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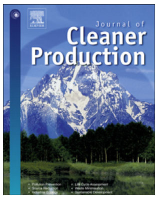

Review

Sustaining the low-carbon emission development in Asia and beyond: Sustainable energy, water, transportation and low-carbon emission technology

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ABSTRACT

Climate change is global issues with significant economic, social and environmental implications. Climate change mitigation in Asia has large impacts on global CO_2 emission reduction. CO_2 emission is the largest source of greenhouse gas emission constitutes about 65% of the total emission. Low-carbon Society initiative is one of the various mechanisms that have been deployed to achieve green economic growth, societal well-being and development, environmental preservation and management in a holistic manner. Energy efficiency improvement in Asia will be a key factor to tackle the climate change issues. Water and energy conservation, green transportation and low emission technology are the key aspects to catalyse the shift towards climate-resilient economic growth. The latest developments in these aspects are reviewed in this special volume to sustain the development of low-carbon emission in Asian countries. The use of holistic management system to integrate these key areas for long-term sustainability goal is also highlighted.

Contents

1. An overview and introduction

Rapid urbanisation and economic growth in the developed and fast developing countries are achieved at a high cost of anthropogenic CO_2 emission. Decoupling of vibrant economic growth and

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CO_2 emission is a great challenge for these countries. Fig. 1 shows the top ten world emitters of CO_2 emission that contributed up to 78% of the global CO_2 emission (32.3 Gt) in 2011 (WRI, 2012). China and India are the largest CO_2 emitters in Asia.

As the world most populous region and to contend the high economic growth, the rapid growth in Asia has caused an adverse effect to the environmental. The heavy reliance on fossil fuels has degraded the air quality and ecosystems, reduced clean water supply, and created significant health hazards. Asia has become the world largest source of greenhouse gas (GHG) emissions, which are linked to global warming and climate change. Fig. 2 shows the GHGs emission intensity per capita GDP in 2011 in which China is the largest GHG emitter (in CO_2 eq.) in Asia.

To pursue green growth, the enabling environment includes the strengthening of policy and regulatory framework, human capital development, green technology investment, and financial instruments. Table 1 shows the policies adopted in Asia to promote low-carbon economy.

A range of policies and measures towards low-carbon and green growth in Asia are shown in Fig. 3. These countries have a fairly ambitious participation to reduce energy intensity and the share of fossil fuels in the energy mix.

Asia urban emission are contributed by energy production (48%), agriculture (18%), industry (11%), residential (9%), transportation (9%) and waste (5%) (Marcotullio et al., 2012). The GHG emission in Asia reached 14.5 Gt CO_2 eq. in 2012, which was about 46% of the global emission. The GHG emission in Asia is likely to be increased and projected to be 21.2 Gt CO_2 eq. (US Energy Information Administration, 2016).

Energy represents the key contributor to GHG emission. As the top CO_2 emitter in Asia, China contributes about 58% of the total CO_2 emission in Asia (Global Carbon Atlas, 2016), a reduction of 1.5% emission was recorded in the year 2015 (IEA, 2016), mainly due to the economic restructuring towards less energy intensive industries and decarbonised electricity generation. A total generation capacity of renewable energy (RE) up to 32.1% was installed in China in 2015 from 22.4% in 2006 of the total power capacity of 435.8 GW (CNERC, 2015). This led to a significant reduction of GHG emission in China.

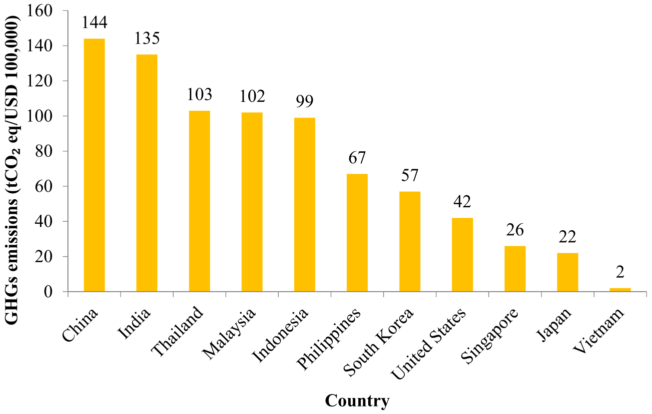


Fig. 2. GHGs emissions intensity per capita GDP in Asia countries excluding land use change and forestry. Adapted from The 11th Malaysia Plan (2015).

The mitigation strategies for climate change in Asian countries can be categorised into three key areas, namely renewable energy, energy efficiency and deforestation. The respective targets in these three areas are shown in Table 2.

Despite the presence of mitigation measures and policies in the Asian countries as shown in Tables 1 and 2 and Fig. 3, there is a huge gap for implementation with the current state of technologies due to the limitation of financial support. International funding to combat climate change is available to support these initiatives, such as the Green Climate Fund established in Songdo, South Korea. The total funding available in the 11 focus countries mainly in Asia (USD 1.6×10^9), Fig. 4 is relatively low compared to the rest of the industrialised and developed countries (USD 34.5×10^9, Table 3). In Copenhagen, many industrialised and developed countries pledged to commit USD 34.5×10^9 as the fast finance over three years 2010–2012, and by 2020 as shown in Table 3.

The public and private funds allocated for combating climate change in Asia are between 20 and 30% of the approximately USD 1 T required to finance the transition to a low-carbon economy (Frankfurt School–UNEP Centre, 2012). Lack of funding represents a key challenge to accelerate the transition towards low-carbon

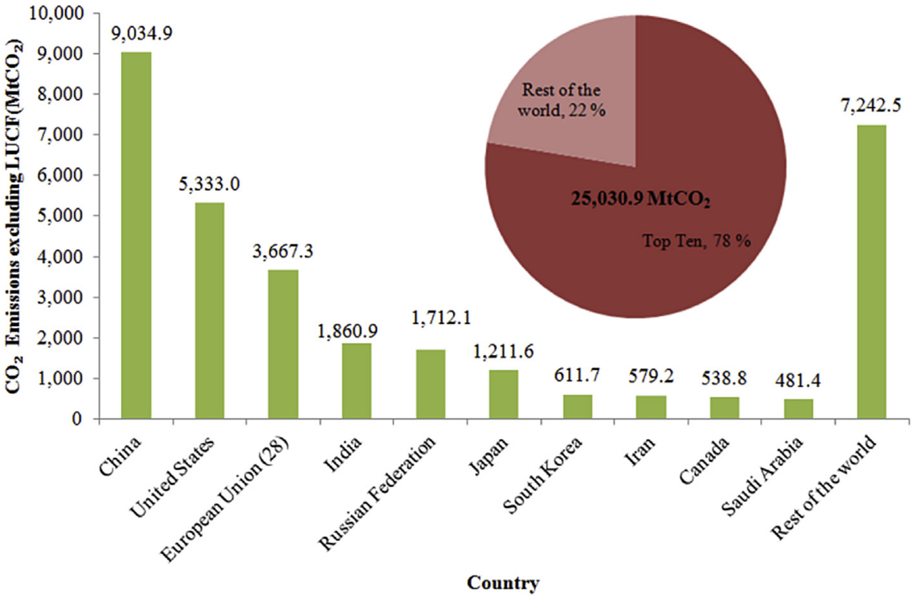


Fig. 1. Top ten world CO_2 emitters in 2011: China, United States, European Union, India, Russian Federation, Japan, South Korea, Iran, Canada and Saudi Arabia. Adapted from WRI (2012).

