obligatory as of 2015 for paper, metal, plastic and glass, by 31 December 2023 for bio-waste and by 1 January 2025 for textile and hazardous household waste.

The success of regulation requires four elements: legal enforcement, economic incentives (fines), customized facilities and engaging communication. In the waste separate collection case, the **legal enforcement** includes, e.g. 1) visual inspection of recycling bags: if the waste worker sees incorrect materials, he can attach a sticker that highlights the non-compliance; 2) weight-based check: food waste is usually wet and heave. If the waste worker notices that the bag is light, it probably means that other waste has been wrongly put to the recycling bag. In both cases, the workers can leave the bag at the pick-up point. Local authorities could issue fines and other penalties to potential offenders.

There is not a single waste collection system that can fit for all waste streams. **Customized waste collection system** may be optimal depending on, e.g. density of inhabitants, kind of housing, climate, collection culture. Civic Amenity Sites (CAS) offer households places where they can drop off almost all sorted waste streams. The two other common systems are door-to-door collection and street containers. In addition, **communication** is critical to inform restaurants and households about the regulation to avoid the potential oversight and has been proved efficient in the Swedish case of wood-waste management (Krook et al., 2008).

4.2.2. Self-regulation

Industry self-regulation (ISR) is the process whereby typically an industry-level organization, such as an industry association, monitors their own adherence to legal and safety standards and manages the partnerships, rather than external regulator monitors and enforces those actions (Héritier and Eckert (2008b)). Industry self-regulation is an institutional complement to existing government regulatory processes. Self-regulation can also be a preventative strategy (Héritier and Eckert, 2008a): in response to the externalities created by business, e.g. in the LE paradigm, waste management could incur many environment externalities. By shaping an action collectively, firms can take the lead and coordinate themselves to transition to the BCE business, while avoiding the external mandatory policy regulations.

Urban community garden is a good example of self-regulation. Many urban community gardens are often self-managing and self-regulating. They are typically managed by gardeners’ associations (Yap, 2019). The association is responsible for organizing events in the garden, reallocating disused plots, managing communications, liaising with the government and authorities and setting up the rules of gardening. Outside of the formal management structure, the garden is developed and maintained according to agreements made by the community of gardeners. For example, decisions on how to cultivate shared and communal areas are made through community discussion. This form of decision-making depends upon the strong and trustable relationships between the gardeners. Gardeners are also self-managed through collaborating whereby tools, seeds, and knowledge are shared and exchanged.

The self-regulation is expected to strengthen the sense of belonging and commitment level, develop more elaborate systems of self-regulation, building new forms of participation and responsibility. Self-regulation is also a strategy to impact potential government regulatory systems when new policy targets are emerging. Self-regulation usually proactively surpasses the expected compliance level, which might be utilized to complement stringent government regulations.

4.2.3. Social supporting system

Citizen awareness, engagement and behavior change are crucial for the success of BCE transition. This means that people participate in new forms of consumption (e.g. purchasing more locally produced food and enjoying more recreational activities in local green areas), recycling and disposal (reducing and sorting food waste) and production (utilizing biofertilizer and biopesticide from biorefineries). Even if the BCE enables people to enjoy new possibilities compared to the LE system, shifting people behaviors still requires time, effort and commitment. This will require addressing not only the extrinsic attributes (e.g. infrastructure and incentives), but also intrinsic attributes (e.g. values and personal norms) of people behaviors (Parajuly et al., 2020).

There are two commonly used social instruments for the behavioral changes in BCE: 1) education; 2) social norm shifting. Here, the education is conceptualized in a broad sense to include all educational programs, information campaigns, or any other organized effort at deepening peoples’ understanding of the effects of their behaviors on the natural resource and environment. In the early 70 s, it was believed that environmental knowledge and awareness were the key factors making people shift to pro-environmental behaviors; the latter was known as KAB (Knowledge-Attitude-Behavior) theory (Laroche et al., 1996). In 1991, Ajzen presented the theory of planned behavior where he outlined three important drivers for pro-environmental behaviors (Ajzen, 1991). The first factor is attitude. A certain attitude towards a behavior is driven by beliefs about the outcomes of the person’s behavior and the evaluation of those outcomes. The second factor is the social norm; i.e. a person’s perception what other people think he should or should not do. The third factor is perceived behavioral control, i.e. people’s perceptions of their ability to perform a given behavior.

