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Review

Cross-disciplinary approaches towards smart, resilient and sustainable circular economy

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A B S T R A C T

Environmental sustainability has gained increasing attention in recent years due to the evident impacts of rapid economic growth and urbanisation. Efficient resources and utility management is one of the vital strategies to minimise waste/losses, pollution and extraction of virgin resources. It facilitates the development of a circular economy. This review discusses the cross-disciplinary approaches devoted to clean technologies, process modelling, monitoring and management framework in the effort to mitigating GHG, air (causing, e.g. smog/haze) and water pollution. The review focuses on the roles of (a) Energy and water management, (b) Waste management and (c) Green policy and pollution minimisation strategies. Each section is divided into two sub-sections starting with the introduction on the assessed areas, followed by the sections based on the latest contribution of a Special Volume and the proposed direction for future research. This review suggests (i) More studies based on case studies in real life context and prototypes involving consensus building among the stakeholders, proven by viable economic feasibility analyses, are needed to enable environmental sustainability. (ii) Data availability, enabling policy and cost of investment is the common barrier to put the proposed solutions or methodologies into practice. (iii) Substantial improvement of environmental sustainability can be benefited through the waste (solid, water, heat) recovery.

Contents

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1. Introduction

The circular economy is a system developed by minimising the use of energy, natural resources and waste generation (Tura et al., 2019). It can be achieved by mitigating, closing and narrowing loops of utilities and materials flows. Circular economy was introduced as an economic model for the transition of linear to the circular system (Millar et al., 2019). The environmental issues have been later considered targets of the circular economy due to the increasing concern on environmental sustainability (Walmsley et al., 2019) with the population growth and economic development. The paradigm of the circular economy includes minimising inputs of raw materials and outputs of waste, keep resources value within the system as long as possible and reintegrating products into the system when reaching the end of life (Suárez-Eiroa et al., 2019). Efficient management of resources and utility is the vital strategies towards a circular economy by minimising waste/losses, pollution and extraction of virgin resources. There have been various single and composite indicators to define environmental performance. Environment impacts include the mid-point, and end-point categories are well established in life cycle assessment. These include global warming potential, acidification, eutrophication, photochemical ozone creation potential, toxicity and human health etc. (Jolliet et al., 2003). Environmental footprints are the common indicators that applied to quantify and assess environmental performance in recent years. The footprints indicators include carbon emission footprint, water footprint, nitrogen footprint, land footprint, emission footprint, energy footprint and ecological footprint etc. (Čuček et al., 2012). Carbon emissions (better GHG) footprint and global warming potential are among the most considered impact and received great concern due to the climate change issue that is subjected to global agreements such as Intended Nationally Determined Contributions as summarised in Lee et al. (2018) and taxation. Indicators of the circular economy specify more on material flow accounting system which is derived based on European Union material flow and Japanese material flow indicator system (Geng et al., 2012). Energy, water and waste are the dominant areas where the efficiency improvement could significantly contribute to the circular economy and consequently environmental sustainability.

Fig. 1 shows the top ten GHG emitters where the 73% (43,737.3 $MtCO_2eq$) of GHG emitted and the source of emission. The energy sector is the GHG main contributor in most of the country. Although there have been many strategies proposed to reduce the impacts of the energy sector, its GHG and air emissions reduction potential remains high. There is still room for research and development. Forman et al. (2016) reported that the energy in service (28%) and the rejected energy (72%) is still having a significant gap based on global statistics. A similar pattern is observed in the energy generation and consumption, where 60% is reported as waste heat/rejected energy (LLNL, 2017) in the US. GHG emissions received global concern as climate changes is a global issue rather than a local/regional issue. It requires cooperative effort due to the increased interconnection between countries as a result of international trading (globalisation). Fig. 2 shows the energy intensity of different countries including Russian Federation, the United States and China. By evaluating the total energy consumption over the gross domestic product (GDP), the energy intensity of China and US is not as high as in the other countries such as Russian Federation, South Korea, Canada and Taiwan. This highlights the importance of accounting from different perspectives including population, GDP as well as the importing and exporting activities. The high energy intensity is mainly explained by the dominance of energy intensive industries, primary commodity exporting-based economies and low energy prices.

Virtual footprint has been proposed to capture the emission and material flows embodied in international trade. Qu et al. (2018) quantify the GHG due to electricity consumption by accounting the flows of the electricity network in 137 major countries/regions. Liu et al. (2017) assess the virtual footprint of carbon and water flow by consumption based. There is no universal strategy to improve the environmental sustainability of energy sectors towards a circular economy. Different countries require strategies adapted to the local condition. For example, WRI (2019) suggested that electrification to create low carbon emissions cities is only valid to the country with the carbon intensity of less than 600 tCO_2eq/GWh. The impact of electricity-mix on GHG emissions have also been assessed by Fan et al. (2019b), in the context of waste to energy processes. The feasibility of renewable energy implementation depends on its availability, maturity of technologies and the policy of a country. Review on the different measures and/or strategies, assessment and quantification approach, could provide the knowledge and ideas that have been established and facilitate further development by identifying the potential research gaps.