Table 1
Various policies adopted in Asia for the development of low-carbon economy.

Country	Name of Plan/Legislation
Bangladesh	Bangladesh Climate Change Action Plan and Strategy 2008
Cambodia	National Strategic Development Plan (2009–2013) Cambodia Green Growth Roadmap
China	National Climate Change Program 12th Five-year Plan (2011–15) China's Policies and Actions for Addressing Climate Change (2011)
India	National Action Plan on Climate Change (NAPCC)-eight core mission run through 2017
Singapore	Sustainable Singapore Blueprint National Climate Change Strategy 2006 (part of Singapore Green Plan, 2012)
South Korea	4th Comprehensive National Action Plan for Climate Change (2008–2012) 5-Year National Action Plan for Green Growth Basic Law on Low Carbon and Green Growth
Indonesia	Guideline for Implementing Greenhouse Gas Emission Reduction Plan National Development Planning Mid-term Development Plan (RPJM, 2010–2014) Indonesia Climate Change Trust Fund (ICCTF) National Climate Change Action Plan 2007
Philippines	Climate Change Act of 2009 Philippines Energy Plan 2004–2014
Thailand	National Strategic Plan on Climate Change 2008–2012
Vietnam	National Target Programme in Response to Climate Change
Malaysia	National Policy on Climate Change, 2009 National Green Technology Policy, 2009

Policies and Measures	China	India	Japan	Australia	Singapore	South Korea	Indonesia	Thailand	Vietnam
ENERGY SUPPLY									
Advanced fossil generation technologies	🟩	🟩	🟩	🟩	🟩	🟩			
Transition/distribution grid improvements	🟩	🟩					🟩		🟩
Retiring old, inefficient plants	🟩								
Feed-in tariff	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Renewable portfolio standards	🟩	🟩	🟩	🟩					
Subsidies, grant, rebates	🟩	🟩	🟩	🟩	🟩	🟩			
Investment excise and other tax credits	🟩	🟩	🟩		🟩	🟩	🟩		
Public investment and loans	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
ENERGY DEMAND									
Efficiency labels	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Sales tax, energy tax, VAT reduction	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩
TRANSPORT									
Mass transit goals	🟩	🟩	🟩	🟩	🟩	🟩			
Control of individual vehicle ownership					🟩				
Vehicle fuel efficiency goals					🟩				
Vehicle emission standards	🟩	🟩	🟩		🟩				🟩
Bio fuel standards	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
AGRICULTURE									
Fertiliser management	🟩	🟩	🟩	🟩		🟩	🟩		
Crop carbon emission	🟩	🟩	🟩	🟩		🟩			
Methane mitigation	🟩	🟩	🟩	🟩		🟩	🟩		
Reduction of open-field burning	🟩	🟩	🟩				🟩	🟩	
Afforestation/reforestation programs	🟩	🟩	🟩		🟩	🟩	🟩	🟩	
[1]REDD							🟩		🟩
RESEARCH AND DEVELOPMENT									
Clean/energy efficiency programs	🟩	🟩	🟩	🟩	🟩	🟩		🟩	
Carbon emission sink	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
FINANCING									
Climate funds			🟩	🟩			🟩		
CAPACITY BUILDING									
Public awareness campaigns	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Institutional capacity	🟩	🟩	🟩	🟩	🟩	🟩			
Human resources development	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
CITY LEVEL MEASURES									
Demand side energy	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Net metering			🟩	🟩				🟩	
Sustainable transport systems	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Compact cities	🟩	🟩	🟩		🟩		🟩	🟩	🟩
Low-carbon emission lifestyle	🟩	🟩	🟩	🟩	🟩	🟩	🟩		

Fig. 3. Policies and measure towards low-carbon and green growth in Asia. Adapted from ADBI (2012). [1]REDD: Reducing Emissions from Deforestation and Forest Degradation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

emission societies in Asia, major gaps exist among the key stakeholders, i.e. the academia and experts, local authorities, policy makers and the industries. More meeting platforms are needed to fill these gaps by creating more synergistic projects and reducing the reliance on public funding.

The International Conference of Low-carbon Asia 2015 (ICLCA'15) aims to accelerate the low-carbon emission development and sustainable growth in Asia. The 1st ICLCA'15 conference was held in Johor Bahru, Malaysia from 11–13 October 2015. It was held in conjunction with the 4th Annual Meeting of Low-carbon Emissions Asia Research Network (LoCARNet) with the theme "Positive Action from Asia – Towards COP21 and Beyond". The LoCARNet is a network for multi-layered stakeholders to promote research cooperation related to low-carbon growth and policy-making. The double-event was attended by 200 international renowned scientists and participants from research institutions, government agencies, municipalities, universities and NGOs including from Cambodia, China, Hungary, India, Indonesia, Japan, Laos, Malaysia, the Philippines, Singapore, Thailand and Vietnam. The double-event culminated in the launch of a regional Low-Carbon Emission Declaration, the "LoCARNet Iskandar Malaysia Declaration" that was disseminated at the 21st yearly session of the Conference of the Parties (COP21), Paris, France. Selected papers from ICLCA'15 have resulted in the publication of this Special Volume (SV) in the Journal of Cleaner Production.

2. The main topics of this SV

A total of 40 papers have been invited for full paper submission for this SV and 22 papers were approved by standard reviewing process and 16 had to be rejected/withdrawn. This overview article presents an overview of the selected articles of this SV. These articles highlight the innovative methods, cases and tools for promoting low-carbon emissions development, the valuable policy insights and a set of low-carbon emissions development actions to meet the challenges of global climate change and the targets for up to 2020 in Asia and beyond.

This SV highlights the key inputs from the accepted papers based on five themes:

(i) Sustainable energy
(ii) Water conservation
(iii) Low emission technology
(iv) Green transportation
(v) Management system for sustainability

Table 2
Climate-change mitigation targets for the three key areas including for renewable energy, energy efficiency and deforestation in Asia.

Countries	Emissions Reduction Targets	Renewable Energy	Energy Efficiency	Deforestation
India	20-25% (2005–2020)	15% by 2020	10,000 MW savings by 2020	Increase forest cover by 20 Mha (2010–2020)
Indonesia	26-41%	15% by 2025	Reduce 1% average annual energy intensity (2005–2025)	Forestry as net carbon sink by 2030
Thailand	30%	20% by 2022	Reduce 25% energy intensity (2005–2030)	Forest cover to be 40% of total land mass
China	40-45% (2005–2020) 17% (2010–2015)	11.4% by 2015 15% by 2020	Reduce 16% energy intensity (2010–2015)	Increase forest cover by 40 Mha (2005–2020)
Vietnam	–	5.6% by 2020 9.4% by 2030	Reduce elasticity of electricity/GDP from 2 to 1 (2010–2020)	Increase forest cover to 16.2 Mha (2010–2020)
Japan	25% (conditional)	16.0 TWh by 2014	Reduce 30% energy intensity (2006–2030)	–
Australia	5-25%	20% (2007–2020)	–	Planned offset scheme as part of domestic carbon market
South Korea	30% (2030)	6.08% (2009–2020)	–	–

Source: Adapted from ADBI (2012).