For example, the possibility that a person will sort food waste depends on his attitude about sorting (e.g. ‘It is a waste of time’ or ‘Food sorting is good for the environment’) and the social norm (‘Will other people sort?’). Finally, the person’s ability (e.g. knowledge about sorting garbage, available time) will also affect his (her) participation in household-garbage sorting.

The attitude will be affected by two factors. First, it depends on the beliefs about the outcomes of the sorting behaviors (e.g. ‘My sorting will not make any difference anyways’ or ‘If everyone sorts food waste in a proper way, we will save our environment’) and the evaluation of these outcomes (‘Is it important or unimportant?’). Education and information campaign can enhance the awareness of the people on BCE and environmental issues. Education can also deliver knowledge of environmental laws and principles of functioning of the natural system to people and help them develop practical skills and the ability to make assessment of the state of the environment. Through education, people are more aware of their own behaviors’ impact on the environment and could adopt a more responsible attitude towards the BCE and environment. Hundreds of higher education institutions currently provide CE education as part of their programs in the fields of sustainability, engineering, business studies and design (Tim, 2018). However, there is still a need to deliver the knowledge of CE to the children in primary and secondary schools and adults in society, through e.g. information campaign, informal education or experience sharing.

In addition to attitudes affected by information and education, the social norm sets up rules which are followed by members of a group, and guides human behavior without the force of laws (Keizer and Schultz, 2018). Social norms can affect individuals for a couple of reasons: people may wish to be accepted, avoid social disapproval, and obtain social reputation. People may also assume that others’ behaviors are most effective when they do not have any prior knowledge themselves. A vast body of evidence demonstrates that social norms impact people’s pro-environmental behaviors (Estrada et al., 2017). Many factors have been found to influence the extent to which social norm impacts pro-environmental behavior. These factors could be ranged from individual characteristics (e.g. intrinsic motivation, socio-demographic characteristics, education level), the types of the social norms (e.g. descriptive vs. injunctive), the reference group (e.g. size, geographical/social/temporal proximity) (Farrow et al., 2017). The social norm is contextual, which means it can vary across countries and be contingent on cultural factors (Culiberg and Elgaaied-Gambier, 2016). The differences in levels of environmental quality, environmental preferences, and social norm dynamics that may be present in countries at different stages of development call for empirical work to test the effectiveness of social norm interventions in influencing environmental behaviors in these contexts.

Given the overall effectiveness of social norms in encouraging BCE and pro-environmental behaviors, we should acknowledge that social norm interventions can indeed be an effective tool for behavior change, which is a primary driver for BCE development. There are four different types of policy instruments that can induce changes in social norms: active norm management, choice architecture, financial interventions, and regulatory measures. The active norm management includes social norms marketing through, e.g. campaign and advertising, which aims to correct the misperception of people's behavior in order to influence personal choices. The choice architecture is the design of different ways in which behavioral choices can be presented to people. Recently, the concept of nudge became popular. A nudge is any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives (Thaler and Sunstein, 2009). An example of nudge in waste recycling is to make the recycling bin much larger than the garbage bin to encourage people recycle more waste. The financial interventions and regulatory measures are discussed in Section 4.2.1.

4.2.4. Reflections of integrated multi-level regulatory systems in supporting BCE transition

In the field of environmental management, there are two types of governance mechanisms, namely top-down and bottom-up, which describes how decisions and changes are planned and implemented (Koontz and Newig, 2014). The top-down governance is the implementation of a policy decision which is made by governments and authorities (central government-led) through statute, executive order, or law to produce the social 'desired effects' (Jones, 2012). Regulation and economic instruments are examples of top-down instruments. In contrast, the bottom-up governance is initiated by regulation target groups (community and user-led) through e.g. self-regulation, education and social-norm shifting.

