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REVIEW

Mobilising the potential towards low-carbon emissions society in Asia

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Abstract Emission of CO_2, CH_4, and NO_x is among the main sources of greenhouse gases (GHGs) emitted through human activities such as fossil fuels combustion for power, heat and transportation, industrial processes, and land-use change. Low-carbon emission has become synonymous with GHG emission, which is often expressed in *t* CO_2 eq. as derived from the major GHG. However, CO_2 emission from fossil fuel constitutes just about 2/3 of GHGs. Low-carbon emission has received high publicity in recent years as a major reason for the potential mitigation of climate change. Achieving low GHG emission targets while decoupling the economic growth from high emissions, pollution, and resource use is desirable. This paper reviews the low-carbon emissions initiatives to develop resilient growth strategies to reduce GHG emissions in Asia and beyond. Four major initiatives, including the modelling of GHG emission and mitigation initiative; sustainable energy systems; sustainable waste management; and education and community outreach, are reviewed for mobilising the potential towards low-carbon emissions societies in Asia. Cooperation from major stakeholders, e.g. government, policy makers, financial institutions, private investors, industrial, commercial sector, residential, has been needed towards realising the goal.

Keywords Low-carbon and greenhouse gases emissions · Asia · Mitigation strategies · Clean technology · Education · Sustainable policy

Introduction

The global energy consumption increased to 389 EJ by 2013, while the global energy-related CO_2 emissions increased by over 50 %, to 32.2 Gt in 2014. This growth is driven mostly by increased industrial production in the developing countries. Two-thirds of the CO_2 emissions budget for limiting global warming to 2 °C by 2050 has already been used. About above 1 °C global warming has been achieved in 2015. The energy consumption in China is expected to continue to grow. The potential of resource and energy efficiency improvement play a key role when tackling energy and environmental issues. The related health impacts could be caused by pollution and especially by the haze. The co-benefits of energy efficiency can provide a deeper understanding to overcome the barriers in the application of energy efficiency measures (Zhang et al. 2016).

Rapid economic growth in Asia leads to high regional footprints of greenhouse gases (GHGs). The International Energy Outlook 2016 reported that the world energy-related CO_2 emissions will increase from 32.3 Gt CO_2 eq. in 2012 to 43.2 Gt in 2040. The GHG emission in Asia is accounted for 46 % of the global emission, equivalent to 14.5 Gt CO_2 eq. in 2012 and projected to double the emission level in 2010 by 2040 to 21.2 Gt CO_2 eq. (US

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Energy Information Administration 2016). Decoupling high GHG emission without compromising the economic growth has been a great challenge. Widely concerted effort at different levels of the society covering from the top-down and bottom-up measures has been essential to implement low-carbon emission societies with reduced GHG footprints. The largest share of the Asian urban emissions is for energy production (48 %), followed by industry (11.1 %), and transportation (10.1 %), where urban represents a 30 % of total GHG emission as shown in Table 1.

CO_2 accounts for 2/3 source of GHG emitted through human activity such as fossil fuels combustion for energy and transportation, industry process, and land-use change (Yong et al. 2016). The development of low-carbon emission is an avenue towards decoupling the economic growth from carbon emissions, pollution, and resource use. It promotes the growth by the creation of environment-friendly products, clean technology, and sustainable supply chains and business models. The top 20 CO_2 emitters in Asia including China (58 %, 9680 Mt CO_2/y) and other rapid developing country in the year 2014 are shown in Fig. 1.

Asia is not just a regional factory, it exports very considerable amounts of materials and products. Liu et al. (2016) presented other results (Fig. 3), when consumption-based principle (Boitier 2012) was applied (Eq. 1) :

$$\mathrm{GHG_{cons}} = \mathrm{GHG_{dcons}} - \mathrm{GHG_{exp}} + \mathrm{GHG_{imp}} \quad (1)$$

where $\mathrm{GHG_{cons}}$—consumption-based national GHG emissions, $\mathrm{GHG_{dcons}}$—GHG emissions from domestic final consumption, $\mathrm{GHG_{exp}}$—GHG emissions embodied in the exports, $\mathrm{GHG_{imp}}$—GHG embodied in the importations.

Asia has a significant role and responsibilities for climate stabilisation. Various top-down and bottom-up strategies are needed to transform the key sectors such as the transportation infrastructure, urban planning, energy production, solid waste management, and agricultural practices. Many Asian countries are moving towards low-carbon emission development with various policy and blueprints launched such as the Iskandar Malaysia Low Carbon Society Blueprint (Low Carbon Society Blueprint for Iskandar Malaysia 2025 2012). More attention is needed to deal with the other GHGs as well, especially when NO_x are playing a role in haze formulation (Fig. 2).

Due to the international trade where Asian countries have been exporting largely substantial amount of raw materials (oil, gas, and coal) and products in huge quantities (electronics, textile) and including a huge amount of virtual GHG emissions (as fertilisers, steel), the role of Asia has been even more underlined (Liu et al. 2016); see Fig. 3.

The overview structure

The presented overview reviews four groups of papers that are relevant to the low-carbon emissions developments, including modelling of GHG emission and mitigation initiative; sustainable energy systems; sustainable waste management; and education and community outreach towards low-carbon emission development. To give the Clean Technologies and Environmental Policy Journal readers a sense of continuity, a review on a selection of published papers has been provided for this review.