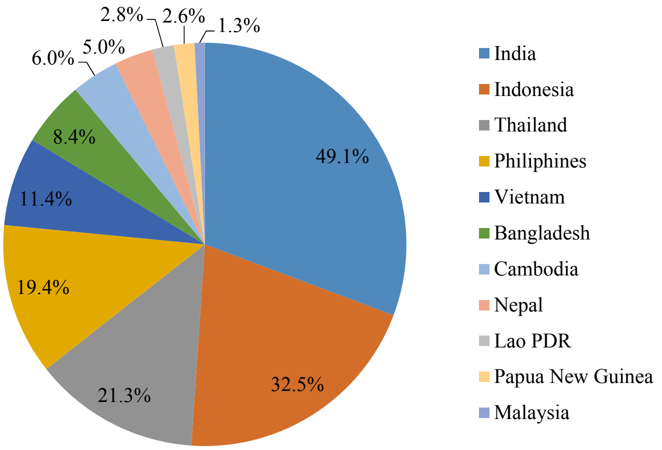


Fig. 4. The international funding (USD 1.6 × 10^9) to combat climate change in 11 focus countries mainly in Asia. Adapted from USAID Asia (2013).

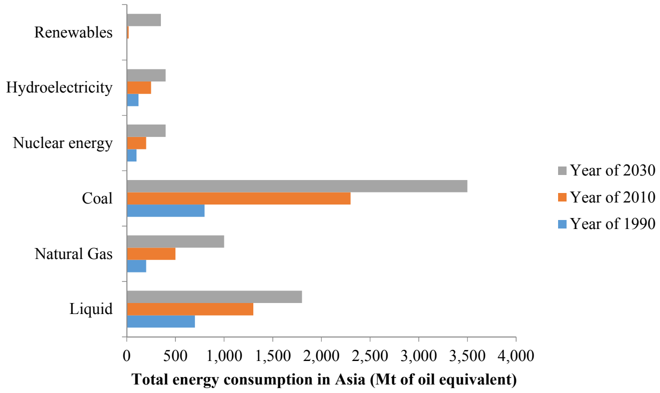


Fig. 5. Total energy consumption in Asia in the year of 1990, 2010 and prediction up to 2030. Adapted from Dulal et al. (2013).

2.1. *Sustainable energy*

The worldwide energy systems are balancing a diverse set of challenges, ranging from energy security, environmental and public health concerns. Rapidly increased energy demand due to economic growth and increased number of population is a major concern for Asian countries because the increased demand is by far met through the increased use of fossil fuel. Referring to Fig. 5, between 2010 and 2030, the total natural gas and coal consumption is expected to increase by 114% and 50%. Continual heavy reliance on fossil fuel means a massive growth in CO_2 emissions in the Asia countries.

Renewable energy supply presents a lower emission pathway that could be a viable option to reduce the higher emissions path. Fig. 6 shows the renewable energy policies in ASEAN countries to accelerate RE share by the intervention of government.

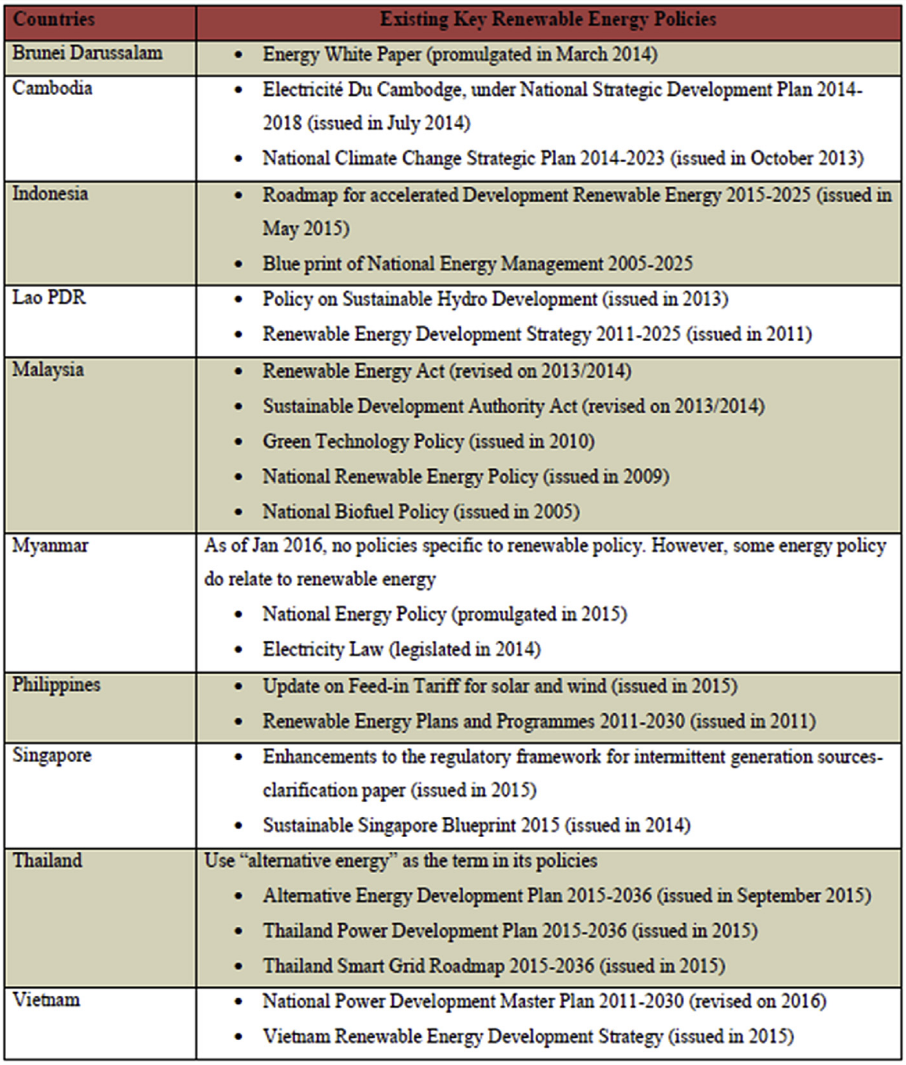
Despite the wide range of policies launched for renewable energy in ASEAN countries since a decade ago, various barriers remained. The top five non-economic barriers are related to the failure of government to provide infrastructure, leadership, reliable information and incentives as shown in Fig. 7. It is crucial for the government to promote effective and coherent renewable energy policies with a long-term strategic perspective and coordinated effort for implementation.

Carbon emissions capture and storage (CCS) is one of the essential interim technologies to mitigate GHG emission from the energy sector. CCS allows the utilisation of the fossil fuels that are relatively inexpensive and reliable in comparison to the inherently low-carbon renewable resources. It involves the reduction of emissions from large industrial facilities (i.e., sources) by capturing the CO_2 from the exhaust gases and subsequently storing it in the appropriate geological storage sites (i.e., sinks) such as depleted oil or gas reservoirs, saline aquifers, coal seams and other similar formations. Retrofitting the power plants for CCS entails a major capital cost as well as a reduction of thermal efficiency and power output. Sources and sinks may need to be clustered geographically

Table 3
A total funding of USD 34.5 × 10^9 pledged by the developed countries for climate change related activities.

Funding pledged for climate-related activities (in 10^9 USD)					
Japan	United Kingdom	United Stated	Germany	Norway	Rest of the worlds
15.3	4.9	2.4	2.2	1.8	8

Source: Adapted from USAID Asia (2013).