The top-down governance approach is a clear-cut system from the government to the BCE industry and citizenship, with clear goals and hierarchy of authority. Government has the resource and capacity to implement the top-down governance. However, the top-down governance often faces with three types of criticisms: 1) policy-makers may fail to consider broader public/private objectives, constraints and potential conflicts in the initial policy design process. O'Toole presented a case where the top-down model initially believed that privately owned treatment plants outperformed public treatment plants. However, when other factors, e.g. labor laws and technology, were integrated into the analysis, it was found public treatment plants outperformed private plants (O'Toole, 1989); 2) Top-down model views policy implementation as a purely administrative process while ignoring the political acceptance and not adapting to local BCE practice, which could result in a policy failure; 3) Top-down models implicitly assume that the regulation framers (policymakers) are key actors. However, the BCE business partners and local citizens have the expertise and may know the real problems better. Therefore, they should be in a better position in the policy design process. Top-down models, however, assume them to be regulated and controlled.

In contrast, the bottom-up governance formulates the regulation from the target groups. Moreover, the bottom-up governance calls for the discretion in the policy implementation with respect to local conditions. The logic behind is that goals, strategies and policy instruments must be deployed with special attentions to the people that the policy will impact. Discretion by target-groups is the underlying premise of the bottom-up governance and may be good when it uses the expertise of local people to increase the likelihood of policy success. In bottom-up governance, one policy may not fit into all cases and the discretion may require a customized local policy setting, which could create a variance in policy goals. Bottom-up governance also face with two criticisms: 1) bottom-up governance may not reflect the general interest in society but pursue for industry-level and community-level targets; 2) bottom-up governance may lack of resource and authority to implement the governance.

In the BCE transition, these two governance models could complement each other to optimize the policy efficiency and reduce the potential policy implementation resistance. The top-down governance could integrate local BCE transition into the overall sustainable development path and ensure the necessary regulation and supports with resource and authority. The bottom-up governance can provide discretion and flexibility to local target group, utilize their expertise and increase their engagement and commit. Therefore, we propose a three-level (government, industry and citizen) mixed (both top down and bottom-up) regulatory and supporting system for facilitating the BCE transition (as shown in Fig. 3). On the top level, the government and authorities could set up an overall strategy and policy targets with the necessary regulation tools and resource. On the industry level, it could be beneficial for them to self-organize and self-regulate because they know the real problems better and require discretion to handle the local tricky condition. On the citizen level, shifting people behaviors in the short-term may require external drives from the top-down governance. In the long-term the self-regulation among citizens through social norm shifts could be more beneficial considering the policy implementation cost and political resistance.

As an alternative policy instrument, tradeable permits may provide a way to reconcile the top-down and bottom-up governances. Tradable permits are a system of cap and trade (CAT) and a market-based approach to controlling pollution by providing economic incentives for reducing the emissions of pollutant. A central authority (usually a governmental body) allocates or sells a limited number of permits that allow a discharge of a specific quantity of a pollutant over a set time period. Polluters are required to hold permits in amount equal to their emissions. Polluters who want to increase their emissions must buy permits from others willing to sell them. Compared to regulation and financial instruments, tradeable permits are a type of flexible environmental regulation that allows government to decide the total environmental targets and local stakeholders to decide how to best meet such targets.

In the EU, USA and many areas of the world, one of the biggest water-quality concerns is nitrogen runoff from fertilizer use. Putting fertilizer onto a field with poor soil won't increase the yields as much, because a lot of that fertilizer will just run off before the crop can use it. There are some governments which made plans for large reduction in dissolved inorganic nitrogen flowing. A nitrogen market could offer a flexible way of encouraging farmers to adopt more biofertilizer, which has long lasting effects due to their slow nutrient release and does not run off into the water as much as chemical fertilizers (Itelima et al., 2018), from the BCE business, as well as rewarding innovations in farming practice. In this way, the biofertilizer can gain more market share and subsidized by the market through the trade of nitrogen allowance, which will support the penetration of biofertilizer in the long term.