Comparing Brazil with the other countries represented in Fig. 1, agriculture has a significant impact on GHG emission. The agriculture sector is also the main contributor to water consumption. Fig. 3 shows the global water demand by sector up to the year 2040. Water is becoming a scarce resource in the next century.

It is essential to improve the irrigation process of agriculture to increase the crops yield. The utilisation of low-quality water by mapping the quality requirement/demand across different processes and improve the conversion efficiency could contribute to environmental sustainability. Re-use of wastewater, minimising wastage and improving the management of water through integrating among different processes can maximise the resource utilisation. This is in line with the circular economy concept where the water input is minimised and kept as long as possible within the system by recycling or reuse. Different water management strategies and concept have been proposed. It can generally be categories as integrated water resources management, sustainable water resources management, water security, adaptive water management as presented by Hoekstra et al. (2018). However, for a more holistic approach, the nexus with the other area such as energy (Dai et al., 2018), land use (Quinteiro et al., 2018) and food (Mannan et al., 2018) have to be considered. Dai et al. (2018) highlighted that there had been many studies aim to develop new methods and frameworks to comprehensively assess interactions between water, energy and other elements. However, the existing frameworks are still under development, and very few of them are designed to support governance and implementation of technical solutions.

Fig. 4 shows the waste generation per year in different regions. One of the main issues for closing the circular economy loop is transforming waste into secondary raw materials. The utilisation of waste as resources can scale down the demand for extraction of new resources and avert the impacts created along the processing chain. This is critical to support the transition from a linear to a circular economy. Inappropriate waste treatment and non-optimal

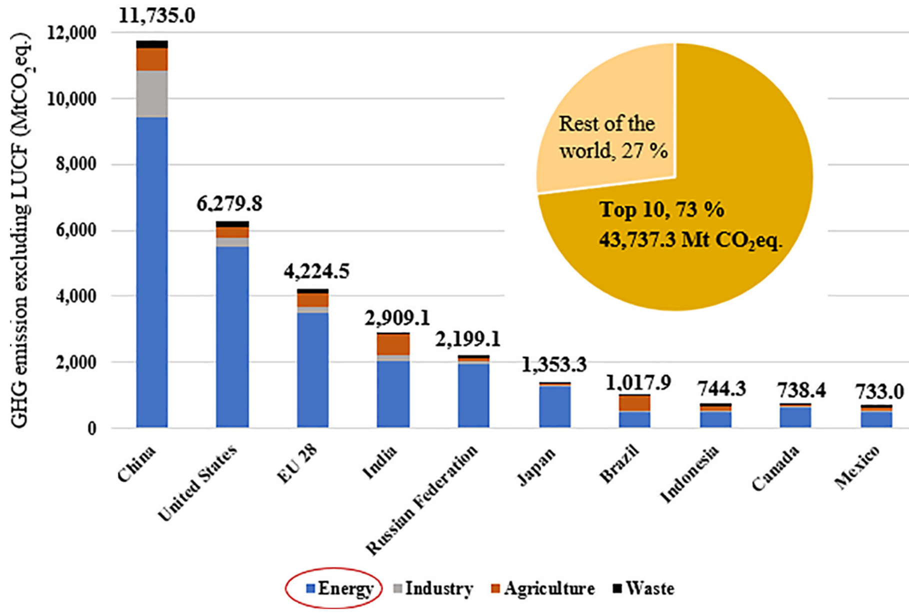

Fig. 1. Top ten world GHG emitters and the sources of GHG. Adapted from WRI (2017). Energy sector focus on emissions from fossil fuel combustion and gas flaring. The industrial sector is mainly CO_2 from cement manufacture and the Fluorinated gases (F-gases). Refer to the source for more information on accounting.

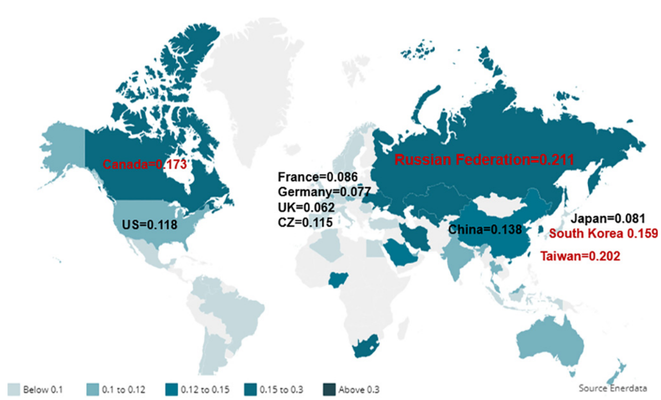

Fig. 2. The energy intensity of different countries (EnerData, 2018). Unit: kgoe/$2015p (kilogram oil equivalent per USD at constant purchasing power parities of the year of 2015).