Countries	Existing Key Renewable Energy Policies
Brunei Darussalam	• Energy White Paper (promulgated in March 2014)
Cambodia	• Electricité Du Cambodge, under National Strategic Development Plan 2014-2018 (issued in July 2014) • National Climate Change Strategic Plan 2014-2023 (issued in October 2013)
Indonesia	• Roadmap for accelerated Development Renewable Energy 2015-2025 (issued in May 2015) • Blue print of National Energy Management 2005-2025
Lao PDR	• Policy on Sustainable Hydro Development (issued in 2013) • Renewable Energy Development Strategy 2011-2025 (issued in 2011)
Malaysia	• Renewable Energy Act (revised on 2013/2014) • Sustainable Development Authority Act (revised on 2013/2014) • Green Technology Policy (issued in 2010) • National Renewable Energy Policy (issued in 2009) • National Biofuel Policy (issued in 2005)
Myanmar	As of Jan 2016, no policies specific to renewable policy. However, some energy policy do relate to renewable energy • National Energy Policy (promulgated in 2015) • Electricity Law (legislated in 2014)
Philippines	• Update on Feed-in Tariff for solar and wind (issued in 2015) • Renewable Energy Plans and Programmes 2011-2030 (issued in 2011)
Singapore	• Enhancements to the regulatory framework for intermittent generation sources-clarification paper (issued in 2015) • Sustainable Singapore Blueprint 2015 (issued in 2014)
Thailand	Use “alternative energy” as the term in its policies • Alternative Energy Development Plan 2015-2036 (issued in September 2015) • Thailand Power Development Plan 2015-2036 (issued in 2015) • Thailand Smart Grid Roadmap 2015-2036 (issued in 2015)
Vietnam	• National Power Development Master Plan 2011-2030 (revised on 2016) • Vietnam Renewable Energy Development Strategy (issued in 2015)

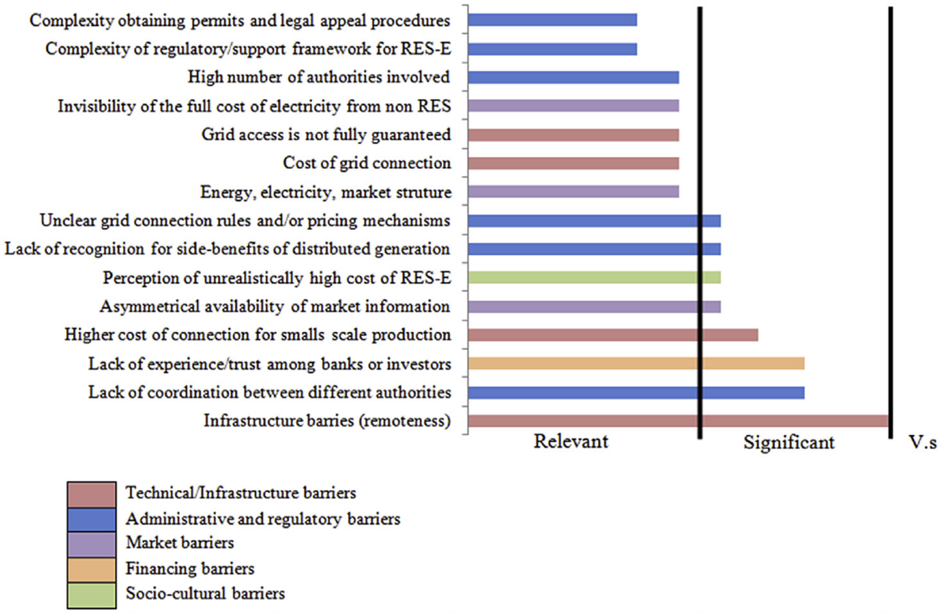
Fig. 6. Existing key renewable energy policies in ASEAN countries. Adapted from ACE (2016).

to minimise the cost of transportation. It is necessary to plan for the additional power generation capacity or efficiency enhancements to compensate for energy losses resulting from the retrofits of CCS. Sahu et al. (2014) presented the PA-based algebraic targeting technique for the planning of grid-wide CCS retrofits for power generation with compensatory power. This technique enables the minimal retrofit of CCS and achieves the specified carbon emission limits for the power sector. An improved PA-based methodology, by simultaneously considering the injectivity constraint of every sink and the availability of various sources and sinks, was studied to improve the efficiency of CCS (Diamante et al., 2014).

CCS is the most costly technologies for CO_2 emission reduction, systematic energy recovery through PA technique could improve the cost efficiency and CO_2 emissions reductions. “An integrated Pinch Analysis framework for low CO_2 emissions industrial site planning” by Abdul Aziz et al. (2017) discussed a step by step framework to guide industrial site planners to achieve an effective heat recovery, power allocation and integration of hybrid renewable energy system with the aims to reduce carbon emission. The framework comprised of three tools: Total Site Heat Integration - TSHI (Liew et al., 2012), Power Pinch Analysis - PoPA (Mohammad Rozali et al., 2013), and Generic Carbon Cascade Analysis - GCCA (Manan et al., 2014). The framework first determines the baseline data of the resources that comprised of electricity, steam and CO_2. TSHI analysis is performed to establish the maximum heat recovery and the potential amount of electricity and steam generation; with the minimum requirement of external utility. PoPA is then applied to integrate the renewable energy hybrid power system into the industrial site. GCCA is applied to reduce the CO_2 emission generated. The framework was applied to an industrial case study, which yielded an overall reduction of 65.7% in heat, 74.3% in power and 99.8% in CO_2 emission. This integrated framework is also applicable to other sectors for more efficient and cleaner processes.

Jia et al. (2016) extended PA technique to include a multi-dimensional analysis (MDPA) of the power generation sector in China. It consists of five key indices namely carbon footprint, energy return on investment (EROI), water footprint, land footprint, and risk to humans. By simultaneously quantifying the five different indices under a common methodological framework, the impact on five different environmental concerns can be coherently assessed. This approach provides a more complete picture of the actual environmental impact for the power sector in China than the analytic procedure focuses on a single environmental dimension. The information can help the policymakers to avoid the problem of shifting environmental impacts to other domains.

Another application of PA can be found in the paper entitled



Relevant, Significant and V.s refer to a barrier that is deemed “relevant”, “significant” or “very significant” based on the survey results. RES-E: Renewable energy sources.

Fig. 7. Ranking of non-economic barriers in the selected ASEAN countries. Adapted from IEA (2010).

“Optimisation and targeting of supply-demand of biogas system through gas system cascade analysis (GASCA) framework” by Othman et al. (2017). GASCA is a time-based PA model to manage the decentralised biogas energy system for the maximised biogas production and minimised GHG emission and disposed waste volume. The method is similar to the algorithm of Electric System Cascade Analysis (ESCA) introduced by Ho et al. (2012). GASCA aims to optimise the biogas supply and demand chain, the capacities of anaerobic digestion and biogas storage system. With the known profile of total electricity demand, the optimal anaerobic digestion capacity for biogas generation and the maximum capacity for biogas storage had been identified as 4,269.53 MJ/h and 16,988.61 MJ/h. The biogas system yielded a potential reduction of 138 tCO_2/d. GASCA provides valuable information for the potential construction of additional biogas plants to promote national energy mix with renewable energy. In Asia, the biogas derived from various biomass resources for cooking and electricity generation are shown in Fig. 8.

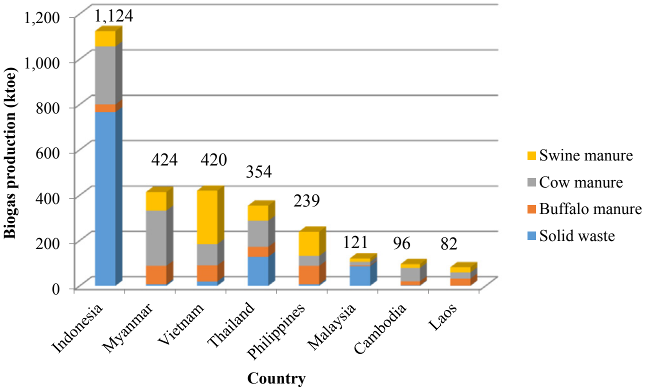


Fig. 8. Biogas production (ktoe) classified by the type of feedstock. Adapted from ASEAN Bioenergy Asian Bioenergy Technology (2014).