Modelling of GHG emission and mitigation initiative

As the idea of low-carbon emission development is receiving a growing attention from the Asian policymakers, a prerequisite quantification of the regional and urban emission becomes essential. Mi et al. (2016) employed a single-region input–output model to calculate the consumption-based CO_2 emissions for 13 Chinese cities. They found that the consumption patterns in these cities have led to significant GHG emissions within their own boundaries and induced emissions in other regions via inter-regional trade. This approach elucidates the growth of emissions, improves cost-effectiveness and justice, addresses carbon leakage, promotes environmental comparative advantages, and encourages technology diffusion. Forecasting the regional and urban emission through different scenario

Table 1 Asian total and urban GHG emission by sector in the year 2000 (Marcotullio et al. 2012)

Sectors	Total GHG		Urban GHG		Urban share of total
	(Mt)	(%)	(Mt)	(%)	(%)
Agriculture	2460	17.49	145	3.38	5.89
Energy	6742	47.93	2648	61.70	39.28
Industry	1564	11.12	492	11.46	31.46
Transportation	1238	8.80	432	10.07	34.89
Residential	1293	9.19	321	7.48	24.83
Waste	766	5.45	253	5.89	33.03
Total	14,065	100.00	4292	100.00	30.52

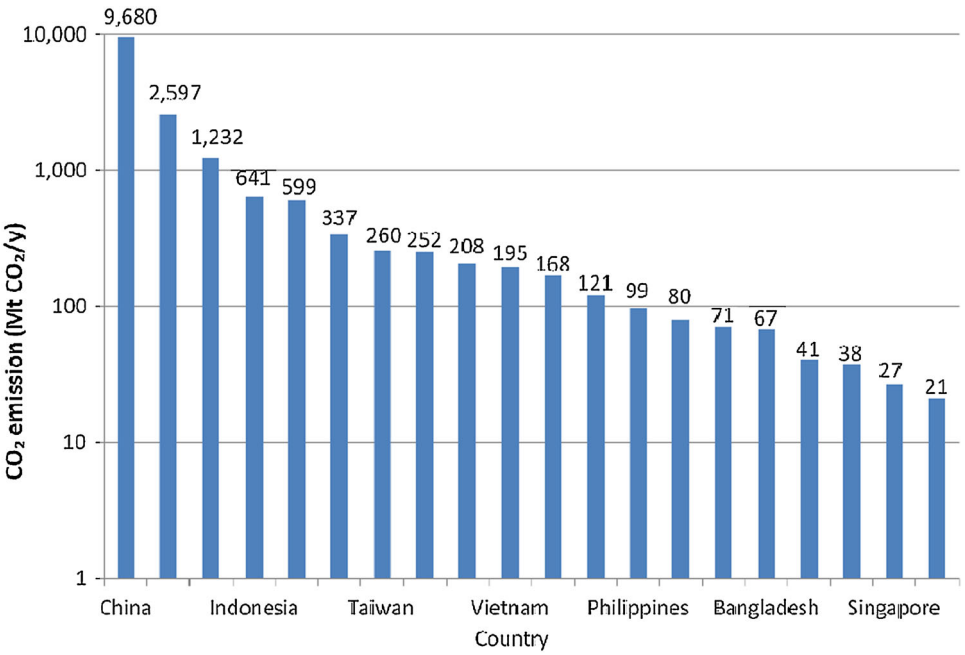

Fig. 1 Top 20 CO_2 emitters in Asian countries in the year 2014 (adopted from The Global Carbon Atlas 2016)

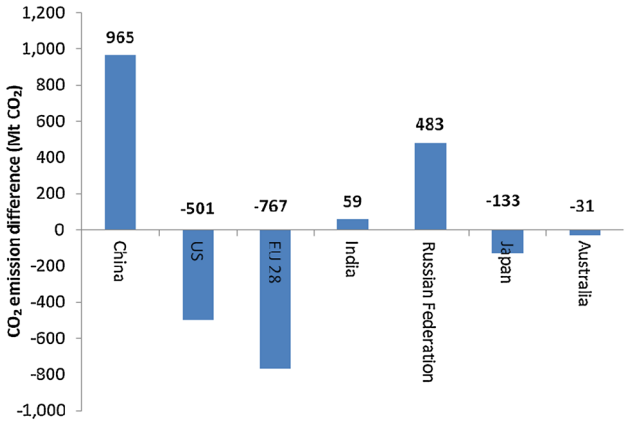

Fig. 2 CO_2 emissions difference between the production-based (positive) and the consumption-based (negative) principles (Liu et al. 2015)

analysis is essential for the planning of low-carbon emission development. Gomi et al. (2010) developed the Extended Snapshot (ExSS) tool to project the sectoral GHG emission under low-carbon society (LCS) scenario against that under the business-as-usual (BAU) scenario. The methodology has been widely applied to several LCS case studies in Asia including the Jilin City, China (Jiang et al. 2009), Vietnam (Hoa et al. 2010) and more recently (Nguyen et al. 2014), Thailand (Winyuchakrit et al. 2016), Bangladesh (Jilani et al. 2011), Putrajaya (Hayashi et al. 2012), Iskandar Malaysia (IM) (Ho et al. 2013), Bhopal (Gomi et al. 2013), and Indonesia (Osawa et al. 2014). Quantitative models are useful to estimate the GHG emissions and mitigation potential, and provide significant inputs for LCS planning and setting enabling policies for low-carbon emission development. For example, IM has the potential to reduce its carbon emission intensity by up to 58 % by 2025 based on the 2005 level through the modelling of the LCS based on the ExSS tool (Ho et al. 2016).