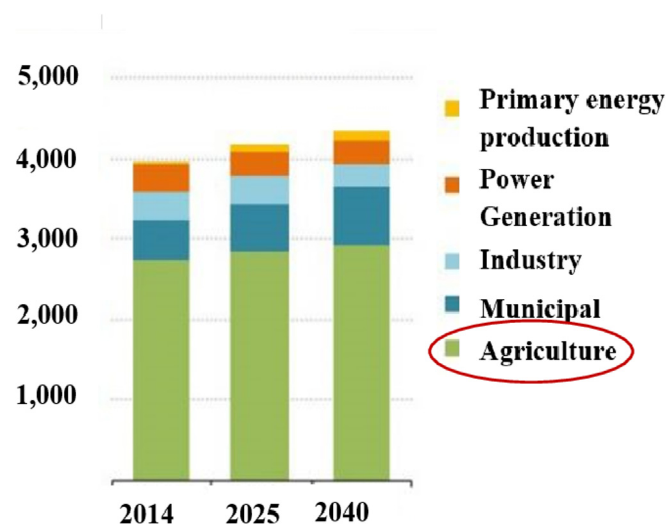

Fig. 3. Global water demand by sector from the year 2014–2040. Unit = 10^9 m^3 (IEA, 2016).

management could contribute to pollution and the consumption of resources or utilities due to the recovering process. Recycling and re-use is the highly preferable option in the waste hierarchy after the effort of prevention. However, there are different barriers including high labour cost for sorting, contamination and hygiene, energy intensive, quality of products and low economic value, for implementation. This is especially the case of plastic where the disposal has been a challenge. The plastic waste intended for recycling has been exported to hundreds of countries around the world. Brooks et al. (2018) identify about half of the plastic waste intended for recycling (14.1×10^6 Mt) was exported by 123 countries, with China taking the most. The announcement of an import ban on plastic by China increases the needed of searching feasible handling alternative, which created some political tensions. The existing waste management system needs urgent upgrading to reduce the quantity of waste and increase its circulation. Methodology to support decision making by considering different situations and factors are essential. It is the key to sustainability and suggesting whether the conversion process is a waste of resources or waste-to-resource and to prevent the shift of environmental footprints.

This review aims to summarise the recent sustainable strategies and methodologies with more focus on environmental components. The strategies can be divided into two major groups: a) maximising resource utilisation (e.g. waste, water, energy) and b) improving process efficiency by identifying the bottleneck.

The review is supported by the published work in the Special Volume (SV) on cross-disciplinary approaches towards a smart, resilient and sustainable community. A wide range of green initiatives in the effort to enable environmental sustainability and efficiency of resources management are considered. The SV benefits from the research presented at the conference series of the International Conference of Low Carbon Asia & Beyond 2017 (ICLCA'17), themed “Sustainable Low Carbon Emission Development in Asia

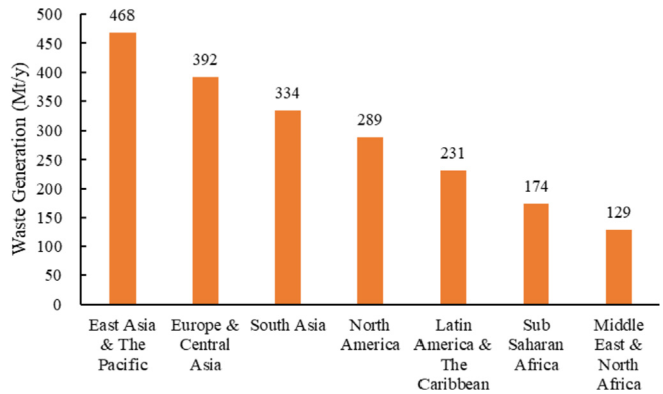

Fig. 4. Regional waste generation. Adapted from Kaza et al. (2018).

and beyond". It has served as platforms for knowledge sharing and to bridge the gaps among different stakeholders. A total of 44 papers have been invited for full paper submission for this SV and 20 papers accepted, and 24 had to be rejected or excluded. An overview of the selected papers is structured into three main sections 1) Sustainable technologies for energy and water management, 2) Development of waste management, and 3) Green Policy and Pollution Minimisation Strategies. This review points out the potential direction for future research as discussed separately in the sections entitled "Suggestions for Future Research" to achieve a circular economy through efficient resources and utilities management.

2. Sustainable technologies for energy and water management

Water and energy are the two main critical issues to be addressed. Human beings need fresh water to survive and clean energy to reduce GHG emissions. Only 71.16% of the global population has access to safely managed drinking water (The World Bank, 2019). The energy sector is the major contributor to GHG emissions, contributing to 72% in 2013 (WRI, 2017). An effective way to produce more drinking water and clean energy to reduce GHG emissions should be searched intensively. The problem is even more complicated when it involves the virtual footprint embedded in international trade (Liu et al., 2017).