In India and Thailand, the electrical grids are at full capacity, it is impractical to add another electricity source. To make use of biogas in these areas, researchers are working on isolating methane for further use. Liquefied or compressed methane could serve as fuel for transportation (Andriani et al., 2014). Public procurement, investment schemes and reduced fringe benefits tax are the important policy instruments to promote biogas as transportation fuel. The support for private biogas cars has been short-sighted in some ways and insufficient to achieve a competitive cost of ownership for biogas cars as compared to the diesel cars. The more visible incentives for private cars and incentives for expanding the fuelling infrastructure network are needed.

Biofuel has gained significant attention due to the depletion of fossil fuels and concerns regarding climate change (Popp et al., 2016). The biofuel derived from the natural resources can contribute to the reduction of the major polluted gas such as the sulphur oxide (SO_x) and GHG. The conventional petrol releases more carbon and sulphur based gases (Chuah et al., 2016). The development and production of biofuel in Asia still face socio-political and technical challenges. These issues include the price and choice of feedstock, competition with food, environmental pollution and engine compatibility.

In the transportation sector, initiatives were undertaken to control the emissions from the motor vehicles by promoting the use of energy-efficient vehicles and biofuel implementation. Hashim et al. (2017) presented in this Special Volume an integrated model-based approach to formulate the tailor-made biofuel blends from the bio-based resources. The model was formulated as a mixed integer non-linear program to meet the EN590 standard properties such as density, kinematic viscosity, cetane number, higher heating value, distillation temperature and sulphur content. The conventional tailor-made biofuel blend involves a trial-and-error approach that is subjected to laborious testing for the fuel to comply with the regulation standard. This process is time-consuming and often has no guarantee that the tested properties adhere to the desired property range. The model is expected to minimise the trial-and-error and laborious approach.

The feasible method to produce biodiesel is by the trans-esterification process where triglycerides are converted into fatty acid alkyl esters in the presence of alcohol and catalysts. The main drawback of transesterification reaction is due to its limited mass transfer, this results in a much lower reaction rate and also much higher cost compared to the diesel fuel. A variety of technologies are being developed to enhance the production of biodiesel such as the membrane reactor, ultrasound, microwave, supercritical process, reactive distillation and via process intensification by integrating the reaction and separation steps into a single operating unit. Chuah et al. (2017a) reviewed different biodiesel technologies to a lower energy requirement and shorter reaction time. Microwave (Chee Loong and Idris, 2016), ultrasonic cavitation and hydrodynamic cavitation (Chuah et al., 2017b) are among the intensification technologies that have become more attractive to overcome the limitation of transesterification process. Chuah et al. (2017b) reported that hydrodynamic cavitation could offer a better product yield, reaction time, energy consumption and product quality. However the design of the plate geometry for hydrodynamic cavitation can be improved with respect to the methyl ester conversion. There are several areas that need to be improved and upgraded for biodiesel production at a wider scale, i.e. feedstock, catalyst and process improvement.

2.2. *Water conservation*

Water is a precious and scarce resource in Asia. It is a valuable resource for the agriculture, industry and domestic sectors. Water scarcity caused by water demand exceeding the supply has left several countries, such as the Middle East and North Africa, facing the water crisis. Increasing world population, the uneven freshwater distribution, water pollution, and unsustainable management have worsened the situation. It is projected that 33 countries will experience high water stress by the year 2040 (WRI, 2015). Fant et al. (2016) projected that the economic, population growth on top of the climate change could lead to serious water shortages across Asia by the year 2050. Fig. 9 shows the dense population area in Asia i.e. a large portion of northern China as well as India and the Indus River systems are experiencing at least a moderate to extremely water stress.

By the year 2050, the United Nation estimates that there will be an additional 1×10^9 people in Asia to suffer water stress as compared to today (Fant et al., 2016). Numerous researchers investigated the water resources management using numerical models. Fant et al. (2016) employed the Integrated Global System Model-Water Resource System (IGSM-WRS) framework to assess the fate of water management systems, depicted by 52 large subregions across Asia. Water Evolution and Planning (WEAP) model has been developed by Stockholm Environment Institute to evaluate planning issues related to water resources for both the municipal and agricultural systems including: sector demand analyses, water conservation, water rights and allocation priorities, stream flow simulation, reservoir operation, ecosystem requirements and project cost–benefit analyses. The model has been applied to assess the scenarios of water resource development in the Pangani Catchment in Tanzania (Arranz and McCartney, 2007). The first paper "Developing a methodology for water footprint of palm oil based on a methodological review" was by Mohammad Sabli et al. (2017). Palm oil production is the largest and rapid growing vegetable oil industry in the market, with Indonesia and Malaysia being the top two largest palm oil plantations. The palm oil industry requires huge water consumption and poses environmental issues such as biodiversity loss from land cover/use changes and river pollution if the wastewater is not properly treated prior to discharge. A plausible method to manage water usage in palm oil industry is desirable. The total number of academic publications observed under the database of Thomson Reuters Institute related to the sustainable palm oil production increased from 11 in 2004 to about 65% of 713 in 2013 (Hansen et al., 2015). The global water footprint (WF) related to the crop production from the year 1996–2005 was 7,404 Gm^3/y (Mekonnen and Hoekstra, 2010). Intensive studies were conducted on WF in the agricultural sector but the existing studies that covered LCA in the palm oil industry were limited (Vijaya et al., 2011). Mohammad Sabli et al. (2017) developed a method to calculate WF for the crude palm oil productions in Malaysia based on LCA. Four generic steps were used to provide a comprehensive review and suitable selections. The methods reviewed for WF is grouped into four categories based on the predefined criteria: methods with single or no indicator in environmental impact assessment; methods with temporal regional or freshwater limit; methods with general sources; and methods that provide a general guideline for WF assessment. They also integrated part of the approach by Angelakoglou and Gaidajis (2015) to measure the environmental sustainability in the industrial system. The International Standard Organisation (ISO) 14046 has been chosen as a guideline due to its consistency and credibility for WF. ISO 14046 can also project the future risks and improve the efficiency of the organisation or process.

