Patterns of technological accumulation: The comparative advantage and relative impact of Asian emerging economies in low carbon energy technological systems

Chan-Yuan Wong, Zi-Xiang Keng, Zeeda Fatimah Mohamad, Suzana Ariff Azizan

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This paper highlights the specificities of the patterns of low carbon energy technological innovations in selected Asian emerging economies. China and the members of ASEAN-4 (Thailand, Malaysia, Indonesia and the Philippines) are included in this analysis for their identical structure of developing economy. We outline a synthetic framework to cluster together the technologies with similar characteristics and analyse the changes of these characteristics over time. This is in order to elucidate the scope of sectoral composition and specialisation of the selected economies, and thereby understand the relative impact of science-based low carbon energy technologies on the niches of technological excellence. The findings show that China was keen to pursue its diversification strategy and develop its capability in low carbon energy technologies since the turn of the millennium. However, China has been gradually losing its momentum in more traditional areas like biomass, hydroelectric power, natural gas and fossil fuels. The ASEAN-4 economies, on the other hand, are showing interest in building a number of niches of technological excellence. This highlights a contrasting relative technological advantage between larger and smaller economies. Our findings also indicate that many of the low carbon technologies in selected economies have yet to attain strong scientific grounding for development. The findings of this paper are expected to provide some insights into low carbon energy technological development of emerging economies, and be useful for other developing economies to establish their strategic moves for energy technology development.

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* Corresponding author.
E-mail address: wongcy111@gmail.com (C.-Y. Wong).

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1. Introduction

As the world’s most populous region with a rising share of global greenhouse gas emissions, low carbon green growth (a path of economic growth that blends investment in technology for resource saving and sustainable management of natural capital [1]) is becoming imperative for many developing countries in Asia. In response to this challenge, various low carbon policy initiatives are being undertaken [2] including the targeting of low carbon energy technology as a prioritised area in their science, technology and industry (STI) development strategies. This STI policy approach provides a dual advantage of enhancing the countries’ industrial catching-up performance [3], while contributing to global de-carbonisation efforts [4].

The East Asian economies’ experience in low carbon energy technology catching-up emerged through a coupling of different semiconductor manufacturing and servicing industrial activities [5]. The accumulated technical knowledge in the semiconductor industry appears to have laid a strong foundation for many newly industrialized economies such as South Korea and Taiwan – establishing a pre-condition for the emergence of low carbon energy technologies [6]. As low carbon is seen as a field that will concord with next wave of technologies in the region, many Asian economies such as Malaysia, Thailand and Indonesia invested heavily in their targeted low carbon energy technologies such as solar photovoltaic, LED (Light-Emitting Diode) and biomass [7,8]. They attempt to reconfigure a new structure of innovation systems that will build new niches for their global and domestic markets. China on the other hand is capitalizing on their advantage of scale and economies of scale in various sectors to venture into diverse low carbon energy related-industrial technologies [9–12]. While the former are dependent on their limited factor of endowment and have to be more targeted, China has instituted an experimentation routine – venturing into different approaches of developing specific sectors and managing complex challenges – as it has a lower risk of systemic breakdown [13,14]. Heilmann [15] and Wong and Cheong [14] covered the uniqueness of China’s institutional structure and national production system in responding to competitiveness in industrial activities.

While many newly industrialized economies have managed to attain new niches in the global low carbon energy technological chain, various policy makers in developing economies express serious concerns about the competitiveness of their industries. Their concerns revolve around what comparative advantage their economy has in the technological global value chain, and which technology is to be targeted so that it will have a positive impact on global low carbon energy market demand. Thus, understanding the process of creative accumulation has been the central effort of various technology and innovation scholars since Schumpeter [16]. Many scholars [17–19] recognised the importance of cumulative learning processes (that are basically driven by the competencies of an industry) to the emergence of new high-technology sectors. While some [20–22] delved into different aspects of competitiveness and various economic indicators to depict the position and technological capabilities of an economy, Nesta and Patel [19] researched into patenting activities to understand and style the national and corporate patterns of technological accumulation. Lee and Lee [23] and Wong et al. [24] employed patenting data to map the patterns of innovation in energy technologies.

