Low-carbon Competitiveness in Asia

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Abstract: Environmental degradation and the risks from climate change have strengthened the need for cleaner forms of economic growth. Using patent, trade and output data, this paper measures the current size of Asia's low-carbon economy and assesses its competitiveness across key sectors, acknowledging that low-carbon is only one facet of the multi-dimensional green economy. Building up from the framework presented in Fankhauser et al., (2013) we look at three success factors for low-carbon competitiveness at the sector level: the ability to convert to low-carbon products and processes (measured by a specialization in green innovation), the ability to gain and maintain market share (measured by existing comparative advantages) and a favourable starting point (measured by current output and scale). Using this framework, we identify the climate change mitigation technologies that Asian countries specialize in and can potentially scale up. The analysis shows that Asia's top low-carbon economies are Japan, South Korea and China. The sectors in which Asia is particularly well-placed to be globally competitive include efficient lighting, photovoltaics, low-carbon road transport, and energy storage. Overall, Asia is a specialist in innovating and exporting climate change mitigation technologies but there are significant regional disparities.

Key words: Green Growth, Low-carbon, Asian Competitiveness

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1. Introduction

Under the precipices of the Paris Agreement, the world is increasingly turning towards cleaner forms of growth. Asian metropolises such as Delhi, Beijing and Jakarta suffer from severe air pollution (WHO, 2016), which is galvanising civil society to demand for change. As countries transition to a new low-carbon production regime, the competitiveness landscape will shift. There will be winners and losers in the short-term but countries can start positioning themselves to profit from the transition. Several Asian countries have incorporated the idea of low-carbon growth into their national strategies. For example, South Korea launched its National Strategy for Green Growth in 2009; India featured sustainability as a key pillar in its 12th Five Year Plan and; China's 13th Five Year Plan promotes a cleaner economy (Stern, 2010). However, despite the announcement of such plans, it is unclear whether Asian countries will be competitive in the global low-carbon market. Studies such as ADB (2015) and Yoshida & Mori (2015) give an overview of Asia's low-carbon economy from a policy perspective but they do not systematically assesses its size or market competitiveness using quantitative methods. This paper will address this gap by sizing Asia's low-carbon economy and assessing its global competitiveness.

Competitiveness refers to an economy's ability to compete successfully in markets for internationally traded goods (Durand & Giorno, 1987). Given that many countries in Asia are developing, it is imperative that the continent finds a way to profit from the low-carbon transition. There are several challenges associated with assessing low-carbon competitiveness. Firstly, it is difficult to define the bounds of the low-carbon economy and secondly, it is not easy to find competitiveness metrics that are internationally comparable. The paper uses a methodology that combines output, trade and patent data to overcome these challenges and, sizes Asia's low-carbon economy and evaluates its competitiveness across low-carbon sectors.

Embracing the low-carbon transition is important for Asia for several reasons. Without Asia, it would be very difficult to meet the Paris Agreement's goal of keeping global mean temperature below 2 degrees Celsius. Additionally, parts of Asia are extremely vulnerable to climate change because of a strong reliance on climate-sensitive sectors such as agriculture and forestry (Adger, 2006). If greenhouse gas (GHG) emissions continue to increase as they have, the annual mean temperature in Indonesia, the Philippines, Thailand and Vietnam is projected to rise by 4.8 degrees Celsius by 2100 from the 1990 level (Intergovernmental Panel on Climate Change, 2014). In the most severe climate change scenarios, rising seas would submerge much of the Maldives and inundate one-fifth of Bangladesh's land (Mimura, 2008). The continent's criticality in the Paris Agreement coupled with the consequences of climate change have heightened the need for low-carbon growth.

The rest of the paper is structured as follows: section II provides some descriptive statistics on Asia's low-carbon economy, including its current size, section III outlines the methodology for assessing competitiveness, section IV presents the results and section V concludes.

2. Asia's low-carbon economy: data, descriptive statistics and size

The challenge with sizing Asia's low-carbon economy is that there is a high degree of flexibility in defining its bounds. A stringent definition would claim that only industries with zero net emissions should count. A less stringent definition would include any industry which produces 'acceptable levels' of emissions that are in line with climate change policy targets. For this study, we use 'climate change mitigation technologies' (CCMTs) to define the bounds of the low-carbon economy. CCMTs are technologies that can reduce the source or enhance the sinks of GHGs - they do not necessarily have to be zero-emission technologies. CCMTs include electric vehicles, efficient lighting, photovoltaics and nuclear energy. The European Patent Office (EPO) has a widely accepted definition of all the technologies that classify as CCMTs, all of which are included in this study and can be referred to in the appendix. To assess low-carbon patenting activity, we use global patent data from EPO. [2] For trade statistics, we gather data from UN Comtrade and establish correspondence with the EPO's CCMT classifications.