The next paper for water conservation entitled "A holistic approach to the design of cost-optimal water networks" was by Sujak et al. (2017). They designed the water networks based on the graphical and mathematical modelling approach to minimise the

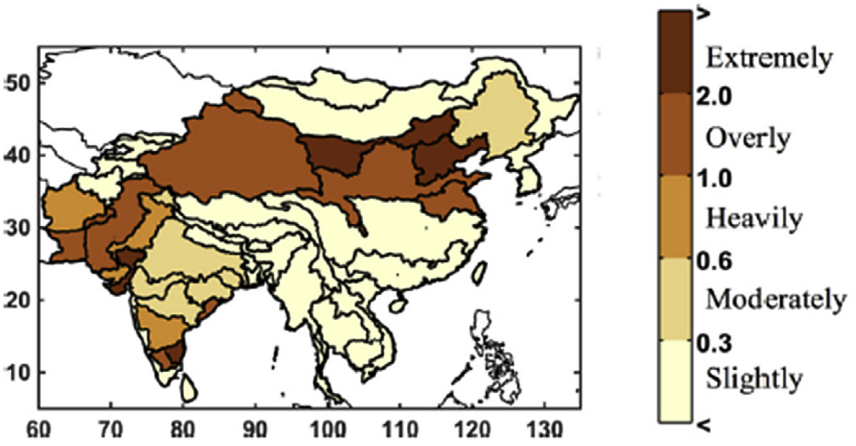


Fig. 9. The distribution of water stress index as simulated by IGSM-WRS from the baseline climate (Fant et al., 2016).

volume of freshwater and cost. A few challenges have been identified based on the conceptual approach for the minimal cost water network designed by Foo (2009). The challenges include the lack of water network synthesis for the retrofit cases and the issues of establishing the capital cost of the water network. Klemeš (2012) indicates that to develop a realistic water network, the cost considerations on water network, piping and pumping, and the freshwater cost, should be well optimised. Li and Guan (2016) proposed an optimal water network using the mathematical modelling to determine the minimum freshwater and recycled water flow rates. Apart of limiting the water reuse and regeneration, Wan Alwi and Manan (2008) emphasised on the pre-design of water network stage to improve cost-efficiency.

The holistic approach for the design of cost-optimal water networks by Sujak et al. (2017) was an extension work by Wan Alwi et al. (2008). Wan Alwi et al. (2008) proposed a cost-effective minimum water network design involving single contaminants problem using water management hierarchy (WMH) for the grassroots and retrofit cases. The design considered the minimisation and economic factors by extending the work of Handani et al. (2010). The approach is based on the first stage of freshwater saving mode (FWS-mode) using the mixed integer linear program (MILP) model; followed by the 2nd stage of the economic mode (e-mode) based on the mixed-integer nonlinear program (MINLP) model to optimise an existing water design. The model is capable of minimising the net annual water usage and saving schemes on multi-contaminants system as the cost factors and WMH (elimination, reuse, reduction, outsourcing and regeneration). The improved Cost-optimal Water Network (CWN) developed by Sujak et al. (2017) offers a more accurate and practical results as compared to the use of heuristic and graphical approaches from the previous studies. The model is proven beneficial for retrofitting the real urban life and the industrial water networks. It is expected to offer realistic annual savings as well as the payback periods.

Sotelo-Pichardo et al. (2011) also used MINLP model to solve the issue of favouring schemes such as water reuse, recycle and regeneration by considering the minimisation of total annual cost as their objective function. The results revealed the optimal option of upgrading the existing treatment units rather than installing the new treatment units to minimise the total annual cost.

This section reveals the great potential of LCA and water network modelling as tools to optimise water conservation and cost saving in the urban area, agricultural and the industrial sectors.

2.3. Low emission technology

The first paper for this theme entitled “Virtual carbon and water flows embodied in international trade: a review on consumption-based analysis” by Liu et al. (2017). GHG growth is usually reported on a territorial basis related to the locations where the emissions are physically released without considering the international trade. Economic globalisation has resulted in a dynamic shift in the geographic patterns of production and consumption of consumer goods. This leads to the shifting of the carbon and water footprints based on the goods internationally delivered. A report by OECD (2014) analysed the regional CO_2 emission, discovered the US, EU-28 and Japan have a significant amount of embodied CO_2 through the international trade. The largest single interregional flow of embodied CO_2 emission transfer is from China to the US, approximately 375 Mt in the year 2004 (Peters et al., 2012). The virtual water trade also shows China as the major virtual water exporter. The largest embodied water flows are observed in the industrial products (57% of the total international virtual water export). The high absolute net CO_2 importers were the US and the EU. Liu et al. (2017) concluded that agriculture goods demanded very high virtual water consumption and low embodied carbon emissions, while industrial products are responsible for higher embodied carbon emissions. These global virtual carbon and water distribution patterns served as important data to support the policy making the process for the development of participation mechanisms and market share (virtual carbon and virtual water) amongst the international partners to reduce carbon footprint.

The next paper focuses on low emission technology in the agricultural sector, entitled “A review on the global warming potential of cleaner composting and mitigation strategies” by Bong et al. (2017). Composting is considered a cleaner technology with the potential to mitigate greenhouse gases (GHG) reduction in waste management sector. Life cycle analysis (LCA) studies offer great supporting tools to facilitate the decision-making for the selection of a cleaner composting process. This study summarised the emission from the degradation process as the major contributor of global warming potential (GWP) for composting The inventory of GHG emission during composting is accounted during the process of generation, collection, transport, handling, treatment, material and energy recovery and its final disposal (Zaman, 2014). The inconsistency in adopting the LCA methodology has contributed to the great discrepancies for the GWP of composting (Bong et al., 2017) due to the variation in data collection, system definition and boundaries (De Benedetto and Klemeš, 2009), and functional unit (Martínez-Blanco et al., 2014). It was suggested that more data for the post application of compost (e.g peat replacement, long-term carbon sequestration, soil improvement), carbon footprint tool, the multi-criteria analysis should be included in the LCA study for composting (Bong et al., 2017).

The next paper entitled “Effect of green waste pretreatment by sodium hydroxide and biomass fly ash on composting process,” by Karnchanawong et al. (2017). The green waste is conventionally treated through landfilling, composting or incineration. Composting of green waste is a more sustainable method with less environmental impact (Saer et al., 2013). It requires a lower financial investment and has a good potential to be applied in the developing countries (Lim et al., 2016). The green waste contains a major portion of lignocelluloses that is more difficult to be decomposed. The biodegradability of lignocellulose in green waste can be improved through various pre-treatment, such as removal of the lignin, loosening the cellulose structure and increase the effective contact area of cellulose with microorganisms (Karnchanawong et al., 2017). Alkaline pretreatment is the most common and low-cost method for lignin removal (Behera et al., 2014). Karnchanawong et al. (2017) investigated the effect of alkaline pretreatment on the composting of green waste using NaOH and biomass fly ash. The lignin mass was significantly reduced by the treatment of 1–2% NaOH and 6.2% fly ash. The higher doses of alkaline increased the nitrogen loss (about 18–50% N compared to the control) from the volatilisation of ammonia at higher pH condition. To enhance the decomposition of green waste while minimising nitrogen loss during composting, 6.2% of fly ash was recommended as the pretreatment for the green waste (Karnchanawong et al., 2017). The fly ash is suggested to be a potential alkaline source for the pre-treatment of composting and mineral source (in the compost) for plant growth.

The paper “Co-composting of palm empty fruit bunch and palm oil mill effluent: Microbial diversity and potential mitigation of greenhouse gas emission,” authored by Krishnan et al. (2017) aimed to identify the microbial diversity during the co-composting of palm oil biomass, i.e. the empty fruit bunches (EFB) and palm oil mill effluent (POME). The potential of GHG mitigation through the co-composting was evaluated. Co-composting is a controlled degradation of organic substrates using more than one feedstock during the composting process to increase the product quality (Rosnani and Rakmi, 2014). Krishnan et al. (2017) discovered the increased population of bacteria such as *Bacillus* species in the EFB-POME compost. The microbial diversity contributed to the significant breakdown of lignin and cellulose hence reducing the composting duration. Shortened composting duration is critical to reducing the product holding time, plant size and the overall operating cost. The co-composting of EFB-POME is estimated to reduce up to 76% of the GHG emission by avoiding the emissions generated from the open dumps of EFB, POME treatment ponds and replacement of chemical fertiliser (Krishnan et al., 2017).