While the literature on energy technological innovation informs us on how to style the pattern of technological accumulation and the generic patterns of low carbon innovation, a systematic approach – with a dynamic perspective to mark the commonalities (and differences) amongst the developing economies in national patterns of low carbon energy technology accumulation and in both aggregate and in sectoral composition and specialisation – is still severely lacking.

In what follows, we will highlight the specificities of the patterns of low carbon energy technological innovations in selected Asian emerging economies. China and the members of ASEAN-4 (Thailand, Malaysia, Indonesia and the Philippines) are included in this analysis for their identical structure of developing economy. These economies share many similarities in term of income structure, science and technology policy options, and status as latecomer economies; they appear to have gained substantially from the composition of world market demand [25].

This paper attempts to expand the findings of Lee and Lee [23] and Wong et al. [24] by incorporating the scope of sectoral composition and specialisation of Asian emerging economies, and understanding the relative impact of science-based low carbon energy technologies on the niches of technological excellence. We outline a synthetic framework to cluster together the technologies with similar characteristics and analyse the changes of these characteristics over time. The findings of this paper are expected to provide some insights into low carbon energy technological development of emerging economies, and be useful for other developing economies to establish their strategic moves for energy technological development.

2. Literature review

The general topic of latecomer catching-up and technological development in Asia has been a popular area of investigation for several decades [26,27], with many policy lessons gained. However, contemporary concerns about climate change have opened up new challenges for policy-makers to ensure that low carbon considerations will be effectively incorporated into the region’s technological development strategies, so as to be in line with environmental sustainability [2]. Due to the significant role of the energy industry in the global decarbonisation agenda, studies on accelerating the innovation of low carbon energy technologies in Asian developing economies – especially China – have gained considerable momentum over the years. Contemporary writing in energy-related development studies has been devoted to elucidating the dynamics of low carbon energy science and technology, as well as possible lessons for catching-up [28–30].

The “technological development trend” line of research is also gaining ground not only with academics of energy technological innovation, but also with policy makers who aspire to lay an institutional platform that is conducive for ‘technopreneurs’ to produce and distribute low carbon energy technology.

Their findings can be a useful contribution to the broader policy concerns of development studies. Our reading of the literature reveals a number of themes that correspond to the perspectives of Schumpeter [16] and Lundvall [31] on innovation capabilities and innovation systems, and to Jaffe and Trajtenberg [32] on knowledge networks. The themes include Albino et al. [33] on eco-innovative activities, Choe et al. [34] and Duan [35] on productive network structure in energy technologies and Wong et al. [24], Li et al. [36], Mueller et al. [37], Wonglimpiyarat [38] and Corsat et al. [39] on capabilities for low carbon energy technologies. The use of publishing and patenting statistics as proxies for low carbon technology appears to be common in their analyses. These papers highlight the national concentration of different low carbon energy technological activities. They also offer developing economies a guide on how to transform existing undesirable technological landscapes into more functional innovation systems – based on multiple transition mechanisms. The mechanisms include subsidies and supports for adoption of low carbon technologies, support for R&D learning, network formation for new technologies, information provision through various channels to attract investment in new technology, and so on [38,40–42].
The innovation system and knowledge network models emerged in the literature to be rich and have a strong foundation as an analytical tool for analysis at the technological level. Building on the studies on technological changes and dynamics of innovation systems of various economies, Albino et al. [33] and Choe et al. [34] studied and discussed the characteristics of low carbon energy technological development. Lee [43] depicts the dynamics of energy technology innovations in order to present possible scenarios for the evolution of energy technology. Patents are used in these studies as proxy for technology capability. Duan [35], on the other hand, studied the cooperation patterns in low carbon energy related R&D with a special focus on the co-publication activities. While two cooperative entities – universities and public research organizations – are highlighted in Duan’s analysis, industry was witnessed to have gradually emerged as a productive partner in co-publishing activities.

The publications and patents statistics are found to be useful and effective in these studies for highlighting the path of technological evolution patterns in the field of low carbon energy. Many of these studies appear to have particular interest in the cases of developed economies. While the findings unveiled the progress of energy technology, we noted that a systematic approach to the understanding of the technological accumulation patterns in the emerging economies (such as China and ASEAN) with regard to the comparative advantage in a dynamic perspective is still severely lacking. In addition, the relative impact of science on low carbon energy technologies in the context of developing economies remains undiscovered. To the best of our knowledge, the literature has not considered mapping low carbon energy technologies with similar characteristics and analysing the changes of these characteristics over time, in order to understand the relative impact of science-based low carbon energy technologies on the niches of technological excellence. The comparative advantage of energy technologies and the impact of science-based low carbon energy technologies remain to be explored. Therefore, we see a need to assess the dynamics of low carbon energy technologies. The assessment is important, on the one hand to validate and ensure the development potentials of low carbon technologies in the emerging economies, and on the other hand to inform the literature of energy technological systems with an account of the dynamic innovation process in the context of developing economies.