Seawater is a rich source of fresh water but requiring extensive energy requirement for the desalination process including reverse osmosis and electrodialysis. To reduce the GHG emissions, one way is to utilise the solar energy for the heating process, i.e., solar still. To achieve high freshwater yield, there is a need to increase the absorption rate of solar still. Apart from the configuration and design of solar still, one way to achieve this objective is to select the material with a high absorption rate for solar radiation. Various researches have been conducted to search for the best material. Nisrin and Tammneh (2017) used a novel epoxy composite material known as carbon fibre-carbon nanotube (CNT). The CNT incorporated with graphene nanophalets resulted in a 30% increment in the production of distillate and enhanced solar absorption rate. Other nanofluids such as Al_2O_3 and TiO_2 (Sahota and Tiwari, 2016) were reported effective for increasing the accumulated distillate due to the enhanced solar absorption rate.

Many studies have addressed the interaction and interdependency between energy and water system for process synthesis and optimisation. From the perspective of process systems engineering for industrial application, Klemeš and Kravanja (2013) reviewed the significant studies regarding the synthesis of the minimum heat exchanger and water network. Ahmetović and Kravanja (2013) formulated a hybrid superstructure of direct and indirect heat transfer to minimise the total annualised cost of the water and heat network. Liu et al. (2018) formulated an MINLP model for simultaneously solving the integration of heat exchanger network and cooling water system. To reduce the complexity of network structure, Hou et al. (2014) proposed a graphical approach known as temperature and concentration order Composite Curve to simultaneously solving the water and energy integration based on potential concentration concept (Liu et al., 2009).

In a broader context of water resource management for urban planning, various researches have been conducted to investigate the water and energy nexus (Nair et al., 2014). Marsh (2008) developed a life-cycle analysis based integrated framework to evaluate the impact of various water and energy options on water resource management. Hurford and Harou (2014) examined water-energy nexus trade-off in water reservoir management by identifying the best possible (Pareto-optimal) allocation of benefits between water supply and irrigation, energy generation and ecosystem services maintenance. Zeng et al. (2017) proposed a multireservoir-based water-hydro energy management model for water allocation planning and hydro energy generation planning under uncertainties. Larsen and Drews (2019) conducted a water-energy nexus analyses in the European case and suggested the need for quantitative studies of the water-energy nexus at different levels to facilitate the improved water resource management.

The comment approach to evaluate the GHG impact of a system includes Life-Cycle Assessment (LCA), Input-Output Model (IOM), and Consumer Lifestyle Approach (CLA) (Guo et al., 2018). The LCA has been used to analyse the energy and emission performance of the system throughout different stages of life-cycle. Zhang et al. (2017) used IOM to evaluate the carbon footprint by examining the input and output dependence relationship of all industries. Guo et al. (2018) used CLA to evaluate the GHG emission focusing on consumer activities. Few LCA studies have evaluated the environmental impact of a hybrid energy system such as diesel-wind generators system (Schofield, 2011) and solar-wind-diesel system (Smith et al., 2015). Saling (2016) reported an Eco-Efficiency Analysis (EEA) method to incorporate product value into the analysis. Arceo et al. (2018) developed a framework based on the EEA method to assess the techno-economic and environmental performance of a hybrid power system (diesel and wind) in the remote area with the potential co-benefits of reducing GHG emission by 9% (26.2 $kgCO_2eq/MWh$) and fossil fuel depletion by 11%.

Hybrid solar heating systems are an alternative to reduce GHG emissions for domestic application. Tamvakidis (2013) evaluated the energy performance of an innovative hybrid solar heating system for the farrowing house. Abd-ur-Rehman et al. (2018) simulated a solar water heating system and a grid-connected solar photovoltaic system for residential building by incorporating government subsidies and eco-environmental benefits. Ramos et al. (2017) conducted a techno-economic analysis of photovoltaic-thermal (PVT) collectors working in combination with solar heating and cooling systems and thermal energy storage.

2.1. Special Volume papers contribution to energy and water management

The solar still is a less energy-intensive method for seawater desalination. Kebeel et al. (2019) developed a triangular pyramid structure solar still and absorber plate with TiO_2 nanoparticle coated with black paint. The coated TiO_2 nanoparticle contributed to a 6.25% increment in daily fresh water production. The economic performance of the developed system is significantly higher than the uncoated system, with a payback period of 1.3 months.

For water management, Zhao et al. (2019a) proposed a concentration potential concept-based method to synthesize the water and heat method in a sequential manner. The proposed method is able to generate cost-effective and straightforward water and heat network. Gao et al. (2019) developed a multi-objective optimisation model, as a water resource management tool, to minimise the water consumption of freshwater and energy consumption in water allocation system for urban planning. The developed tool has successfully been applied to a case study in Tianjin to examine the interaction between water and energy resource. The results show that freshwater consumption could be decreased by 17% with less energy consumption by using imported water and a centralised supply.