Agriculture intensification is largely practised through the use of chemical nitrogen (N) fertilisers to increase the crop yield. The increased use of nitrogen (N) fertiliser to fulfil increased food demand has caused negative environmental impacts. The global N fertiliser demand is expected to increase to135 Mt in 2030 (Xiang et al., 2015) from the current 110 Mt (Tallaksen et al., 2015). Eutrophication of downstream waters associated with the excess nitrate pollutant runoff is a major environmental concern in the agricultural sector. The next paper entitled “Stochastic optimal control of agrochemical pollutant loads in reservoirs for irrigation” by Mabaya et al. (2017) proposed a novel approach to minimise such pollutant run-off. They proposed a novel model based on the Markov decision process (MDP) to formulate the optimal operating policies for controlling the stochastic agrochemical pollutant loads in the reservoirs for irrigation. The model was applied to an irrigation reservoir in Japan that is prone to nitrate pollution from the upslope of the green tea plantations. They found that the irrigation reservoirs can be operated at an optimum storage volume below 10% to control the agro-fertiliser pollutants while satisfying the irrigation demand of the area (Mabaya et al., 2017). The optimised operation can protect the water source from pollution while sustaining the productivity in the agricultural area.

The carbon footprint (CF) of crop production is used to measure the total amount of GHG emissions from the materials used for crop production, crop protection and farm equipment operation in a single cycle (Cheng et al., 2015). Assessing the CF of crop production provides insights into the contribution of crop production to climate change. Such assessment is vital to identify the key areas that require GHG mitigation (Yan et al., 2015). The next paper termed “Investigating low-carbon crop production in Guangdong Province, China (1993–2013): a decoupling and decomposition analysis” by Zhen et al. (2017). The authors analysed the dynamic changes in the CF of crop production in Guangdong Province, China from 1993 to 2013 by applying the decoupling index and the decoupling stability analysis. The driving factors of the total CF were decomposed and quantified by the Logarithmic Mean Divisia Index (LMDI) method. The changes in the CF were decomposed into six effects, i.e. the technology improvement, the investment promotion, the investment intensity, the agricultural economic level, the urbanisation, and the population (Zhen et al., 2017). They discovered that the increased crop production output is not always positively correlated with an increased CF while weak decoupling is the main tendency between CF and crop production. The authors concluded that agricultural economic level played the most important role in driving the CF of crop production, followed by investment intensity and population. Based on these key effects, it shows a greater need for urban and rural economic planning and policies for land use, population distribution, and investment intensity that would shape the agriculture sector with minimised climate change impacts.

Conversion and utilisation of CO_2 by advanced technology have been intensively researched to reduce the anthropogenic CO_2 emission. The three pathways available for CO_2 conversion and utilisation include: 1) utilising CO_2 as a medium for energy recovery, heat transfer and solvent; 2) converting CO_2 for fuel synthesis via renewable energy sources for sustainable development; 3) using CO_2 as a feedstock to produce industrially useful chemicals and materials, which adds value to the process (Wu and Zhou, 2016). In order to chemically convert CO_2 to chemicals or fuels, a substantial input of energy and an active catalyst are required due to its stable molecule involving rather low energy content $\Delta Gf0 = -394$ kJ/mol in the gas phase (Wu and Zhou, 2016).

Catalytic conversion of CO_2 to chemical and fuel is a promising alternative to energy production and mitigate the impact of anthropogenic CO_2 emissions. Mignard et al. (2014) reported the production of methane (CH_4) as renewable fuel from the electroreduction of CO_2 at a gas diffusion electrode loaded with a strontium-doped lanthanum cuprate perovskite, $La_{1.8}Sr_{0.2}CuO_4$ as the electrocatalyst in 0.5 M KOH. Toemen et al. (2017), in the article entitled “CO_2/H_2 methanation technology of strontia based catalyst: physicochemical and optimisation studies by BoxeBehnken design” applied strontia-based catalyst impregnated with Ru/Mn/Al_2O_3 to investigate its potential for the conversation of CO_2 to CH_4. They discovered the optimum conditions to achieve a conversion of 73.10% CO_2 and 43.58% CH_4. The novel formulation of Ru/Mn/Sr (5:30:65)/Al_2O_3 serves as a green catalyst which applied the waste to product concept.

Gas separation membranes play a key role in the CO_2 capture system due to the light weight, operational flexibility, compactness, less energy consumption and their ability to minimise overall environmental impacts. Conventional polymeric material for gas separation membranes poses weakness during the long-term operation which significantly reduces the carbon capture performance. Koonaphapdeelert and Li (2007) discovered that ceramic membranes, using metal oxide membranes circumvented with the hydroxyl group and silane agent such as fluoroalkyl silane (FAS), is able to enhance the hydrophobicity of metal oxide membrane surface and maintaining the thermal stability. Yu et al. (2015) had successfully developed a superhydrophobic ceramic membrane for CO_2 absorption after coating the surface of the alumina tube with a ZrO_2 layer. Abdulhameed et al. (2016) aim to fabricate a low cost, high-performance superhydrophobic kaolin-alumina hollow fibre membrane via phase inversion-based extrusion and sintering techniques, followed by a grafting with FAS. The hollow fibre membrane was spun from a suspension of kaolin and alumina mixture via the phase inversion-based extrusion method, sintered at 1450 °C and followed by grafting with FAS. The membrane exhibited superhydrophobic property and excellent CO_2 absorption performance (0.18 mol m^{-2} s^{-1}), owing to the very low mass transfer resistance of the membrane layer. Advancement in innovative membrane technology provides a good potential for efficient and cleaner technology for CO_2 capture, storage and further utilisation.

The application of heterogenous catalyst is desirable to facilitate its reusability as it is easily separated from the reaction products and avoided the undesired saponification reactions (Martino-Di et al., 2008). The production of biodiesel through transesterification reaction with homogeneous base catalysts poses some drawbacks of an inevitable production of wastewater from the washing process of catalyst residues and unreusability of the catalysts (Farooq et al., 2013). A recent study by Chen et al. (2015 proved that utilisation of silica supported CaO catalyst derived from Na_2SiO_3 as raw material for biodiesel production had a better reusability as the amount of Si compound increased. The method used pure methanol as raw material instead of the waste materials. Lani et al. (2017) conducted a study entitled “Synthesis, characterisation and performance of silica impregnated calcium oxide as a heterogeneous catalyst in biodiesel production”. They synthesised and characterised a novel low-cost and highly efficient supported base catalyst using two waste materials, i.e. rice husk ash and egg shell, for the transesterification of palm oil to yield fuel grade biodiesel. The hybrid catalyst (silica-CaO) showed high catalytic activities for the transesterification reaction with the biodiesel production of 87.5% at 2 h. The authors examined the reusability of the synthesised catalyst and found that the catalyst has the potential for six times repeated usage while maintaining the biodiesel yield at around 80%. The findings highlighted the good potential of hybrid catalyst derived from waste materials (rice husk and egg shell) for biodiesel production.