The following sub-sections are organized with an attempt to bridge the gaps in the literature. Section 3 on methodology of the study discusses the conceptual framework. The findings and analysis are discussed in Section 4. Section 5 concludes.

3. Methodology

Following Pavitt’s pioneering work [44] on using patent statistics to map the nature of technological accumulation, many studies had contributed quantitative evidence to elucidate the accumulation trajectories of science and technology of various emerging economies. While some scholars [18,19] provide indications of which economies specialise in what leading edge technologies, others [23,45] elucidate what technologies would likely lead to opportunities in the global technological value chain. Their studies employed patent statistics to construct proxy variables for technological innovation, and to quantify the change in technology and national specializations in the global value chain. The literature has made heavy use of the total count of national applied and granted patents as proxy for the technological capability of an economy; the intensity of national patents in specific fields as proxy for the technological competitive advantage of an economy; and patent citations as proxy for both the intensity of knowledge flow and value in the market or society. The patent statistics have been useful. While many measures of research and technological activities (e.g. expenditure of R&D or scientific publications) rarely indicate direct economic values, benefits or profit, patent statistics can be used to represent the codified part of technological innovation that reflects the interest in commercial exploitation of a new technology.

Existing studies in the literature appear to lack any documentation of sectoral specialisation of emerging economies, and fail to understand the relative value of science-based low carbon energy technologies. Therefore, we believe we can make a worthy contribution to enrich the literature of innovation systems and low carbon energy technology accumulation of developing economies. Drawing upon the findings of Wong et al. [24], this study extends the analysis with the aim to analyse the sectoral specialization (proxied by patents) in selected emerging economies in Asia. We employed the keywords search used in Wong et al. [24] to identify low carbon energy related patents. Please note that Energy / Electricity Storage is grouped under both renewable and fossil fuel categories. We record the annual number of applied patents of the selected Asian economies from 1980 to 2012 from the Patent Cooperation Treaty (PCT of the World Intellectual Property Organization) database. The keywords are according to the line of technology of different fields (see Table 1).

We then follow Nesta and Patel’s approach [19] to formulate the index of national comparative advantage in low carbon energy technologies. Revealed Technological Advantage (RTA) index can be depicted as:

\[
RTA_{X_i} = \frac{PAT_{X_i}/\sum_i PAT_{X_i}}{\sum_i PAT_{i}/\sum_i PAT_{X_i}}
\]

where:

- \(PAT_{X_i}\) denotes the number of applied patents of \(X\) economy in technological field \(i\) (see Table 1) of year \(t\); and
- A value above unity (above 1) indicates a field of relative strength, while a value below unity (below 1) indicates a field of relative weakness.

As typical developing economies in the race to secure comparative advantages in low carbon technological value chains, China and ASEAN member economies are facing the urgency to transform their productive routines – from duplicative imitation, into a structure that supports science-based technological innovations. They have initiated many science and technology programs to institute a routine that allows co-evolution between scientific activities and technological innovations. In this study, we are interested to explore what positions in technological value chains these economies attained, as well as what science-based technologies have been targeted in these economies to create a positive impact on their markets and societies. We employ the number of science-based backward citations to patents (patents that cite scientific related literature) extracted from the US Patents and Trademark Office (USPTO) database in order to frame the Relative Impact Index (RII) [19 p. 538] and study the relative impact of science on technology. Positing an intensity value of backward citation as a nominator of RII function enables us to identify the technologies that are dependent on the spillover of scientific knowledge for development, and will subsequently allow us to highlight the relative impact of science-based technologies on the overall value of technologies [58]. RII is therefore defined as follows:

\[
RII_{X_i} = \frac{BC_{X_i}/\sum_i BC_{X_i}}{PAT_{X_i}/\sum_i PAT_{X_i}}
\]
Where:

- BC indicates the number of science-based backward citations to patents received by country X in technology field I; and
- A value above unity implies a field of relative high impact of science on technology.