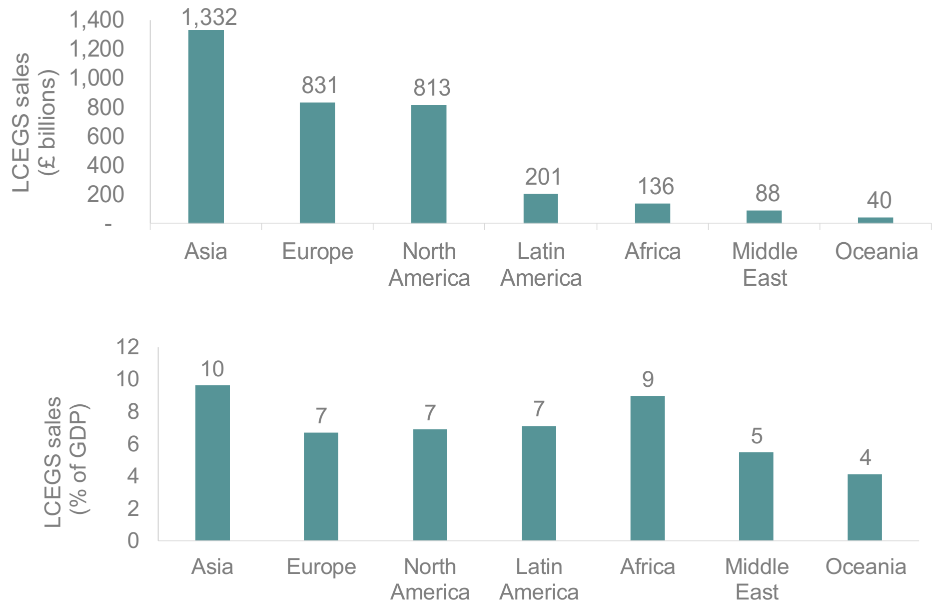
A second challenge is whether we measure the low-carbon economy by sector or at a more granular level that cuts across sectors. Early efforts at sizing the low-carbon economy, such as OECD (1998), overlooked low-carbon activity in non-environmental sectors. For example, if we labelled transportation as non-environmental, we could overlook low-carbon aspects within the sector such as catalytic converters, electric vehicles and energy-efficient engines, which can result in underestimating the true size of the low-carbon economy. HSBC (2009) confirms that majority of low-carbon revenue does not accrue in explicitly environmental sectors.

To account for this, we use the Low-Carbon Environmental Goods and Services (LCEGS) database developed by the United Kingdom Department for Business, Innovation and Skills in 2011 to value the low-carbon economy (UK BIS, 2011). This database defines a set of 'environmental sectors' whose activities cut across conventional sectors. For example, 'air pollution' is a sector in the LCEGS dataset whose activities cut across agriculture, manufacturing, and services. The LCEGS database uses sales data rather than value-added which lets us to capture more of the low-carbon economy since a significant proportion of activity, such as pollution control, happens in the operational stages. Using this database, we compare the relative size of Asia's low-carbon economy.

Asia has the largest value of LCEGS sales in absolute terms and per unit of GDP relative to other continents (**Error! Reference source not found.**). The top five largest global producers of LCEGS are: the United States, China, Japan, India, Germany, and the United Kingdom, out of which three are Asian. Within Asia, China has the largest value of LCEGS sales (figure 2). This is to be expected given to the size of its economy. However, relative to GDP, the Philippines has the highest value of LCEGS sales, followed by India. In both countries, LCEGS sales are worth approximately a fifth of GDP.

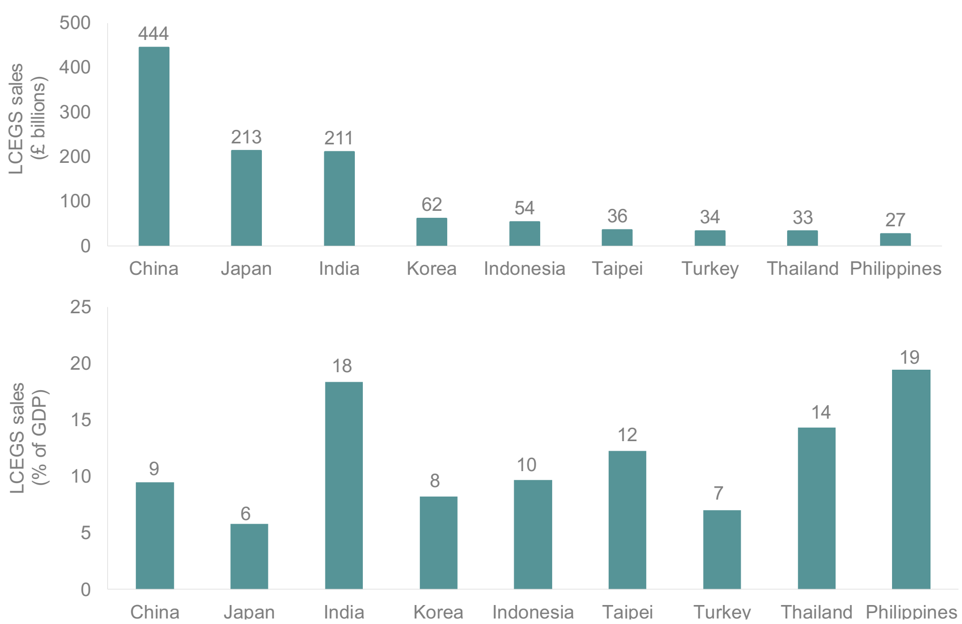
[2] Patent data has been used successfully in several studies of green innovation such as (Dechezleprêtre & Calel, 2012; Dechezleprêtre, Glachant, & Ménière, 2011; Dechezleprêtre, Martin, & Mohnen, 2013)

Figure 1. Low-carbon environmental goods and services sales worldwide



GDP = gross domestic product, LCEGS = Low-Carbon Environmental Goods and Services.
Note: Data are from 2011–2012.
Sources: United Kingdom Department for Business, Innovation and Skills; Vivid Economics.