The sectoral analysis of GHG provides the clearer indication on the areas that need to be targeted for the mitigation strategies. Y.A. Fatimah and W.K. Biswas in their work "Remanufacturing as a means for achieving low carbon SMEs in Indonesia" used life cycle assessment (LCA) approach to analyse a number of remanufacturing strategies to identify an option that could reduce GHG emissions and satisfy the technical feasibility in terms of the reliability, durability, and warranty period criterion. The study found a significant mitigation of GHG emissions and embodied energy consumption by maximising the use of recyclable alternators from the automobile sector. K.K. Lawania and W.L. Biswas in their work entitled "Cost effective GHG mitigation strategies for Western Australia's housing sector: A life cycle management approach" examined the GHG mitigation strategies that are cost effective for the building sector in the Perth city. They integrated energy rating software (AccuRate) and life cycle cost (LCC) in the LCA tool to ascertain the environmentally and economically viable alternative for a building. The result suggested that buildings with cast in situ sandwich walls, recycled core materials and double-glazed windows, and equipped with solar energy system for electricity and water heating provide the best mitigation performance and economic feasibility. A diverse form of

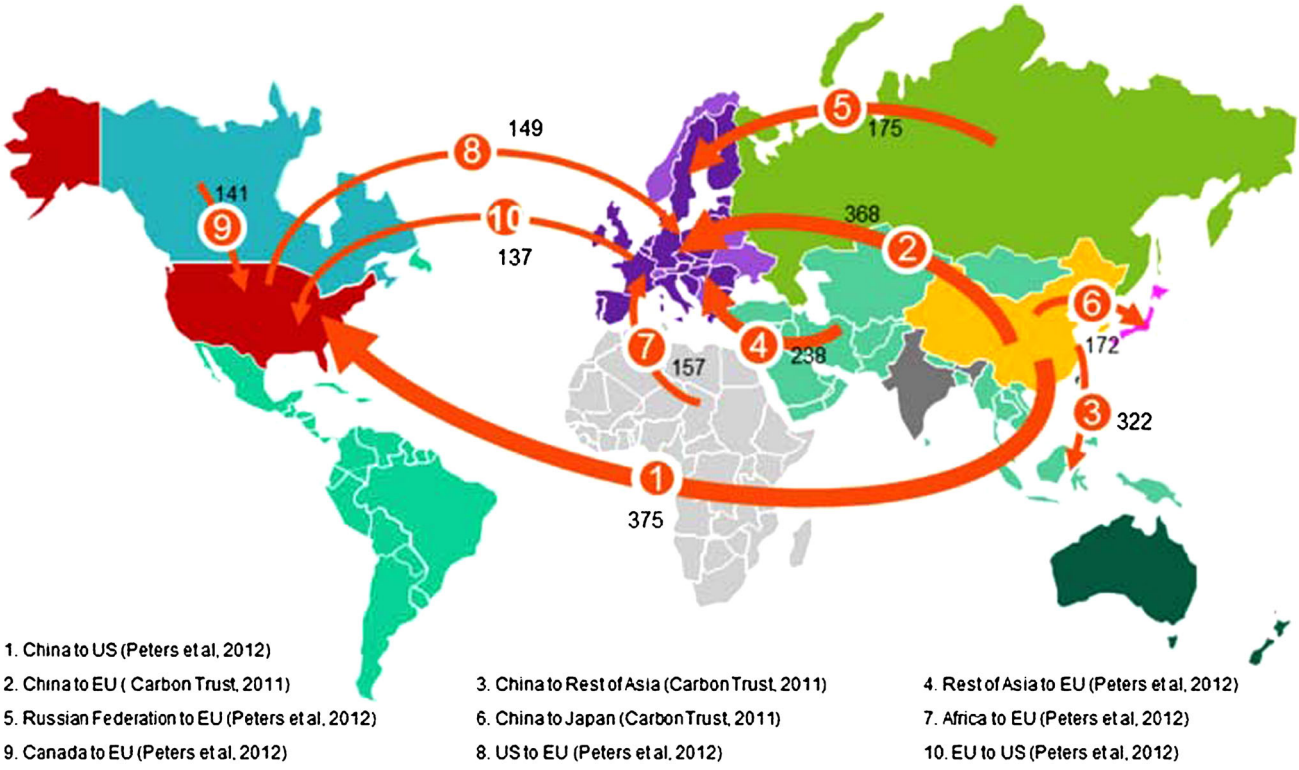

Fig. 3 Virtual CO_2 emissions flows in the international trade (adopted from Liu et al. 2016)

GHG emission is found in the urban and rural areas, and it is critical to measure and benchmark the performance of GHG emissions for different cities. Tan et al. (2016) developed a low-carbon emission city indicator framework to evaluate the GHG emission for the major cities in Asia and beyond. Various developmental plans are available to promote the development of low-carbon emissions for the major cities in Asia such as Beijing, and the city was ranked the lowest or emitting the highest GHG level compared to others world cities due to its high energy consumption pattern (Tan et al. 2016). The results identified the key contributors for the GHG emission in each city and enable the city to continuously mitigate GHG emission.