To provide a context for understanding the scope of sectoral composition of selected economies, we established a map (Fig. 1) that enables us to visualise the comparative advantage of selected economies in low carbon energy technologies. We plot each technology on a 2-dimensional map, with RTA along the X-axis and patent share along the Y-axis. The lower left quadrant represents the low technological advantage position, whereby the technologies clustered under this quadrant have not been a priority of an economy to secure a specific global market position. The technologies belonging in the upper left quadrant may have attained a specific global market position due to the competencies of an economy that were acquired over a long period of time, but such a position has low correlation with the change of technological advantage over other technologies. This may be attributed to the relatively large size of the field, that ultimately led to the failure of an economy to gain a comparative advantage over other economies. Those technologies in the lower right quadrant exhibit their niche advantage position for an economy in relatively small fields, and those in the upper right quadrant indicate their distinctive position of technological advantage of an economy over others, whereby such a position has enabled an economy to extract rent from its patents portfolio.

To map the relative impact of science-based low carbon energy technological research on the niches of technological excellence, we developed another map that allows us to cluster each technology into one of four groups. The lower left quadrant of Fig. 2 represents a position in which the technologies have no direct linkages with scientific knowledge, and thus gained limited value in the market and society. The upper left quadrant represents a position in which the impact of technological innovations of an economy has little correlation with the science-based technologies. The lower right quadrant describes a position in which science-based technologies have made little impact on the overall value of technologies. Finally, the upper right quadrant elucidates a position of high correlation between science-based technologies and overall value of technologies in the market and society.

### Table 1
Indicative list of technologies classified under low carbon energy. 
Source: [24, p. 5].

<table>
<thead>
<tr>
<th>Energy service</th>
<th>Category</th>
<th>Technology (Keyword)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Production</td>
<td>Renewable</td>
<td>• Combined heat and power</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Tidal energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Wind turbine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Geothermal energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Solar energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Photovoltaic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Solar thermal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Biomass energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Biogas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Energy / Electricity storage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Hydro energy</td>
</tr>
<tr>
<td>Fossil fuel</td>
<td>Energy Saving</td>
<td>• Fossil fuels (all types)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Natural gas</td>
</tr>
<tr>
<td>Demand-side Management</td>
<td>Energy Saving</td>
<td>• Energy / Electricity storage</td>
</tr>
<tr>
<td>System</td>
<td></td>
<td>• Energy efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Building ventilation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Building insulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Light tubes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• LED</td>
</tr>
</tbody>
</table>

4. Results and analysis

This section focuses on cross-economy similarities and highlights the differences in low carbon energy technology capabilities. Firstly the common share of low carbon energy related patents of selected economies is discussed. Next, the comparative advantage of selected economies is discussed in the following sub-section. Then, comparisons are made between China and ASEAN member economies. Malaysia, a member country of ASEAN that is known to have committed to building science and technology capabilities since the 1980s [46], is used as a case study to reflect the changes of technology targets in ASEAN economies.

As comprehensively described in the ADB [2], China and Malaysia already have their respective low carbon energy-related policies in place (Table 2). However China’s approach has been more comprehensive, covering more types of policy instruments. Malaysia, on the other hand, is more limited to public investment, capital assistance and feed-in tariffs. Both China and Malaysia are viewed as economies that have attained strong policy ownership (capability of policy to stimulate the research interest of capable high technology firms) and have mobilized policy instruments mentioned above to achieve their desired goal. [14] The measure used for stimulating low carbon energy technological innovation (e.g. R&D grants) is particularly important and can be instrumental for both economies to advance development, as they have reached the upper middle income level and instituted productive R&D routines. Both economies are positioning themselves in the global technological value chain, in order to attain high income via capability to produce leading-edge products and services. Effectively executing measures for R&D activities may be difficult for developing economies at the low or lower middle income level [47], as
knowledge capital derived from semiconductor technologies [50].

4.2. Revealed technological advantage

Table 4 compares China and ASEAN-4 member economies in 18 low carbon energy technologies, in terms of RTA measures across three periods of time (i.e. 2000, 2005 and 2010). We measure the variation of the RTA (CV) by deriving the coefficient between the standard deviation and the mean of RTA values to determine whether an economy has targeted niches of technological excellence (relatively high CV) or diversified its competence to a wide spectrum of specialization (relatively low CV).