To evaluate the efficiency of renewable energy and energy efficiency improvement options, Arceo et al. (2019) developed an eco-efficiency analysis (EEA) framework to evaluate a hybrid energy system in the remote area of Western Australia. The hybrid energy system consists of diesel loading, incorporation of exhaust gas recirculation and installed rooftop photovoltaic systems. The EEA framework could potentially reduce life cycle CO_2 emissions by 9% and the life cycle cost by 1%. Elias et al. (2019) quantified the CO_2 emissions reduction by upgrading household furnace in Canada. They modelled the actual movement of natural gas prices and their impact on financial saving. Taler et al. (2019) monitored a hybrid solar energy system consisting of condensing gas boiler, ground and air heat pump, and solar collectors for a year, and identified the potential annual natural gas reduction of 21,621 m^3 and emissions reduction of 13.32 t. Mardani et al. (2019) predicted the carbon emissions by using ensemble-Adaptive Neuro-Fuzzy Inference System based on the renewable energy consumption and economic growth. The performance of the proposed model is evaluated by mean absolute error (MAE). The MAE value (0.047) is lower than the other prediction of other methods such as neural network (0.196) and support vector regression (0.121).

2.2. Suggestions for Future Research to energy and water management

Current contributions on energy and water management researches focus on the new methods and quantification tools to evaluate the environment and/or economic impacts of the proposed system. More holistic approaches have been seen for the integrated management of energy and water to reduce the environmental footprints (Čuček et al., 2012), i.e. based on the water-energy nexus perspective. Future research should focus on the interaction and impact between energy and water management and their improvement options. The developed methods should be tested and validated on more case studies to prove its robustness to be adopted under different scenarios. More indicators on different aspects related to sustainability, such as social-economic impacts, can be incorporated in the proposed methods.

3. Development of waste management

Waste management is a common issue that affects human health, environment, country development and economy. Solid waste management alone accounts for 5% of global GHG emission, excluding transportation (Kaza et al., 2018). Inappropriate waste management could lead to a severe environmental problem such as water pollution, soil pollution and significantly affect human health with high environmental costs incurred. Limited land for safe disposal further increases the environmental footprint due to the transporting activities and underground water contamination. Waste is defined as unwanted or unusable substances. The waste or by-products of the processes can be the resources of other processes. Waste management is an important part of the transition of linear to a circular economy. This section reviews the studies regarding sustainable waste management, focusing on the solid waste (including biomass), wastewater and transportation sector.

Waste-to-energy (WtE) has been one of the solutions that received high research attention due to its two-folds benefits (waste disposal and energy recovery). The examples of WtE treatment are anaerobic digestion, pyrolysis, gasification, incineration and landfill gas recovery (Beyene et al., 2018). Maragkaki et al. (2018) optimised the biogas production from sewage sludge by co-digesting with the dried mixture. The co-digestion with food waste, cheese whey and olive mill wastewater improve the biogas production up to two-fold. Kang et al. (2018) assessed the optimum sampling cycle using biomass fraction estimation method to identify the representable data to calculate flue gas-based GHG from the incineration facilities for municipal solid waste (MSW). This assessment is vital to enhance the reliability of the GHG inventories for waste incineration. Kibler et al. (2018) reviewed the alternatives for food waste management and proposed a conceptual model of food-energy-water nexus. However, the quantitative operationalisation of the food-energy-waste system approach is yet to be developed.

Ibáñez-Forés et al. (2018) identified that door-to-door selective collection of recyclable waste in a municipality of Brazil significantly improves the overall environmental indicators. However, the collection stage has a significant environmental impact to the overall waste management system. It highlighted the need for improving the efficiency of transportation including optimising the collection routes and loading. Šomplák et al. (2019) reported that the global warming potential of the complete treatment process including transportation as 37 kg CO_2eq/t of waste. Efficient management of comprehensive data and logistics are important issues to be addressed to enhance the efficiency of waste management.

One of the challenges in handling biomass or agriculture waste is recalcitrant properties. A wide range of pre-treatment is researched to enhance the degradability of the biomass and to enhance product yield such as the biogas. Shah et al. (2018) studied the pre-treatment and substrate ratios for the co-digestion of plant biomass and poultry waste. They found that the Fenton reagent and Fenton reagent with ultrasonic pre-treatment does not affect the biogas generation. Zheng et al. (2014) reviewed a wide variety of pre-treatment of lignocellulosic biomass, including the physical, chemical and biological approaches, to enhance the biogas production. In some cases, they are little positive results, and even adverse effects were reported. Fan et al. (2019a) assessed the pre- and post-treatment of anaerobic digestion from the perspective of cost and environmental impacts. Thermal hydrolysis pre-treatment is suggested to be less suitable for municipal solid waste (−5% to +15.4% enhancement). Cremiato et al. (2018) reported a wider scope by considering the environmental impact of anaerobic digestion, materials recovery and secondary fuels production. Sun et al. (2018) proposed different MSW management options by integrating MSW management and urban symbiosis network through integration with energy management. The energy recovery efficiency and GHG emission are applied as the efficiency quantification.