Particulate matter emitted by urban activities is a constant source of air pollution. Coal burning is one of the major sources of particulate matter and other air pollutants. Air pollution in an urban area is caused mainly by the motor vehicles in Asia, particularly those fuelled by diesel fuel and two-stroke engines (Haq and Schwela 2008). Local emission that degrades the air quality should be taken seriously since these emissions are not intermittent but continual and it could eventually reach a hazard level. M.A.Z. Zahari, M.R. Majid, C.S. Ho, G. Kurata, N. Nordin, and N.I. Zen in their work "Relationship between land use composition and PM_{10} concentrations in Iskandar Malaysia" investigated the relationship between land-use composition (residential, commercial, industrial) and its ambient concentration of 10 μ-or-less particulate matter (PM_{10}). PM_{10} is evidently more affected by the commercial land use, followed by the industrial and residential land use. The study provides evidence to the policy maker and local authorities to control air pollution and improve the planning for land use. While modelling tools are getting comprehensive in estimating the GHG emissions, up-to-date inventory of the data is essential to improve the accuracy of the models. Implementation of the mitigation measures would require the cooperation from the multiple stakeholders including the enabling policy to provide incentive/rewards and monitoring of the local authorities to achieve the desired level of low GHG emissions.

Sustainable energy system

Energy supply is the main driver for the development of modern society. It represents the largest emitter of GHG (47.93 %) in Asia among all sectors as shown in Table 1. The transition towards sustainable, efficient, and low-carbon emission energy system can bring numerous economic and environmental benefits to Asia. The complex issue of sustainable energy systems and the interlinked roles of technology development, local energy resources, and societal factors are the key topics to be dissolved. Solving the complexity of electricity consumption with regards to

the economic factors has been the research focus. Karanfil and Li (2015) examined the long- and short-run dynamics between electricity consumption and the economic activities of 160 countries. They concluded that the gross domestic product (GDP) and electricity consumption present only short-run or little causality for the high-income region, while a stronger relationship was found in the long run for the low-income region. Y. Wang, J.M. Zhang, and H. Guo conducted an extended study "Decomposition of electricity consumption in China by primary component analysis" by employing the principle component analysis to remove the multicollinearity of variables, so as to investigate the influence of GDP with regards to population, the product of primary, secondary, and the tertiary industry on the pattern of electricity consumption.

Some researchers focused on the local energy resources for the future development of low-carbon emission. For instance, microalgae are recognised as a promising alternative energy source with reduced GHG emission (Demirbas 2011). A.R.C. Villagracia, A.P. Mayol, A.T. Ubando, J.B.M.M. Biona, J.N.B. Arboleda, M.Y. David, R.B. Tumlos, H. Lee Jr, H.L. Ong, R.A. Espiritu, A.B. Culaba, and H. Kasai studied in their work "Microwave drying characteristics of microalgae (*Chlorella vulgaris*) for biofuel production" for its suitability to produce biofuel. A mathematical model based on the Page Model was able to characterise the effect of moisture ratio during the microwave drying process. The microalgae have high lipid and carbohydrate contents indicating that *Chlorella vulgaris* is a good potential source of biomass for the production of renewable biofuel.

An innovative methodology for energy integration and management also gained increased attentions by the researchers. Pinch analysis (PA) was pioneered by Linnhoff and Flower (1978). PA was first applied for heat integration by Smith (1995). PA technique has also been applied in other analogous system processes such as for mass exchanging networks (El-Halwagi and Manousiouthakis 1989), water network (Wang and Smith 1994), gas network (Alves and Towler 2002), production planning (Singhvi and Shenoy 2002), biomass supply chain (Lam et al. 2010), carbon emission planning (Tan and Foo 2007), power system planning (Alwi et al. 2012), Total Site Optimisation (Klemeš et al. 2014), and waste management (Ho et al. 2016). Klemeš et al. (2013) reviewed various application of PA as sustainable solutions for the management of water, energy, and materials. W.H. Liu, K. Kaliappan, S.R. Wan Alwi, J.S. Limand W.S. Ho, in the paper "Power Pinch Analysis supply side management: Strategy on purchasing and selling of electricity", determined the strategies for power supply side management of a hybrid power system (HPS) comprising of renewable power generators and energy storage system. The study showed that the manipulation of the demand and supply sides of energy can result in a substantial benefit to the design and operation of an HPS. A.M. Hafizan, S.R. Wan Alwi, Z.A. Manan, J.J. Klemeš studied in their paper "Optimal heat exchanger network synthesis with operability and safety consideration" the inherent safety and operability aspects of optimal heat exchanger networks (HENs) designed through PA. The most flexible HENs yielded the highest percentage of energy saving at 22 %. S.R. Lidu, N.A. Mohamed, J.J. Klemeš, P.S. Varbanov, and S. Yusup conducted in their work "Evaluation of the energy saving opportunities for palm oil refining process: Sahabat oil products (SOP) in Lahad Datu, Malaysia" heat integration implementing PA to analyse the potential energy and cost savings of a palm oil refinery process. The presented scoping study confirms the potential of energy savings in the palm oil refining process, revealing that total annualised cost saving of MYR 56,519 (USD 13,819) is possible. The results also indicated a potential saving of 3.5 % heating and 3.1 % cooling as compared to the existing utility consumption and related emissions. Aziz et al. (2016) developed a systematic framework to serve as a total site planner using the PA tools towards optimisation of energy consumption with reduced CO_2 emissions. The novel framework demonstrated a significant reduction of 99.8 % CO_2 emissions for an industrial site with reduction of 56.7 % in heat and 74.3 % of power consumption. Modelling and optimisation methods are widely reported to solve various problems for the implementation of renewable energy (RE). Mixed integer linear programming (MILP) is a relatively simple modelling method to obtain the best solutions for the allocation of energy resources and capacity expansion plans with minimised system cost, maximised system reliability, and maximised energy security (Cai et al. 2009). Z.A.B. Muis, W.S. Ho, H. Hashim, M.Y. Lee, and A.F. Ramli presented work titled "Sustainable multi-period electricity planning for Iskandar Malaysia". They developed a comprehensive multi-period plan for the supply and demand of electricity comprising of non-RE and RE with a CO_2 reduction target. The study concluded that the selection and choice for power generation technology are driven by the capital cost, availability of RE sources, and CO_2 emission targets.