Figure 2. Low-carbon environmental goods and services sales in Asia



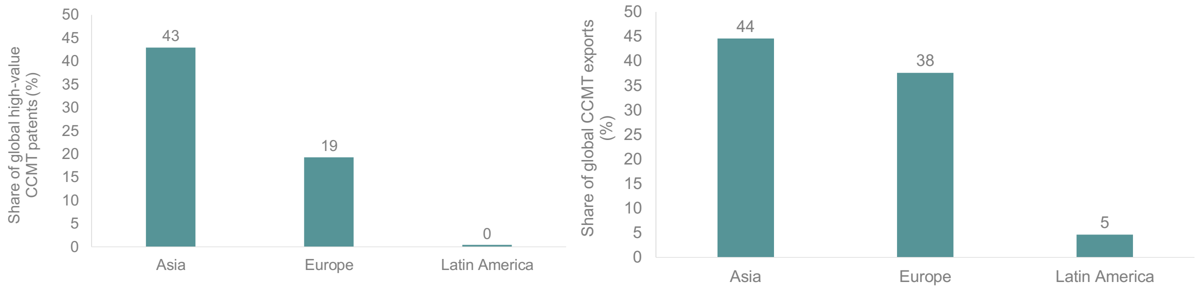
GDP = gross domestic product, LCEGS = Low-Carbon Environmental Goods and Services.
Note: Data are from 2011–2012.
Sources: United Kingdom Department for Business, Innovation and Skills; Vivid Economics.

In terms of low-carbon innovation and trade, Asia accounts for 44 percent of global CCMT exports and 43 percent of global high-value CCMT patents (figure 3). High-value patents are defined as those that have been filed in two geographies. Since it is costly to file patents, filing in a second territory may indicate that the invention has high-value and can gain return in more than one market. While this is an imperfect proxy for value, it is one that is commonly used across patent literature (Dechezleprêtre and Martin 2010).

Japan is Asia's leading innovator and accounts for nearly a quarter of global high-value CCMT patents (figure 4). China is the largest exporter accounting for 21 percent of global CCMT export (figure 4). Other Asian countries such as Indonesia, Vietnam and the Philippines have negligible levels of patenting activity in CCMTs. This is because these economies do not file many patents in general. Patent data on other economies, such as India and Bangladesh is poor but there is anecdotal evidence that suggests that these nations engage in process-related innovation which is not typically captured in patent data.

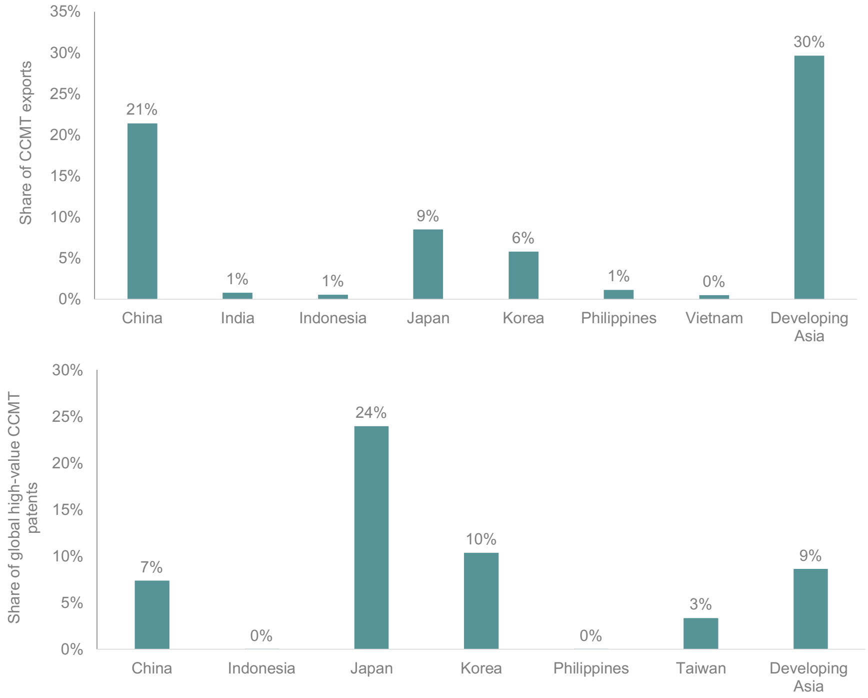
Asia's stark regional disparities are illustrated by the fact that once you exclude highly developed Asian economies (Japan, South Korea and Taiwan), 'Developing Asia' only accounts for 9 percent of global high-value CCMT patents, compared to the initial 43 percent. In terms of trade, the difference is not so stark. Developing Asia accounts for 30 percent of global CCMT exports which is significant, although it must be noted that two-thirds of this comes from China (figure 4).