Real-time prediction and big data collection have been vital for the future operation of sustainable solid waste management. “Internet of Things” (IoT) (Saha et al., 2017) has been introduced step-by-step to enable efficient waste management. Edmondson et al. (2018) introduced a conceptual approach for the development of real-time predicted analysis of sewage asset performance. Bong et al. (2018) reviewed the role of IoT for smart waste management within a smart agricultural system. The scarcity of freshwater supply might be due to the increasing demand, pollution, unsustainable management, and variation in space. Dursun (2018) proposed an integrated fuzzy multicriteria decision-making methodology to determine the suitable wastewater treatment alternative. Philip et al. (2019) provided an overview of sustainable wastewater management through a decentralised system for treating and providing other benefits such as water reuse, energy reuse or nutrient reuse. Wong et al. (2018) reviewed the application of activated carbon from waste material for wastewater treatment. The activated carbons modified with magnetic materials as well as the challenges for application were discussed.

3.1. Special Volume contribution to development of waste management

In the effort to converting the waste into resources, Vakalis et al. (2019) proposed the conversion of agricultural waste into biocoal. Frictional pyrolysis is applied, and the excess energy from renewables (wind, solar energy) are integrated into the process. Different agricultural waste is assessed as illustrated in Fig. 5. The proposed process is suitable for woody waste and needs to work in a local-centralised way to reduce transportation costs. Azat et al. (2019) assessed three different methods for the production of pure silica from rice husk. Citric acid pre-treatment was assessed instead of the traditional HCl pre-treatment. Citric acid pre-treatment is relatively inexpensive with lesser environmental impacts. The amorphous silica produced from risk husk showed high purity at a yield of 20%. Manu et al. (2019) assessed the optimum condition for drum composting of household wet biodegradable waste in semi-continues mode. Many studies reported various issues due to the complex biological process and a wide variation of waste composition and volume. Characterising and kinetic modelling of the complex biological composting processes are active research trend. This trend is expected to grow in the next decade notably on the waste degradation rate in the presence of different microbial consortium and to overcome the issue of product quality and reproducibility at feasible cost and shorter composting time.

Wastewater and water management play a significant role in dealing with water scarcity issues. Agriculture is the dominant sector of water consumption. Sriphirom et al. (2019) evaluated the GHG emissions, water use and yield of rice cultivation by implementing alternate wetting and drying system. The results indicated the increased N_2O emission (+14.79%) but reduced CH_4 emission (−23.10%) by implementing a complete wetting and drying system. In the wet season, continuous flooding was a better water management practice than the alternate wetting and drying system. Li et al. (2019) proposed a novel aquaponics system to control the quality of water and to enhance nutrient efficiency. The objective was achieved through the installation of immobilised biofilm units between the upstream hydroponics unit and a downstream aquaculture unit.

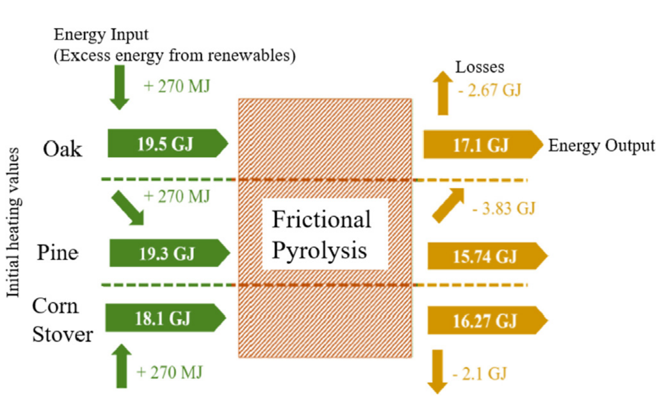

Fig. 5. Conversion of agricultural waste to biocoal. Adapted from Vakalis et al. (2019).

Social sustainability aspects deserved more attention in the literature compared to economic concern and environmental sustainability. All these aspects should be integrated as the social part plays an important role to be implemented in the real world. Jamaludin et al. (2019) developed the carbon emissions footprints for the palm oil mills. Integrated palm oil mill carbon emissions footprint and accounting and palm oil mill sustainability index are proposed as the quantitative measurement. The applicability is demonstrated through a case study in Malaysia to achieve a balance between environmental, economic, and social aspects in the palm oil mill sector. Kumar and Anbanandam et al. (2019) proposed a framework for assessing social sustainability using Indian freight transportation as an example. Future study would extend the current analyses to a larger number of freight transportation companies and the involvement of government officials and sustainability auditors for a comprehensive assessment.

3.2. Suggestions for Future Research to the development of waste management

Municipal solid waste (MSW) has been managed largely by landfilling in the developing countries. Many countries search urgently for viable and sustainable waste management strategies to divert waste from landfilling. The future solutions will vary depending on available resources, proof-of-concept technology that fulfils desirable socio-economic impacts. New methodologies, framework and simple quantification index, are important to facilitate the decision making of policymakers and interested stakeholders including the private and public sector for implementation. Future research should include comprehensive and robustness tests and showcase prototypes toward real implementation. The waste treatment solution that has flourished in recent years is biochar production mainly due to the carbon sequestration potential. However, it is currently still restricted by the feasibility for large scale application due to high energy requirement (Pourhashem et al., 2019) and the presence of contaminants that exist naturally in the biomass (Aviso et al., 2019).