An innovative methodology for the modelling and sustainable management of energy has widely been reported, and more efforts and platforms are needed to accelerate the translation of science into practice and policy in many fast-developing countries in Asia.

Sustainable waste management

Solid waste management poses a great challenge in many fast-developing countries and cities in Asia. The cost for

sanitary landfill sites is prohibitive, approximately raging widely USD 10–100/t of waste (Wilson 2015), where waste is disposed at large in the open dump. Economic feasibility studies and environmental assessments are vital to promoting the best practices for sustainable waste management and to lure potential investors for implementation.

Waste-to-wealth (UNU-INWEH 2016) is a concept to leverage on the economic and social benefits of nutrient recycling, biogas generation, soil amendment, and new livelihoods from wastewater management. It promotes the financial incentive for communities to collect and treat their waste, forming the basis of a sustainable and affordable wastewater management framework.

Organic waste represents the major portion of the municipal waste in many fast-growing countries. For example, it had been reported that about 50 % of the municipal waste stream in Malaysia consists of the organic waste. Conversion of organic waste via composting can be a viable technology. However, so far it has been hindered by complex issues such as the requirement of a large area for the composting system and long holding period (2–3 months), lack of waste segregation at source, and poor understanding of the further application. Quality assurance and the safety of the end compost are one of the key factors that would pave the way for the compost market in the developing countries. Y.V. Fan, C.T. Lee, J.J. Klemeš, C.P.C. Bong, and W.S. Ho proposed in their work "Economic assessment system towards sustainable composting quality in the developing countries". It comprises of a system proposing the minimal analysis needed to assess the compost quality. The assessment system could be useful for improving the compost utilisation towards sustainable composting in the developing countries. The large-scale conversion of biomass to compost is still hindered by the lack of enabling policy in the developing countries to regulate the supply chain of biomass and secure the interest of the investors.

The long duration of composting is also one of the key challenges in composting. D. Malamis, K. Moustakas, and K.J. Haralambous in their work "Evaluating in-vessel composting in treating sewage sludge and agricultural waste by examining and determining the kinetic reactions of the process" studied the performance of a prototype in-vessel composting system by examining the kinetic reactions of the processes developed for the treatment of sewage sludge and agricultural waste. The first-order kinetic model was capable of modelling the degradation rate of biodegradable organic matters with the attempt to determine the rate-limiting parameters including temperature, moisture content, and oxygen concentration. However, the effect of these parameters was found to be not significant nor served as the limiting parameters in the study. More other parameters, such as the microbial concentration and the substrate-to-water ratio, could be considered in the future based on the model developed to speed up the in-vessel composting process.

Innovative technology converting waste to value-added products is desirable. M.S. Mohaiyiddin, H.L. Ong, W.T. Owi, C.H. Chan, C.H. Chia, S. Zakaria, A.R. Villagracia, and H.Z. Akil in their paper "Characterization of nanocellulose recovery from *Elaeis guineensis* frond for sustainable development" derived and characterised a novel nanocellulose with excellent characteristics for biodegradability, thermal stability, and biocompatibility from the oil palm (*Elaeis guineensis*) frond (OPF). The nanocellulose was synthesised from OPF using the alkaline, bleaching and acid hydrolysis processes, the conventional methods that are reasonably simple, low cost, and non-toxic. About 100 kg/ha of OPF waste is produced from the oil palm plantation, and the waste is typically open dumped in the plantation as a low-nutrient soil mulcher. Malaysia is the top world producer of palm oil, and it was estimated that 71 Mt (dry weight) of the palm solid biomass waste was produced in 2010 alone, and OPF represents 84.5 % of the biomass (60 Mt) followed by the empty fruit bunch (EFB), the mesocarp fibre (7 Mt), and the palm kernel shell (4 Mt). The total solid biomass waste is projected to increase to 85–110 Mt in the year 2020 (Chan 2014). OPF is currently open dumped where a large portion will undergo anaerobic condition with the emission of methane gas (CH_4), a GHG nearly 12-fold stronger than the CO_2 in terms of the global warming potential. The continuous improvement of economic feasibility for the production of the nanomaterials from OPF is expected to offer positive socio-economic and environmental impact for the disposal of OPF.