Figure 3. Asia's share of Global CCMT Exports and Patents



Sources: United Nations Commodity Trade Statistics Database (UN Comtrade 2015); European Patent Office (2015), Vivid Economics. 2012 data.

Figure 4. Asian countries share of Global CCMT Exports and Patents



Sources: United Nations Commodity Trade Statistics Database (UN Comtrade 2015); European Patent Office (2015), Vivid Economics. 2012 data.

This section shows that as a whole, Asia has favourable scale in the low-carbon economy, although there are regional disparities. The continent accounts for nearly half of the world's exports and high-value patents in climate change mitigation technologies. The proportion of low-carbon environmental goods and services is also the largest in Asia relative to other continents.

According to Fankhauser et al., (2013), one of the indicators of future success in the low-carbon economy is current scale. If an economy already has sizable low-carbon sectors, it can take advantage of economies of scale, scientific clusters, demand externalities and other agglomeration benefits to further grow its low-carbon economy, all other things being equal.

3. Methodology for assessing Asia's competitiveness in the low-carbon economy

Following Fankhauser et al., (2013) for each CCMT, we calculate two indicators associated with low-carbon competitiveness: the green innovation score (GIS) and revealed comparative advantage (RCA). These metrics satisfy the conditions set out in Durand & Giorno (1987) for competitiveness indicators, that is, they cover sectors that are exposed to competition and are constructed from data that is internationally comparable.

The first indicator, the GIS, is a measure of innovation specialization. It relates to the ability to convert to low-carbon products and processes The GIS employs patent data to indicate whether a country specializes in innovating a low-carbon technology. The GIS is the technology's share of patents in the region normalised by its share of patents in the world. It is calculated as follows:

$$GIS_{is} = \frac{p_{is}^{g}/p_{is}}{\sum_{i} p_{is}^{g}/p_{is}},$$

where p_{is}^{g} is the number of low-carbon patents and p_{is} is the total number of patents in sector s and country *i*. Normalising against broader patenting activity corrects for idiosyncrasies in patenting behaviour in particular sectors or countries (Fankhauser et al., 2013)

Different values of the GIS can be interpreted in the following manner, for a given technology:

- GIS = 1 implies that the country has no particular advantage or disadvantage over the rest of the world with regards to innovation. The country's level of patenting in the technology is equal to the global average.
- GIS > 1 implies that the country specializes in innovating in the technology. The country's level of patenting in the technology exceeds the global average. This corresponds to better long-term prospects of capturing value from design.
- GIS < 1 implies that the country is less well-placed than the global average in innovating in the technology.

In constructing the GIS, only high-value patents are considered. Patents offer an indication of the value that accrues from design. However, patent data may fail to capture incremental or process-oriented innovation. Notwithstanding this drawback, patents do provide a good, internationally-comparable indication of innovative capacity.

The second indicator measures comparative advantage, using a standard Balassa score of revealed comparative advantage. The Balassa score employs trade data to assess whether economies have an export specialization in low-carbon technologies (Balassa, 1965). On the assumption that comparative advantages develop slowly, sectors with a competitive edge today are likely to be internationally competitive in the future and able to capture global market share (Hidalgo, Klinger, Barabasi, & Hausmann, 2007; Ricardo & Hidalgo, 2010). The RCA is calculated as follows:

$$RCA_{is} = \frac{e_{is}/\sum_{s} e_{is}}{\sum_{i} e_{is}/\sum_{s}\sum_{i} e_{is}}$$

where e_{is} is the level of exports from sector *s* in country *i*. It is the technology's share of exports in the region normalised by its share of exports in the world.

The RCA has an analogous interpretation to the GIS, i.e. for a given technology:

- RCA = 1 implies that the country has no particular export advantage or disadvantage over the rest of the world.
- RCA > 1 implies that the country specializes in exporting that technology. This is likely to correspond to better long-term prospects of capturing global market share and value from trade.
- RCA < 1 implies that a country is at an export disadvantage as the share of exports in the country is below the global average.

The advantage of looking at RCA is that it adjusts for size of the economy to pin down comparative advantage. We can infer that a higher RCA is likely to correspond to lower opportunity costs of production, but this is not a given since government intervention and other factors can also lead to a higher RCA and opportunity costs are not observed directly.

Placing the GIS and RCA on the y and x axes of a plane, respectively, provides the basis for a SWOT (strengths, weaknesses, opportunities, and threats) analysis:

- The top right quadrant corresponds to strengths: it means the country is a specialist innovator and exporter in the CCMT and is likely to be well-placed to capture global market share in the low-carbon economy.
- The bottom left quadrant corresponds to weaknesses: it means the country is neither a specialist innovator nor specialist exporter in the CCMT and is poorly-placed to capture global market share.
- The top left quadrant corresponds to opportunities: it means the country is a specialist innovator in the CCMT but does not have an export specialization. This is an opportunity because the country can exploit its position as a strong innovator to build its export industry.
- The bottom right quadrant corresponds to threats: it means the country is a specialist exporter in the CCMT but does not have enough innovation. This is a threat because it is possible that once the technology paradigm changes, that country's export market becomes outdated and it loses market share.