Waste management deals with a range of issues from waste segregation to efficient collection, treatment and product distribution so as to close the loop for waste-to-wealth. It is important to have the involvement of different stakeholders to put the proposed framework into practice. Schanes et al. (2019) regarded food waste as a complex and multi-faceted issue that cannot be attributed to any single variable. Stronger integration of different disciplinary perspectives is crucial. The study systematic reviewed the cause of food waste generation using the social- and psychology-related approaches. They proposed the prevention strategies that link the identified factors with a set of policy, business, and retailer options.

Waste data collection is a key challenge that has to be overcome for detailed assessment and appropriate planning. Systematic data collection is costly and remains a key challenge that must be overcome in developing countries if a sustainable waste management system is to be designed. Most of the applicability of the presented methodology is demonstrated based on an illustrative case study or with assumption due to the lack of data availability and confidentiality of data disclosure. Smart waste management system using IoT could serve as automatic data collection to record the amount of waste and probe waste generation locations. However, the cost of introducing IoT for waste management and its footprint (energy consumption, disposal of e-waste) should be considered. In the effort of enhancing the waste treatment performance, waste prevention and reduction shall be improved in tandem. Integrated waste management (Sun et al., 2018) that combines a variety of strategies for both waste management and waste reduction (reduction, collection, recycling and disposal) is an important systematic approach deserved more research attention.

The other two potential research directions are 1) the LCA study of replacing plastic with the other materials such as cotton, paper, glass and metal, and 2) the circularity of the waste management system. To date, there is no consensus on the sustainability of the plastic replacement. A detailed study by NSW EPA (2016), which including the durability factors (see Table 1) should be conducted as any replacement has its own environmental impacts. These include material use, water and energy consumption, marine impacts, GHG and litter. A comprehensive and localise assessment is required before a final determination can be made on the feasibility of any alternatives. The selection of waste treatments is usually from the economic perspective with environmental consideration as the sub-objective. With the effort of moving toward a circular economy, circular economy related indicator, such as material flow accounting system as summarised by Geng et al. (2012), can be applied to assess the circularity of the integrated waste treatment system. There have been studies on assessing the circularity of different industrial processes, such as the aluminium cycle (Geng et al., 2012). However, the assessment focuses on different waste treatment for decision making is still limited. Circular material use rate proposed by Eurostat (2018) could be one of the possible approaches.

4. Greener policy and pollution minimisation strategies

Policy and regulations are the key pillars to ensure the sustainability of a city, region or country. To formulate an effective policy, the policymakers would need to evaluate the status-quote of the sustainability aspect. It is also important to identify the hot spot so that relevant key strategies could be implemented to improve the performance.

The usual approach to evaluate the sustainability of a city is by assessing its GHG emissions according to the IPCC method (IPCC, 2006). At the country level, computable general equilibrium (CGE) is one crucial integrated assessment tool to evaluate the socioeconomic and environmental performance. CGE has been applied in the context of policy analysis of international trade (De Melo and Robinson, 1989), energy (Fujimori et al., 2014) and environment (Hasegawa et al., 2016). In the context of China, CGE has been widely used by the researchers to evaluate the impacts of the policy such as environment tax and carbon tax. Liang et al. (2017) studied different carbon tax schemes in China by using a CGE model based on base year data of 2002. In the later researches, SO_2 tax (Ma, 2008) and integrated tax for CO_2 and other three pollutants SO_2, CO and NO_x (Xiao et al., 2015) were studied.

In Japan, the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) is widely adopted by the government agencies to evaluate the sustainability of municipality, city or area. To conduct CASBEE, a virtual boundary is created around the evaluated area or system. The Built Environment Efficiency rating is awarded based on the interior quality (Q) of the environment and activity, and environment load (L) of the system (Murakami et al., 2011). However, this method does not consider the monetary value of non-market goods such as land or labour markets. Such factors should be considered to evaluate the viability of implementation in any specific area.

Apart from sustainability, pollution is another paramount issue, which could lead to a severe impact on human life. For example, heavy metal toxicity also decreases fertility, destroy organs, and cause fatality in animals (Authman et al., 2015). It is critical to determine the concentration of heavy metal to take necessary remedial actions. The common methods include chemical analysis (CA) using aqua regia digestion (Santoro et al., 2017) and geoelectrical survey (Martínez-Pagán et al., 2009).

4.1. Special Volume contribution to greener policy and pollution minimisation strategies

A range of modelling and experimental works is conducted to predict and minimise GHG and the air pollutants. A recent work by Sununta et al. (2019) used the IPCC method to evaluate the GHG emissions of a local city in Thailand, i.e., Dan Sai Municipality. It was observed that fuel combustion of on-road transportation contributing most to the GHG emissions in the city, followed by energy generation for electricity. It is expected that the mitigating options such as the installation of solar on rooftops, the replacement of LED household bulbs even in the developing countries and RDF (refuse-derived fuel) could further reduce the GHG emissions.