For the agricultural industries, the wastewater contains a substantial amount of organic matters that could serve as nutrients to grow valuable crops such as microalgae and for raising fish in the aquaculture industry. If the wastewater is contaminated with a substantial amount of detergent, it would not be suitable to cultivate edible products. However, it has the potential to grow biomass as a source of renewable energy. Increased research has been reported for the cultivation of microalgae with high lipid content to serve as biomass for the production of biofuel. R. Resdi J.S. Lim, H. Kemyab, C.T. Lee, H. Hashim, N. Mohamad, and W.S. Ho in their work entitled "Review of microalgae growth in palm oil mill effluent for lipid production" reported the competent technology for the cultivation of high-lipid microalgae using the palm oil mill effluent (POME) as substrate. The reuse of POME reduced the volume and chemical oxygen demand (COD) of the wastewater and produced the valuable products through efficient nutrient recycling. Microalgae are competent in diminishing CO_2 emissions and reducing the organic

components in POME. Microalgae-based biofuels processes were reported to realise significant GHG reductions relative to a petroleum diesel baseline, i.e. a negative GHG emission or mitigation value for microalgae biofuel (−71.73 g CO_2 eq./MJ) against the positive emission of 17.24 g CO_2 eq./MJ for the petrochemical-based diesel. The net negative CO_2 eq. output in the microalgae biofuel was due to the CO_2 capture intrinsic in the production of biomass during photosynthesis, the displacement of petroleum, and the displacement of coproducts (Batan et al. 2010). H. Kamyab, M.F.M. Din, S.E.H. Hosseini, S.K. Ghoshal, V. Ashokkumar, A. Keyvanfar, A. Shafaghat, C.T. Lee, A.A. Bavafa, and M.Z.A. Majid in their paper "Optimum lipid production using agro industrial wastewater treated microalgae as biofuel substrate" resulted in a high lipid content (17 mg lipid/mg CDW) in the microalgae strain of *Chlorella sorokiniana* using simple biological treatment with POME as the substrate. These results revealed that POME could be a suitable growth media for *Chlorella sorokiniana* to maximise the lipid yield for biofuels production.

Due to the bulk volume of the solid waste and wastewater which incur high transportation costs, decentralised and on-site solution through innovative, low-cost, and efficient solutions are needed to significantly reduce the waste volume to the landfill and avoid open dumping and the presented scoping study confirms the potential of energy savings in the palm oil refining process, revealing that total annualised cost saving of MYR 56,519 (USD 13,819) is possible. CH_4 emission counts for a sizable part of GHGs. Enabling biomass policy to facilitate a proper database management of biomass material flows is essential to monitor the pricing, supply and demand of biomass. The database will facilitate the economic and environmental assessment for waste and biomass management and boost the confidence of the investors to implement waste-to-wealth business case. The USA has enabling policy instruments and reporting to empower the utilisation of microalgae as bioenergy (US Energy Information Administration 2016).

Education and consensus building towards low-carbon development

Sustainable development towards low-emission carbon future cannot be realised through innovative technological alone. Other drivers, through political regulation, financial instruments, a platform for strategic networking, are critical for consensus building among multiple stakeholders. The 21st yearly session of the Conference of the Parties COP21, Paris, France, www.cop21paris.org, LCSNet lcs-rnet.org and LoCARNET locarnet.org are among the active regional network for multi-layered stakeholders to promote research cooperation related to low-carbon emission development and policy making for climate change. The LoCARNET serves as a network for researchers to support the low-carbon emission development in the Asian region. Education and consensus building are the powerful vehicles to implement real projects on the ground across different stakeholders. A few Asian countries such as Japan have driven intensive efforts in the education and community consensus building for low-carbon emission. Kyoto city in Japan began the global warming curriculum in the elementary school in the year 2005 to educate the knowledge-related global warming and encourage low emissions carbon lifestyle. This initiative named as the Children's Eco-life Challenge is a cooperative project run by the local authority and non-profit organisations such as the Kiko Network, Junior Chamber International Kyoto, and National Institute for Environmental Studies (NIES), Japan (Ueda 2013). F.A. Phang, W.Y. Wong, C.S. Ho, A.N. Musa, J. Fujino, M. Suda in their work "Iskandar Malaysia Ecolife Challenge: Low carbon education for teachers and students" reported that the low emissions carbon education system was later adopted and conducted in the region of IM (Iskandar Malaysia). The Iskandar Malaysia Eco-life Challenge (IMECL) implemented in 80 primary schools in IM, contained several topic on low-carbon emissions development, such as recycling, saving water, and saving electricity, as well as the completion of a workbook designed to raise consciousness of local and global environmental concerns. The pre- and post-programme surveys for IMECL revealed the effectiveness of the programme for inculcating green awareness among the participating students.

The process of moving towards LCS in IM also incorporated community engagement to build a strong partnership and consensus among community and stakeholders. For example, the project of Low Carbon Eco-Village in FELDA Taib Andak formulated the community action plan and activities to develop the low-carbon lifestyle within the community (Ngah and Zulkifli 2014). A community composting programme was implemented where the technology and knowledge were transferred to the community. A good practice of 3R (reduce, reuse, and recycling) was also introduced. Ideally, the composting model should be sustained and duplicated in other communities to provide the co-benefits of reduced waste tipping fee and cost saving of fertiliser for the oil palm plantation (Bong et al. 2016).