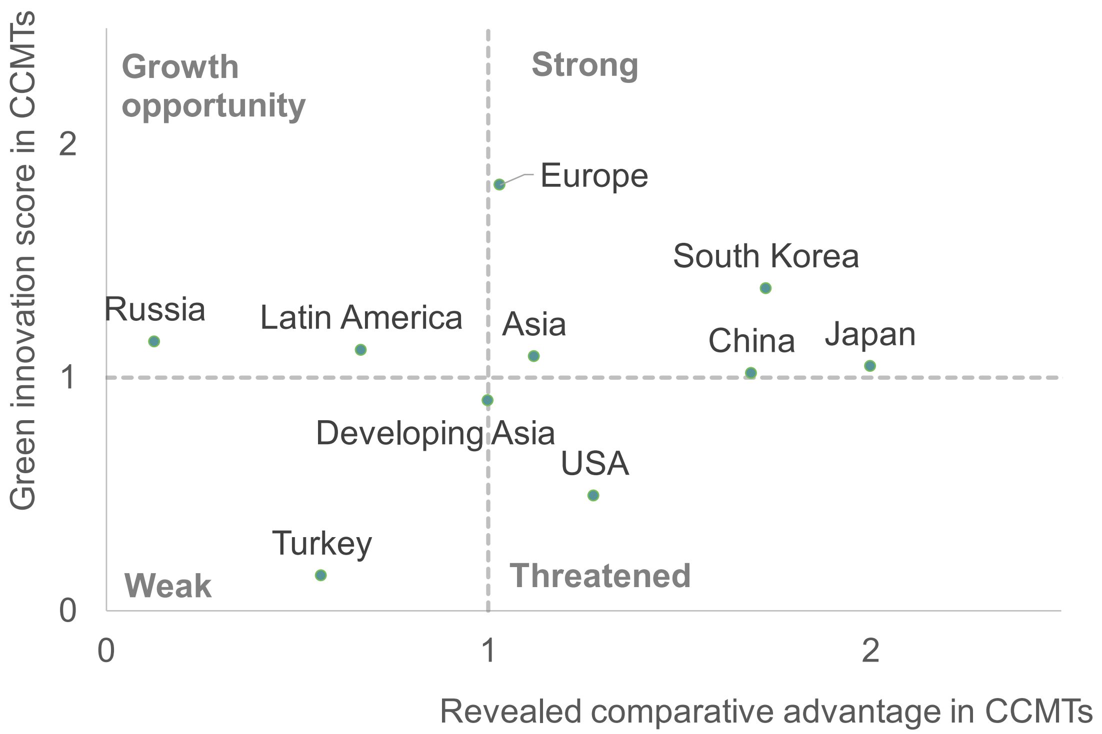
It is important to note that although innovation and export activity in CCMTs are important metrics, they are only two dimensions of a multidimensional set of low-carbon competitiveness indicators. Some important dimensions that are missing from this analysis are technology adoption (as opposed to innovation) and the scale of domestic production. It may be possible that a country does not innovate in a technology but still becomes a leading manufacturer in it. Often this is because of other factors such as proximity to a large consumer base and cost competitiveness in manufacturing, which is not always captured in export data if the country caters mainly to domestic consumers. The implication of this is that there can be cases, where our analysis does not reflect competitiveness in a particular technology where one exists. A case in point is China, which often does not innovate in a technology but is an early adopter, that leverages its comparative advantage in manufacturing to decrease costs and become globally competitive.

4. Results: Asia's competitiveness in the low-carbon economy

This section presents the results of the competitiveness analysis for Asia as a whole and then focuses on the continent's strongest sub-region: East Asia.

The analysis shows that overall, Asia is a specialist innovator and exporter in CCMTs. Asia's position in the upper right quadrant of figure 5 suggests that it is a competitive low-carbon economy. Combined with the fact that Asia already has scale in the production of LCEGS, the continent is well-placed to capture global market share, and value from the design and export of CCMTs. Within Asia, South Korea, Japan and China have particularly strong positions as specialist innovators and exporters in the low-carbon economy, as indicated by their high GIS and RCA values in CCMTs. When we exclude South Korea and Japan from the sample, and consider 'Developing Asia', we see an GIS score of 0.9 and a RCA score of 1.0 in CCMTs, indicating that the region is at the cusp of being competitive and has room for development in building an innovation specialization and comparative advantage in CCMTs.