5. Conclusions

Transforming the LE, which has remained the dominant model since the beginning of industrial revolution, into CE is not an easy task. Such transformation changes our current production and consumption patterns radically, which will have a significant impact on the economy, environment and society. The first contribution of this paper is we systematically review the ecosystem services of BCE within the re-defined ecosystem framework. We redefined the concepts of four categories of ES to fit into the BCE ecosystem processes including nutrient fluxes, intra- and intersectoral competitions between different FW processors,

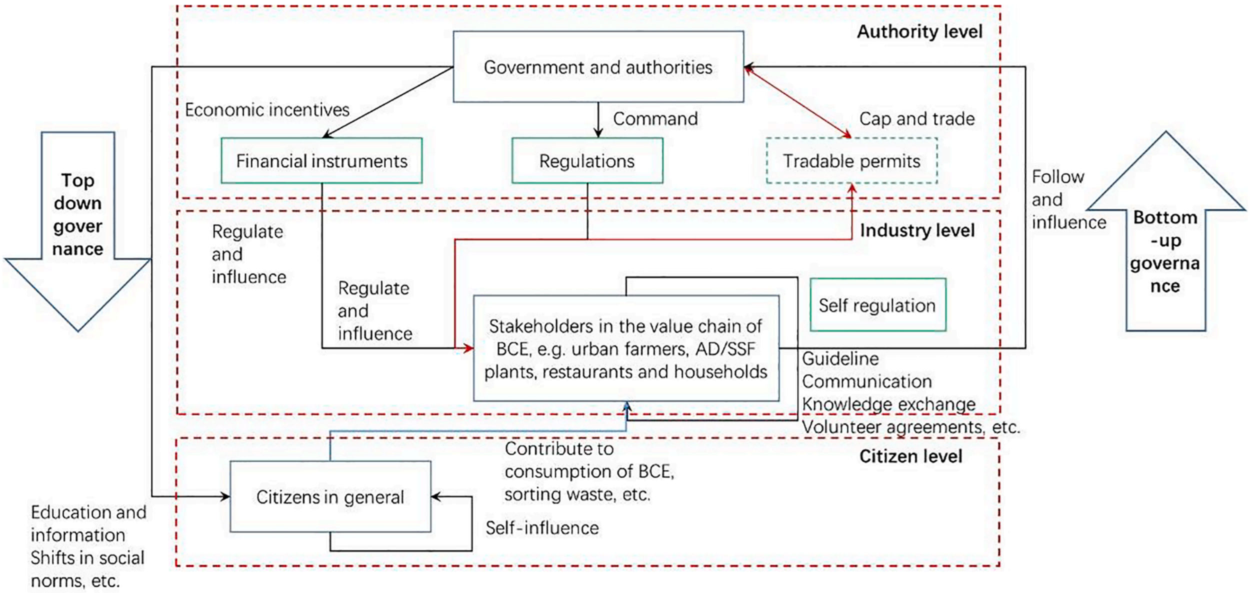

Fig. 3. Multi-level regulatory and supporting systems for BCE transition.

and the connections between ES, human welfare and economic systems. To our knowledge this paper is the first one to redefine the ES framework into the BCE field. We suggested that our study can be a reference to guide practitioners, companies and public actors to reorganize their activities and collaborate in the ecosystem settings, informing them of market (provision services) and non-market benefits (supporting, regulating, social and cultural services) we can enjoy from the transition from LE to BCE in a broad sense, while considering risk mitigation strategies to insure quality and safety of BCE products.

The second contribution of this paper is based on a review of the potential barriers in implementing BCE transitions and current regulatory instruments from different levels (government, industry and citizens), we propose a multi-level mixed (both top-down and bottom-up) regulatory and supporting system and some alternative policy instruments such as tradeable permits, which is expected to utilize the advantages of government, BCE industry and citizens in a harmony way to maximum the policy efficiency and avoid policy failure. Regulatory barriers and regulatory instruments are extensively discussed in the literature on CE transition (De Jesus and Mendonça, 2018; Ranta et al., 2018). We see our paper as an integration of existing knowledge of current and potential instruments with a focus on the roles of stakeholders at different levels.

With the proposed regulatory and supporting system, we hope that SMEs and citizens will have more incentives to be part of the BCE as producers and consumers of products and services (local fresh food, sorted food waste of high-quality, recreational and functional urban environment), aligning with the sustainable development goals set by the governments. The proposed multi-level mixed regulatory and supporting system can contribute to the solutions for pricing public goods and minimizing the policy monitor and implementation costs, through combinations of top-down governance, self-regulations and volunteer agreements and shift of social norms.

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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