The more top-down effort is essential to empower the experts and community leaders to educate and outreach the consensus building among various stakeholders. The 11th Malaysian Plan 2016–2020 (2016) has preached to pursue the green growth for sustainability and resilient under one of its six key thrusts. The Malaysia National Blue Ocean Strategy (2016), through Urban and Rural Transformation

Centres, has dispensed funding for community programmes involving multiple stakeholders to provide practical solutions for sustainable energy, water, and waste management.

Conclusions

This paper addresses the recent research works on four topics dedicated to the low-carbon emissions development in Asia, including the GHG modelling and mitigation initiative; sustainable energy systems; sustainable waste management; and education and consensus building towards low-carbon emission development. Despite the ongoing developments in all the areas considered, there are still great challenges to accelerate the transformation towards low-carbon emission societies. The potential towards low-carbon emission in Asia requires a sustainable and holistic framework that involves top-down and bottom-up approaches from different levels accelerated by the enabling policy instruments, competitive technology supported by viable economic feasibility studies and leadership for consensus building and implementation.

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References

Alves JJ, Towler GP (2002) Analysis of refinery hydrogen distribution systems. Ind Eng Chem Res 41(23):5759–5769

Alwi SRW, Rozali NEM, Abdul-Manan Z, Klemeš JJ (2012) A process integration targeting method for hybrid power systems. Energy 44:6–10

Aziz EA, Alwi SRW, Lim JS, Abdul-Manan Z, Klemeš JJ (2016) An integrated Pinch Analysis framework for low CO_2 emissions industrial site planning. J Clean Prod. doi:10.1016/j.jclepro.2016.07.175

Batan L, Quinn J, Willson B, Bradley T (2010) Net energy and greenhouse gas emission evaluation of biodiesel derived from microalgae. Environ Sci Technol 44:7975–7980

Boitier B (2012) CO_2 emissions production-based accounting vs. consumption: Insights from the WIOD databases. In: WIOD Conference Paper. www.wiod.org/conferences/groningen/paper_Boitier.pdf. Accessed 7 Aug 2016

Bong CPC, Goh RKY, Lim JS, Ho WS, Lee CT, Hashim H, Mansor NNA, Ho CS, Ramli AR, Takeshi F (2016) Towards low carbon society in Iskandar Malaysia: implementation and feasibility of community organic waste composting. J Environ Manag. doi:10.1016/j.jenvman.2016.05.033

Cai YP, Huang GH, Tan Q, Yang ZF (2009) Planning of community-scale renewable energy management systems in a mixed stochastic and fuzzy environment. Renew Energy 34(7):1833–1847

Chan TK (2014) Green wealth in oil palm. Global Oils Fats Bus Mag 11(2):24–28

Demirbas MF (2011) Biofuels from algae for sustainable development. Appl Energy 88(10):3473–3480

El-Halwagi MM, Manousiouthakis V (1989) Synthesis of mass exchange networks. AIChE J 35:1233–1244

Gomi K, Shimada K, Matsuoka Y (2010) A low-carbon scenario creation method for a local-scale economy and its application in Kyoto city. Energy Policy 38(9):783–4796

Gomi K, Deshpande A, Kapshe M (2013) Aligning low carbon society scenario with city development goals in Bhopal, India. Global Environ Res 17(1):129–138

Haq G, Schwela D (2008) Foundation course on air quality management in Asia: urban air pollution in Asia. Stockholm Environment Institute, Stockholm

Hayashi Y, Simson JJ, Gomi K, Matsuoka Y (2012) Development of a method to design a low-carbon society in small community and its application to Putrajaya, Malaysia. Environ Res 67(6):213–224

Ho CS, Matsuoka Y, Simson J, Gomi K (2013) Low carbon urban development strategy in Malaysia–the case of Iskandar Malaysia development corridor. Habitat Int 37:43–51

Ho CS, Chau LW, The BT, Matsuoka Y, Gomi K (2016a) 'Science to Action' of the sustainable low carbon city-region: lessons learnt from Iskandar Malaysia. In: Nishioka S (ed) Enabling Asia to stabilise the climate. Springer, Singapore

Ho WS, Hashim H, Lim JS, Lee CT, Sam KC, Tan ST (2016b) Waste management pinch analysis (WAMPA): application of pinch analysis for greenhouse gas (GHG) emission reduction in municipal solid waste management. Appl Energy. doi:10.1016/j.apenergy.2016.01.044

Hoa NT, Gomi K, Matsuoka Y, Tu TT, Fujino J, Kainuma M, Shrestha RM (2010) Preliminary study on sustainable low-carbon development towards 2030 in Vietnam. 2050nies.go.jp/report/file/lcs_asia/Vietnam_Brochure_20100415.pdf. Accessed 28 July 2016

Jiang K, Zhuang X, Hu X (2009) Scenario analysis on low-carbon economy development of Jilin City. 2050.nies.go.jp/report/file/lcs_asialocal/Jilin.pdf. Accessed 28 July 2016

Jilani T, Gomi K, Matsuoka Y (2011) Low-carbon society development towards 2025 in Bangladesh. 2050.nies.go.jp/report/file/lcs_asia/Bangladesh_2012.pdf. Accessed 28 July 2016