In Table 4, we noted that both China and ASEAN economies have not only advanced their technological advantage in number of low carbon energy technologies over a 10 year period, but also attained better positions in terms of the number of RTAs above unity (6 and 10 respectively in 2010). The ASEAN economies appear to have achieved a critical mass of technological competencies (10 over 18 technologies with RTA > 1 in 2010). China has, on the other hand, attained lower value of CV compared to ASEAN economies. It is seems that China has attempted to broaden its competencies to a wider spectrum of areas in order to support the growing domestic market demand for low carbon energy technological innovations.

There are a number of high coefficients of variation of RTA values per technology for China (CV above 100), while ASEAN also has an advantageous position in securing niches from potential market value chains. The technologies include wind turbines, hydroelectricity power and natural gas. The position establishment of these technologies may be attributed to those economies being endowed with abundant natural resources or geographical advantages, in which ASEAN has found their advantage to develop competencies in these areas. China has a strong technological advantage in light tubes and LED (3.16 and 3.79 respectively) consistent with its active role in spawning niches that are derived from semiconductor technological capabilities. Energy efficiency and building ventilation, the two technologies which attained the two highest CV values for ASEAN-4, have been losing RTA value in the ASEAN economies. Possibly some aspects of diminishing marginal returns have set in as the technologies mature.

Table 5 and Table 6 provide the evolution patterns of technological advantage of China and ASEAN member economies. We noted commonalities and differences in the scope of specialization of low carbon energy technologies. Both are relatively strong and experiencing growth in wind turbines. Combined heat and power and building insulation for both China and ASEAN are in advantageous positions but experiencing contracting growth of said positions. Noteworthily, biomass energy, energy / electricity storage and building ventilation are not the priorities for both economies.

4.1. The share of applied patents in low carbon energy technologies

Table 3 shows the proportion of low carbon energy technology patents of the selected countries. The low carbon energy patents have seen a quantum leap in the past decades for most economies, indicating the seriousness with which these economies are pursuing low carbon energy technologies. In the meantime, a marginal increase is observed for the case of Indonesia.

Fig. 3 and Fig. 4 show the breakdown of the apparent fields of applied patents of China and ASEAN-4 respectively. It is noted that China emerged to have committed to patenting of LED, Energy Efficiency, Photovoltaic and Solar Energy. While ASEAN economies shared similar interests with that of China, Malaysia emerged to have committed to patenting of Natural Gas. Thailand and Indonesia seem to have committed their resources in Wind Turbines. The commitments for Natural Gas patenting for Malaysia and Wind Turbines for Thailand and Indonesia are probably attributed to the efforts of each respective economy to extract innovation rents from their country's exclusive comparative advantage.

Fig. 5 shows the plots of the share of applied patents in low carbon energy technologies for selected economies over time. We noted that there was virtually no interest in the selected economies for building low carbon energy technologies in the 1980s and 1990s. The year 2000 witnessed a commitment to developing and advancing low carbon energy technologies. The following year 2001 marks the commencement of diversification of technologies. LED, solar energy, photovoltaic, energy efficiency processes, natural gas and wind turbine appear to have dominated the landscape of low carbon technologies in the selected economies. This phenomenon is probably attributed to the stepping-up of commitment by the respective governments in building R&D routines in the 1990s, [14] that led to substantial investment in low carbon energy technological patenting. The investment is viewed as part of the effort in building their technological positions in the global technological value chain. Light tubes, geothermal, and building insulation emerge in the early 2000s as complementary assets for the development of core industries. The share of two technologies, LED and energy efficiency processes, has been remarkable.

We believe that the high technology development focus of LED is attributed to the interest in building potential markets in the global technological value chain through utilizing the aggregate

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### Table 2

Comparison of policies that promote low carbon energy transitions between China and Malaysia.

Source: Adapted from ADB [2]; updated according to latest literatures [48,49].

<table>
<thead>
<tr>
<th>Feed-in-tariff</th>
<th>Renewable portfolio standards</th>
<th>Capital subsidies, rebates, R&amp;D Grants</th>
<th>Tax credits</th>
<th>Tax reduction</th>
<th>Tradable renewable energy certificates</th>
<th>Public investment loans or refinancing</th>
<th>Public competitive bidding</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
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<td>Malaysia</td>
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### Table 3

The proportion of low carbon energy technologies in percentage of total number of applied patents of selected economies, 2000 and 2010.