"A cleaner and greener fuel: Biofuel blend formulation and emission assessment" by Hashim et al. (2017) focused on the sustainable assessment of tailor-made biofuel blends from the palm biomass. Biofuel is recognised as an environmentally friendly and renewable source. It is predicted that around 27% of the transportation fuel would be replaced by biofuel by 2050 (IEA, 2013). The authors reported that Malaysia currently implemented biofuel through B5 diesel with 5% blend of fatty acid methyl ester obtained from the palm biomass, there are no specific standards to compare the B5 biofuel with the conventional diesel. Most of the current studies on fuel blend design employ a forward approach relying on property prediction (Hechinger et al., 2012) from a set of fuel blend compositions (Manuel and Wolfgang, 2016). To fill the gap, the authors developed a new framework to design the tailor-made biofuel blends via a computer-aided model-based approach and further validated with experimental work. A decomposition-based method was applied to solve the blending problem, where the objective was to quickly screen out the optimal biofuel blends that satisfy the properties set by the EN590 fuel standard at minimum cost, maximum calorific value and less environmental impacts. Five optimum tailor-made biofuel blend formulations were generated based on cost, gross calorific value and emission limitations. Significant CO_2 reductions and less sulphur content have been achieved for Blend 1 that contains B5 diesel, butanol, and butyl levulinate. The model yielded about 26% CO_2 emission reduction and 22% less sulphur content in compliance with the EN590 fuel regulation standard.

This section reviewed the latest low-emission technology and methods relevant to agriculture, conversion and utilisation of CO_2 and the greener production of biofuel. For the agriculture sector, there are still research gaps to consolidate the methods for the quantification of GHG using LCA notably regarding the boundary definition, and the methodologies and standard units used. This is crucial to facilitate cross-studies comparison and to find solutions for the key contributors of GHG emission. For the conversion and utilisation of CO_2 and the production of biofuel, the economic and environmental feasibility are still relying on the process efficiency and advancement of novel material (i.e. catalyst, membrane) and process optimisation and modelling.

2.4. Green transportation

Transportation is a major contributor to global climate change that accounted for approximately 20% of the world total CO_2 emissions from fossil fuel combustion in 2013 (IEA, 2014). The road-mobile pollutant is the probable reason for the air quality pollution. The electric vehicle (EV) expansion serves as one of the main strategies for sustainable transportation systems. EV powered by the present European electricity mix offers a 10–24% decrease in the global warming potential (Hawkins et al., 2013). EV also has a better indication in the life cycle assessment (LCA) of Abiotic Depletion and Ozone Layer Depletion (Shi et al., 2016). The limitation of battery performance and high investment cost had hindered the potential of EV in the global market.

The first paper in this theme entitled "A study on the activation plan of electric taxi in Seoul" by Kim et al. (2017) analysed the operating and charging behaviours of electric taxis. The study reported a promising financial feasibility and good socioeconomic benefits with reduced air pollutants and CO_2 by converting the private taxi to electric taxi. With these positive impacts shown by the study, proactive legal and policy frameworks are needed to promote the implementation of electric taxis.

The next paper, "Electric vehicles and India's low carbon passenger transport: A long-term co-benefits assessment" by Dhar et al. (2016) studied the energy system of EV in India. The implementation of EV in India is currently supported by the demand incentives for EV under the Faster Adoption and Manufacturing of Electric Vehicles (FAME) program (GoI , 2015). Dhar et al. (2016) applied the energy system model ANSWER-MARKAL to assess different scenario for the performances of EV in India from 2010 to 2050. The EV scenarios show that direct financial incentives to EV buyers. The support of upfront investments in the infrastructure can increase the share of EVs in India in the short-to-medium term by the year 2030. The market share for EV in India is small; the two-wheeler EV has a greater future demand as compared to the four-wheeler EV by 2030. Due to the absence of sustainability measures, CO_2 emissions from transport will remain high in India even for the scenario with EV. The high and rising carbon emissions price under the low-carbon emissions scenario causes a higher emission decarbonisation effect of electricity and enables EVs to deliver a greater mitigation in CO_2 emissions. The results show an asymmetry impact of the national and global policies on the co-benefits by EV.

For the last paper in this theme, Nasab and Lotfalian (2017) reported the "Green routing for trucking systems with classification of path types". Vehicle routing problem (VRP) combines the optimisation and integer programming to find the optimal set of routes for a fleet of vehicles to a given set of customers. The optimal set of routes will reduce the fossil fuels consumption hence the total CO_2 emissions. Zhang et al. (2015) incorporated fuel cost, carbon emission cost, and vehicle usage cost into the conventional VRP and established a low-carbon routing problem model. Bauer et al. (2010) showed the potential of intermodal freight transport to reduce the GHG emissions. Fagerholt et al. (2010) considered a shipping scenario and propose a model to reduce the fuel consumption and fuel emissions by optimising the speed. Nasab and Lotfalian (2017) formulated a mathematical model to minimise the fuel consumption of trucks by classifying the routes based on the vehicle average speed and minimising the cost and delivery time. Pollution during the transportation process is considered by the specific penalty of fuel consumption that is related to the selected routes. The results suggested that setting the proper fuel consumption factors can lead to a better control of environmental pollution during the route planning.

Green transportation is expected to mitigate air pollution. The world largest study shows the effects of long-term exposure to air pollution and traffic noise on blood pressure (Financial Times, 2016). The promotion of EV and modelling tools to minimise transportation emissions and costs are among the key research scopes captured by this SV to promote green transportation. These efforts should be coupled with the enabling policies and real-time monitoring of air quality to correlate and validate the impacts of green transportation on air quality.

2.5. Management system for sustainability

Growing global concern towards sustainable development that emphasises the development in economic, environment, and social aspect (Li et al., 2015), trigger the need for holistic management systems for sustainability. Sustainable development could be applied in various contexts, at global, country, regional, city or even organisation scale. There are a few management systems that incorporate the sustainability aspect, such as the Total Quality Management (TQM), ISO 9001:2008 management system, ISO 50001:2011 Management System, ISO 14001:2004 Management System and Eco-Management and Audit Scheme (EMAS). A holistic method for the management of sustainability at the organisation level is still lacking. Mustapha et al. (2017) developed an integrated green management framework known as the Sustainable Green Management System (SGMS) to holistically manage the sustainability elements of an organisation. This study used common ISO standard criteria as the basis for integration. The chosen criteria are frequently used by most organisations for the integration of ISO standards. Bernardo et al. (2009) stated that the common integrated ISO standard requirements cover planning, internal audits, management reviews, control of nonconformities, preventive and corrective actions, product realisation, resource management, determination of requirements, improvements, document control, record control and internal communication. The authors demonstrated the benefits of SGMS through a case study that utilised a unified green index, an indicator that simultaneously covers the aspects of energy, water and materials conservation, as well as the reduction of environmental emissions.

Referring to Fig. 7, one of the top five non-economic barriers to promote renewable energy in ASEAN was the lack of coordination among the relevant authorities. Implementation of management system for sustainability at national and regional level is useful to fill this gap.

3. Conclusions

This SV concludes that addressing the key areas of energy, water conservation, green transportation and low emission technology can significantly promote the development of low-carbon emission. The energy sector is the key contributor for GHG emission. The dependency of non-renewable energy in Asia countries remains high despite the various mitigation plans. This SV also suggests the future research should have more focused on the green transport as it is one of the major climate change contributors and comparatively less considered in the Asian countries. The use of management system for sustainability integrating the footprints for water, energy and materials are essential to achieve the holistic goal of sustainability. Such system should be developed to facilitate the implementation of low-carbon manufacturing process, mechanism, business model and policies. The integrated management and planning system should be adopted by various stakeholders, notably the industrial players, technology providers, and policy makers to sustain the low-carbon emission development in Asia and beyond. Though a low-carbon emission future requires a sustainable and holistic framework for long-term implementation, it is expected that Asian region will continue to make great progress in shifting to a less carbon reliance and more sustainable future.

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