Karanfil F, Li Y (2015) Electricity consumption and economic growth: exploring panel-specific differences. Energy Policy 82:264–277

Klemeš JJ, Varbanov PS, Kravanja Z (2013) Recent developments in process integration. Chem Eng Res Des 91(10):2037–2053

Klemeš JJ, Varbanov PS, Alwi SRW, Abdul-Manan Z (2014) Process integration and intensification: saving energy, water and resources. De Gruyter, Berlin

Lam HL, Varbanov P, Klemeš JJ (2010) Minimising carbon footprint of regional biomass supply chains. Resour Conserv Recycl 54(5):303–309

Linnhoff B, Flower JR (1978) Synthesis of heat exchanger networks. Part I. Systematic generation of energy optimal networks. AIChE J 24(4):633–642

Liu X, Klemeš JJ, Čuček L, Varbanov PS, Yang S, Qian Y (2015) Export-import of virtual carbon emissions and water flows embodied in international trade. Chem Eng Trans 45:571–576. doi:10.3303/CET1545096

Liu X, Klemeš JJ, Varbanov PS, Čuček L, Qian Y (2016) Virtual carbon and water flows embodied in international trade: a review

on consumption-based analysis. J Clean Prod. doi:10.1016/j.jclepro.2016.03.129
Low Carbon Society Blueprint for Iskandar Malaysia 2025 (2012) Johor Bahru, Malaysia. 2050.nies.go.jp/cop/cop18/SPM_LCS%20Blueprint_Iskandar%20Malaysia.pdf. Accessed 27 July 2016
Marcotullio PJ, Sarzynski A, Albrecht J, Schulz N (2012) The geography of urban greenhouse gas emissions in Asia: a regional analysis. Global Environ Environ Change 22(4):944–958
Mi Z, Zhang Y, Guan D, Shan Y, Liu Z, Cong R, Yuan X, Wei Y (2016) Consumption-based emission accounting for Chinese cities. Appl Energy. doi:10.1016/j.apenergy.2016.06.094
Ngah I, Zulkifli AS (2014) Participatory approach in planning for low carbon and ecovillage: a case of Felda Taib Andak. In: 8th International Symposium of the Digital Earth (ISDE8) IOP Publishing IOP Conf. Series: Earth and Environmental Science 18. iopscience.iop.org/article/10.1088/1755-1315/18/1/012150/pdf. Accessed 28 July 2016
Nguyen TH, Gomi K, Matsuoka Y (2014) A scenario for sustainable low-carbon development in Vietnam towards 2030. Int Proc Chem Biol Environ Eng 61(1):1–5
Osawa R, Gomi K, Matsuoka Y (2014) Development of low carbon society scenarios considering energy and agriculture, forestry and landuse in Indonesia. Environ Res 70(5):201–209
Singhvi A, Shenoy UV (2002) Aggregate planning in supply chains by pinch analysis. Trans Inst Chem Eng Part A 80:597–605
Smith R (1995) Chemical process design. McGraw Hill Inc, New York
Tan RR, Foo DCY (2007) Pinch analysis approach to carbon-constrained energy sector planning. Energy 32:1422–1429
Tan S, Yang Y, Yan J, Lee C, Hashim H, Chen B (2016) A holistic low carbon city indicator framework for sustainable development. Appl Energy. doi:10.1016/j.apenergy.2016.03.041
The Global Carbon Atlas (2016). www.globalcarbonatlas.org/?q=en/emissions. Accessed 27 July 2016
The 11th Malaysian Plan 2016–2020 (2016) http://rmk11.epu.gov.my/pdf/11MP%20Summary%20BI.pdf. Accessed 10 Aug 2016
The Malaysia National Blue Ocean Strategy (NBOS) (2016). www.blueoceanstrategy.com/malaysia-nbos/. Accessed 10 Aug 2016
Ueda M (2013) Changing to a sustainable socio-economic system: A challenge for Kyoto as a historic city. Springer, London
UNU-INWEH (2013) The United Nations University, Institute for Water, Environment and Health. inweh.unu.edu/wp-content/uploads/2013/09/Waste-to-Wealth-Background-Paper.pdf. Accessed 9 Aug 2016
US Energy Information Administration (2016) International Energy Outlook 2016. www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf. Accessed 17 Aug 2016
Wang YP, Smith R (1994) Wastewater minimization. Chem Eng Sci 49(7):981–1006
Wilson DC (2015) Global Waste Management Outlook (GWMO). UNEP DTIE International Environmental Technology Centre, Osaka
Winyuchakrit P, Limmeechokchai B, Matsuoka Y, Gomi K, Kainuma M, Fujino J, Suda M (2016) CO_2 mitigation in Thailand's low-carbon society: the potential of renewable energy. Energy Sour Part B 11(6):553–561
Yong JY, Klemeš JJ, Varbanov PS, Huisingh D (2016) Cleaner energy for cleaner production: modelling, simulation, optimisation and waste Management. J Clean Prod 111:1–16
Zhang S, Worrell E, Crijns-Graus WHJ (2016) Relationships between energy efficiency and air quality. A project presented on Researchgate. www.researchgate.net/project/Relationships-between-energy-efficiency-and-air-quality. Accessed 19 Aug 2016