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</thead>
<tbody>
<tr>
<td>China</td>
<td>2%</td>
<td>7%</td>
<td>0%</td>
<td>9%</td>
<td>0%</td>
<td>9%</td>
<td>4%</td>
<td>5%</td>
<td>0%</td>
<td>7%</td>
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<tr>
<td>Malaysia</td>
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<td>Thailand</td>
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<td>Indonesia</td>
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<td>Philippines</td>
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</tbody>
</table>

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they have yet to attain the policy capability to lead capable firms to invest in low carbon energy technologies. Therefore, the subsequent sub-section discusses the relative impact of science-based technologies of China and Malaysia on their overall value of patents.
Fig. 3. The share of applied patents of China, 1980–2012.

Fig. 4. The share of applied patents of ASEAN-4, 1980–2012.

Fig. 5. The share of applied patents for the selected economies by field of low carbon energy technology.
cases. While China has increasing strength in photovoltaic and LED, ASEAN has a relative advantage in clean energy source (natural gas) and solar-related renewable energy storage systems.

Fig. 6 shows the technological maps of China. We noted that China is in a leading position for a number of low carbon energy related technologies. Combined heat and power, wind turbine, photovoltaic, light tubes, building insulation and LED have emerged as leading technologies which might provide China with a dominant position in global market value chains. The scatter plot for China appears to suggest a positive linear relationship. While there are six technologies moving ahead, many others are located in the lagging behind quadrant. Geothermal, solar energy, solar thermal and energy efficiency are the technologies that have lost the momentum of gaining comparative advantage over other economies.

For the case of ASEAN economies (Fig. 7), we observed that many technologies were oriented towards niches of technological excellence, with only two (building insulation and wind turbines) targeted to compete in the leading ahead quadrant. LED, fossil fuels, building insulation, natural gas, hydroelectricity power, light tubes, solar thermal and solar energy emerged to be the niches for ASEAN economies. It would be of interest to explore the position of Malaysia’s technologies (see Fig. 8) to reflect the overall evolution pattern of ASEAN’s development in low carbon energy technologies. We observed that many technologies of Malaysia have evolved from the lagging behind quadrant to the niche quadrant. In addition, light tubes – a technology which used to provide Malaysia with a leading position in the global value chain – has moved to a niche position in order to target specific consumers’ needs, instead of a wider spectrum of consumers in the global market chain. In the context of Malaysia, the government could have regarded these technologies as the targeted areas that might generate economic value to the market and society. A combination of techno-entrepreneurial infrastructure that would stimulate the interests of techno-entrepreneurs in these technologies, together with a supply of engineers who are capable of exploiting the market opportunities of these technologies, is crucial for the successful economic catching-up of Malaysia.

### Table 4

<table>
<thead>
<tr>
<th>Technology</th>
<th>China 2000</th>
<th>China 2005</th>
<th>China 2010</th>
<th>ASEAN-4 2005</th>
<th>ASEAN-4 2010</th>
<th>ASEAN-4 CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined heat and power</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Tidal energy</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Wind turbine</td>
<td>17.28</td>
<td>0.35</td>
<td>2.53</td>
<td>382.76</td>
<td>0.00</td>
<td>8.39</td>
</tr>
<tr>
<td>Geothermal energy</td>
<td>0.00</td>
<td>0.79</td>
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<td>1.09</td>
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<td>51.61</td>
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<td>0.85</td>
</tr>
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<td>0.49</td>
<td>44.92</td>
<td>0.00</td>
<td>0.13</td>
</tr>
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<td>3.16</td>
<td>46.10</td>
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<td>117.02</td>
<td>0.00</td>
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<td>Natural gas</td>
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<td>0.19</td>
<td>107.93</td>
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<td>Energy efficiency</td>
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<td>0.59</td>
<td>0.52</td>
<td>80.60</td>
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<td>0.37</td>
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<td>4</td>
<td>6</td>
<td>2</td>
<td>8</td>
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### Table 5


<table>
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<tr>
<th>Advantage (RTA &gt; 1)</th>
<th>Increasing</th>
<th>Marginal Change/Stable</th>
<th>Decreasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind turbine</td>
<td>Combined heat and power</td>
<td>Light tube</td>
<td>Combined heat and power</td>
</tr>
<tr>
<td>Photovoltaic</td>
<td>Light tube</td>
<td>Combined heat and power building insulation</td>
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<td>LED</td>
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<td>Combined heat and power building insulation</td>
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<td>Disadvantage (RTA &lt; 1)</td>
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<td>Solar energy</td>
<td>Hydroelectricity power</td>
<td>Natural gas Energy efficiency Building ventilation Geothermal energy</td>
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### Table 6

The evolution of technological advantage of ASEAN, 2005-2010.