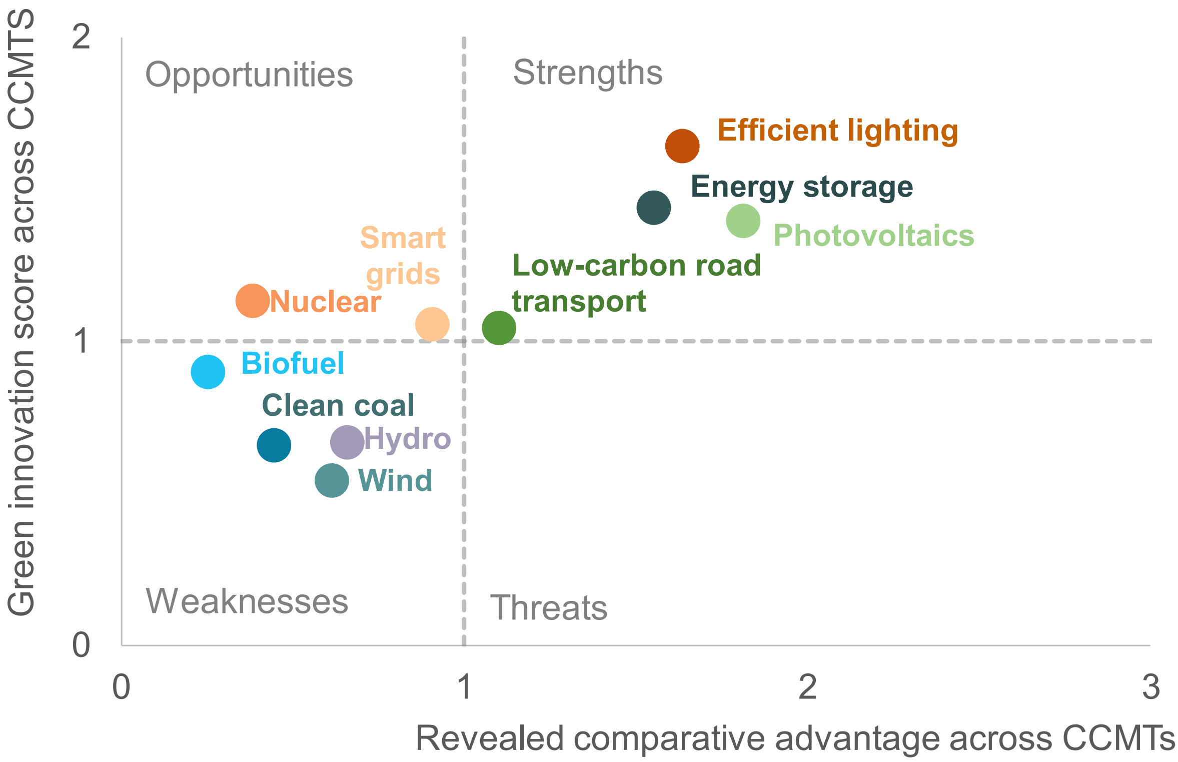
Figure 5. **Innovation Specialization and Revealed Comparative Advantage in CCMTs**



Sources:United Nations Commodity Trade Statistics Database (UN Comtrade 2015); European Patent Office (2015); Vivid Economics. 2012 data.

Across CCMTs, Asia's strengths include efficient lighting, energy storage, low-carbon road transport and photovoltaics (figure 6). In these technologies, Asia's share of patenting and exporting activity exceeds the global average. Technologies in which Asia is at the cusp of becoming competitive include nuclear and smart grids. However, it is worth noting that the low RCA score for nuclear could be due to regulation rather than a lack of comparative advantage. Weaknesses, where Asia has neither an export nor innovation specialisation, include biofuels, clean coal, hydro and wind energy.

Figure 6. **Asia's performance across CCMTs**

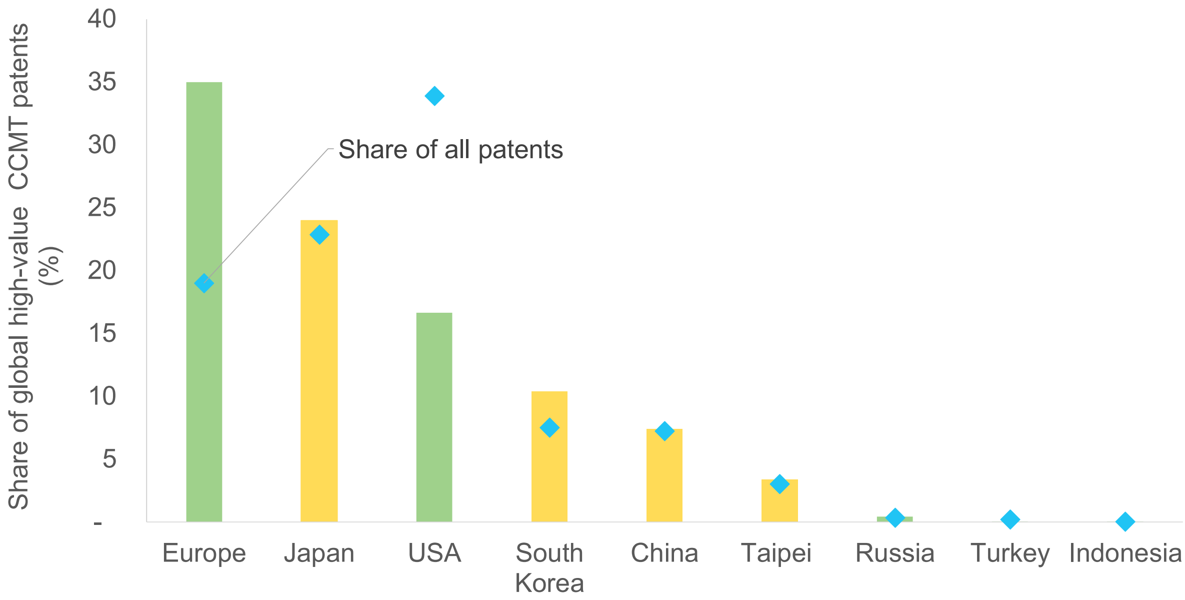


Note: 2012 data for green innovation score and revealed comparative advantage.
Sources: International Energy Agency; United Nations Commodity Trade Statistics Database (UN Comtrade 2015); European Patent Office (2015); Vivid Economics.