Li and Masui (2019) developed a CGE model to evaluate the impacts of Environmental Protection Tax Law (2018) for China. The results indicated that the environmental tax could reduce the majority of pollutants at the cost of decreased Gross Development Product (GDP). The reduction of pollutants is due to the output loss in heavy polluted sectors and energy-intensive sectors. The environmental tax could have a positive impact on the output of clean energy sectors and the service sector.

Nakamura (2019) developed the land price function using a geographically weighted regressed model related to entrepreneurial, environmental, economic, and social factors for selected cities in Japan to reduce pollution. The results showed that environmental quality, social vitality, and entrepreneurship have a positive relationship with land price function, while nature conservation, resource recycling, and financial viability have a negative impact.

Puttiwongrak et al. (2019) proposed an integrated approach of combining chemical analysis using aqua regia and geo-electrical surveys, i.e., electrical resistivity imaging and induced polarization, to obtain the approximate levels of contamination for both lateral and vertical landscapes in the coastal sediments at Saphan Hin, Phuket, Thailand. The advantages of the proposed approach included the reduction in the required sample size and able to access difficult-to-access location in depth seas. Tahir et al. (2019)

Table 1
The durability and impacts of different bag type (NSW EPA, 2016).

Bag type	Number of reuses required for life cycle equivalence with an HDPE bag	Consumption			Litter marine impacts	GHG
		Energy	Water	Material		
HDPE	–	◆◆	◆	◆◆◆	◆◆◆◆◆	◆◆
Paper	3	◆◆◆◆◆	◆◆◆	◆◆◆◆◆	◆	◆◆◆◆◆
LDPE	4	◆◆◆	◆	◆◆◆◆	◆◆◆◆◆	◆◆
Non-woven polypropylene	11	◆	◆	◆	◆◆	◆
Cotton	131	NA	NA	NA	NA	NA

NA = information not available. ◆ is the rating from one to five.

fabricated a structured Ni/MMT supported TiO_2 composite catalyst to improve the photocatalytic CO_2 reforming of CH_4 to renewable syn-gas under normal temperature and atmospheric pressure with a higher yield (10-fold higher for H_2) and selectivity than the existing thermal process.

The above studies showed that quantification of GHG and pollutants by modelling or combined with experimental work, which provides indicators to set environmental or green policy such as the tax schemes. The environmental tax could provide pressure to the hot-spot sector to further mitigate pollution or to pay for the cost to clean up the environments. Tax incentives should be provided to the corporate that adopts greener materials with a level of pollutants and GHG reductions quantified.

Generation of greener materials with economic feasibility calculated is highly desirable. Zhao et al. (2019b) proposed a hydrogenation technology with modified Ni/A_2O_3 catalyst using Ag to promote higher hydrogeneration of acetylenes. The simulations showed that the proposed system was able to reduce the harmful emissions by recovering acetylene and converting it into valuable products, i.e., butane and benzene, with the sales benefits of 43 USD/t acetylene.

4.2. Suggestions for Future Research to greener policy and pollution minimisation strategies

Comprehensive and integrated assessment tool comprising of sustainability index, GHG emissions, environment, economic and social is required for policymakers to formulate good policy. Input of accurate data is crucial for such tools to be useful. It is critical for the involved stakeholders to formulate an effective strategy to collect the required data at minimum cost and avoid redundancy in the data collection process (Das et al., 2019). The stakeholders should also leverage on the advancement of big data analysis to interpret the data in a more meaning way and provide insights to any potential strategies and regulation. A novel data analytic method has been proposed by Niska and Serkkola (2018) to collect more detailed waste generation information, with feedbacks from stakeholders, for the planning and optimisation of waste collection and recycling. Consensus building among different administrative units in the government sectors for data collection and sharing are imperative towards the creation of enabling policy and measures to realise environmental sustainability.

5. Conclusions

This review dealt with efficient resource management work towards sustainable development, particularly from the environmental perspective. The scope includes energy, water and waste (solid and water) management as well as the policy and pollution minimisation strategies. Apart from energy and the renewables energy, water and raw material, waste is deemed as resources in this study. In promoting waste prevention or reduction, waste should also be transformed into resources with the prerequisite that the recovery process should be environmentally feasible. Directions for future research are suggested in each reviewed area of recent research.

1) In all the proposed environmentally sustainable methodologies and strategies, the investment required, and data availability are the common hindrance to put the suggestions or potential solutions into practice.
2) Data collection with the aids of IoT (e.g. real-time) could further demonstrate the reliability and improve the credibility of the proposed framework.
3) Involvement of stakeholder is also the linchpin of practical solutions and implementation.

Integration of smart concept in energy, water and waste management could significantly improve environmental performance through the smart sensor and real-time monitoring. However, there is still a research gap on the offset/saving versus the footprint of the IT sector. Continuous research and development, assessment and validation are needed. The articles in this special issue provide an overview of the recent development for efficient resource management. The authors believe the papers from this Special Volume can contribute to the future work of the respective fields to enable the circular economy.

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