<table>
<thead>
<tr>
<th>Advantage (RTA &gt; 1)</th>
<th>Increasing</th>
<th>Marginal Change/Stable</th>
<th>Decreasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind turbine</td>
<td>Fossil fuels</td>
<td>LED</td>
<td>Combined heat &amp; power Light tube Hydroelectricity power Building insulation</td>
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<td>Solar energy</td>
<td>Biomass energy</td>
<td>Energy efficiency Building ventilation Energy / Electricity storage</td>
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<td>Solar thermal Natural gas</td>
<td>Combined heat and power</td>
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<tr>
<td>Photovoltaic Biogas</td>
<td>Combined heat and power</td>
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4.3. Relative impact of science-based technologies

The function shown in (2) is used to measure the relative impact of science-based technologies on the overall value of technologies in the market and society. See Fig. 7 and Fig. 8 for the plots of citations per patent over RII. We observed that there are many technologies of China and ASEAN (such as wind turbines and building insulation) that are considered in the position of comparative advantage over the other economies that are now excluded in the plots. Many technologies appear have little link to scientific activities. For the technologies that are excluded in the plots, we see little exploratory research value in the process of advancing the knowledge of these technologies.

For the case of China (Fig. 9), we noted that only four technologies – light tubes, natural gas, energy efficiency and LED – have evolved from the low impact quadrant to the high impact quadrant. It appears to us that these four technologies are dependent on the spillover of scientific knowledge, and that they have made an impact on the overall quality of the respective patent classes. For the case of Malaysia (Fig. 10), there are six technologies that have evolved from low/no impact quadrant to high impact quadrant. Combined heat and power, light tubes, electricity storage, natural gas, energy efficiency and LED are the technologies that have emerged to rely on scientific knowledge for development. Two technologies that are realised have little advantage in building global market position of ASEAN economies, i.e. energy efficiency and energy storage, emerged to have generated substantial value to the quality of their respective patent classes from their intangible scientific knowledge assets. We conjecture that advancing the scientific knowledge of these
technologies would complement the generic development of low carbon science energy technologies.

5. Conclusion

Asia is becoming the fastest growing emitter of GHG emissions. Recent estimates by ADB [2] suggest that Asia accounts for 27% of the world’s energy-related CO2 emissions, and the share is likely to increase to 44% by 2030. The role of emerging economies in Asia therefore must be at the centre of the global agenda on low carbon energy technological development, particularly in its industrial and technological catching-up strategy [1,51]. The findings in this paper highlights four main areas – diversification, specialisation, technological comparative advantage and impact of science based technologies – in which the prospects of Asia in low carbon technological advancement can be observed:

a) Diversification: There is a clear diversification in the development of low carbon energy technologies since the turn of the millennium, most significantly in the areas of LED and energy efficiency, followed by solar technology, photovoltaic, energy efficiency processes, natural gas and wind turbine. This means the selected economies have progressed in their low carbon technology development – in terms of both volume and diversity – thus showing high potential for the region to become an important player in this field of low carbon energy technology.

b) Specialisation: A closer RTA analysis revealed that there is a clear technological specialisation within this diversification. Both China and ASEAN-4 achieved a significant RTA score, 7 and 11 respectively, by 2010. This means that over the years, there has been a critical mass of technological competencies accumulated in specific areas that can be strategically exploited. China has a relative advantage in photovoltaic and
LED, while ASEAN-4 has a relative advantage in solar energy, solar thermal and natural gas. Both share high potential in wind turbines. However, China has lower overall CV values compared to the ASEAN-4 economies, demonstrating its broader competencies in a wider spectrum of technological areas. On the other hand, the ASEAN-4 economies have high CV values in specific technologies, e.g. wind turbines, hydroelectric power and natural gas, thus showing a more targeted niche of technological excellence. In short, this highlights a contrasting relative technological advantage between larger and smaller economies. The former tends to be less focused on building niche positions as it has the capacity to build diversified low carbon energy technological structures. Due to the advantage in size and economies of scale in various industries, China can afford to venture into various energy technologies and manage complex challenges with a lower risk of systemic breakdown. By comparison ASEAN-4 is more dependent on their limited factor of endowment, and have to be more targeted.