4.1. The low-carbon economy in East Asia

East Asia has promising prospects in the low-carbon economy. Japan accounts for a quarter of global high-value CCMT patents while South Korea, China and Taipei collectively account for one-fifth (figure 7). In all of these regions, the level of innovation in CCMTs either equals or exceeds that of general innovation, illustrating the shift towards low-carbon development. In South Korea, the share of low-carbon patents is higher than general patents which may be explained by the fact that it was one of the first economies in Asia to announce a 'green growth' strategy.

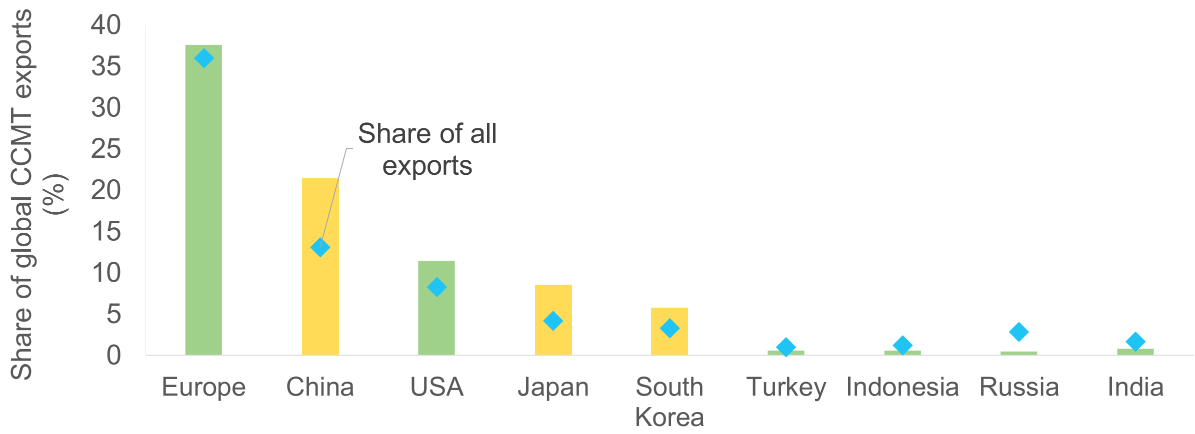
Figure 7. **Low-carbon Patenting Activity in East Asia**



Note: 2012 data for green innovation score and revealed comparative advantage. East Asian countries highlighted in yellow. Sources: International Energy Agency; United Nations Commodity Trade Statistics Database (UN Comtrade 2015); European Patent Office (2015).

East Asia seems well placed as an exporter of low-carbon technology (figure 8). China accounts for one-fifth of global CCMT patents while South Korea and Japan together account for 15 percent. The share of CCMT exports exceeds the share of general exports for all three East Asian economies.

Figure 8. **Low-carbon Exporting Activity in East Asia**



Note: 2012 data for green innovation score and revealed comparative advantage.
Sources: International Energy Agency; United Nations Commodity Trade Statistics Database (UN Comtrade 2015); European Patent Office (2015).

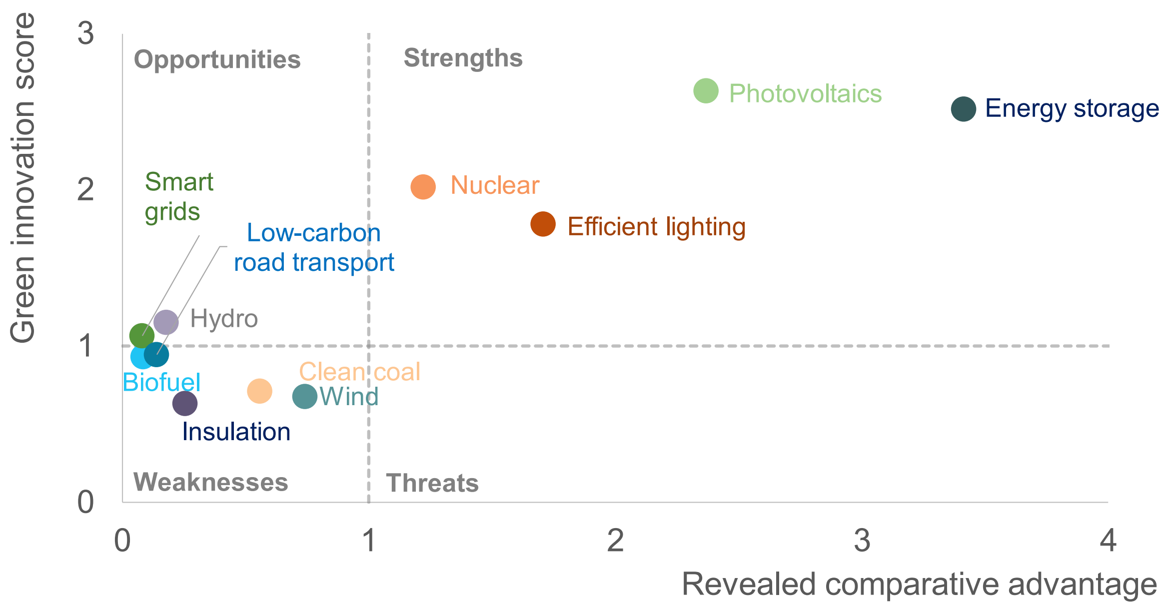
China, Japan, and South Korea are key exporters and innovators in CCMTs as shown in figure 5. All three economies fall into the 'strengths' quadrant. This is a strong indicator of East Asia's potential, as more innovative and export-focused economies are better placed to capture value from the global low-carbon transition. The subsequent sections will look at individual country profiles to identify strengths and weaknesses at a more granular level.