c) Technological comparative advantage: China has six technologies (combined heat and power, wind turbines, photovoltaic, light tubes, building insulation and LED) in the ‘leading ahead’ quadrant, revealing their dominant global position in these areas. On the other hand, growth of technologies like geothermal, solar energy, solar thermal and energy efficiency have slowed down and moved to a more niche position. With the exception of tidal energy, China is losing momentum in more traditional areas like biomass, hydroelectric power, natural gas and fossil fuel. While the ASEAN-4 economies are showing a number of niche technological excellences (LED, fossil fuel, building insulation, natural gas, hydroelectric power, light tubes, solar thermal, solar energy), only two technologies (building insulation and wind turbines) are in the leading ahead quadrant. ASEAN-4 are lagging behind in both traditional and new areas (biomass energy, geothermal, photovoltaic, geothermal energy, electricity storage, energy efficiency, building ventilation). This mapping of technological comparative advantage draws attention to the existing technological strengths of the economies that should be maintained and enhanced, plus areas of losing momentum and lagging behind that can be improved, re-evaluated or even terminated.

d) Impact of science-based technologies: The profile of technological advantage, however, does not coincide with the impact of science-based technologies. Most of the technologies observed have little link to scientific activities. However there are exceptions. In the case of China, four technologies (light tubes, natural gas, energy efficiency and LED) have evolved
from low impact quadrant to high impact quadrant. Except for natural gas, these coincide with areas in which China is leading ahead technologically. For ASEAN-4, the impact of science on areas like energy efficiency and energy storage is relatively high – but these are the exact technological areas in which the economies are lagging behind. Such findings point to the interesting fact that the development of low carbon technologies in Asia may not have strong scientific grounding yet, except for limited areas of technology. It also leads to the question of how far investments in low carbon R&D in Asia are paying off [2], and in what ways can they be improved. In this instance, China seems to be performing better than the ASEAN-4 economies.

From these findings, we can conclude that evidence from China and ASEAN-4 has shown that emerging economies in Asia have the potential to be significant players in the growing low carbon energy industry, not only in terms of volume but also growing diversification and specialisation of technologies. We also highlighted that the economies have the propensity to play out different strategies in their low carbon technological development – be it niche or broad based – depending on their path dependency and factor endowments. A closer analysis on such comparative advantage can be a way forward to synergise efforts and increase strategic collaboration for low carbon energy development in the region.

However, China’s aggressive low carbon strategy (Table 2) has resulted in better positioning in terms of technological comparative advantage and harnessing the impact of science-based technologies. This is in line with the trends observed by Yuan et al [52] that China’s 45% CO2 intensity reduction target by 2020 is not only within international expectations, but also consistent with the country’s economic and social development strategy. China is also forging ahead in the development of science-based technologies in the areas of LED, light tubes and energy efficiency. On the other hand, ASEAN-4 is performing less effectively – none of their strengths in science-based technologies have contributed to their technological comparative advantage.

Nevertheless, the findings as a whole have shown that science-based technologies have very little impact in overall technological competitiveness in both China and ASEAN-4. In the case of China, this resonates with the findings by OECD [53]: China’s RTA in green technology has slipped considerably even as the country’s 12th Five Year Plan for S&T Development (2011–2015) brought considerable attention to the development of clean energy industries and related low carbon technologies.

This opens up the question of the effectiveness of STI policies in the region, especially on how much R&D efforts and investments [2] are supporting long-term competitiveness in low carbon energy technologies. Indeed, increasing the impact of R&D investment has been a persistent STI policy challenge for Asian latecomers [54], especially for the ASEAN-4 economies [55–57]. Therefore it is interesting to explore further whether the situation is being further exacerbated in the more challenging context of low carbon energy technology, where national-global and social-economic-environmental implications of technological development are closely intertwined.

Acknowledgement

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References