4.1.1 The Republic of Korea's Low-Carbon Economy

South Korea was one of the first countries in Asia to announce a green growth plan. The country's natural asset base was under consistent strain with depleting water resources and forest cover. However, the Government of Korea committed to address this threat through its National Strategy for Green Growth (2009–2050) wherein it stated that green growth is a strategic priority (Ministry of Government Legislation 2010). Consequently, research and development expenditure related to green growth and share of green overseas development assistance grew rapidly. According to the OECD and Statistics Korea, South Korea's economy is becoming greener (Statistics Korea, 2012). Indicators show that environmental and resource productivity, including CO_2 emissions productivity, energy productivity, and domestic material consumption, have improved since 2000.

South Korea has a strong RCA and GIS in several technologies, demonstrating that the country may have directed its efforts strategically. Our analysis shows that it is well-placed to take advantage of the low-carbon transition across nuclear, photovoltaics, efficient lighting, and energy storage technologies (figure 9). South Korea is particularly competitive in energy storage and is poised to have one of the world's largest energy storage systems. Compared to other countries, the data suggests that South Korea innovates in areas where it has an existing export advantage (or vice versa), thus playing to its strengths.

Figure 9. **The Republic of Korea's Performance across CCMTs**



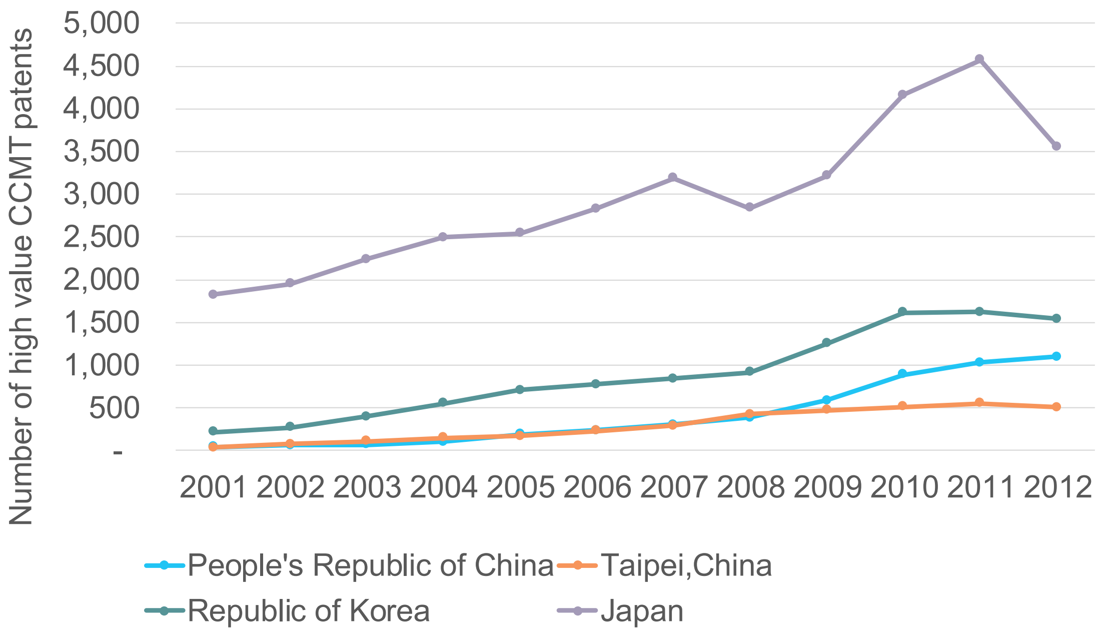
Notes: 2012 data. Sources: United Nations Commodity Trade Statistics Database (UN Comtrade 2015); European Patent Office (2015).

4.1.2. Japan's Low-Carbon Economy

Japan's 2009 growth strategy placed a strong emphasis on innovation and low-carbon growth. Key priorities were renewable energy, low-carbon innovation, and zero emission residential and commercial buildings (Capozza, 2011). Japan's overarching green economy objective for 2020 is to generate market value of over half a trillion USD and 1.4 million jobs in environment-related sectors. It also aims to reduce global GHG emissions by promoting Japanese technology worldwide.

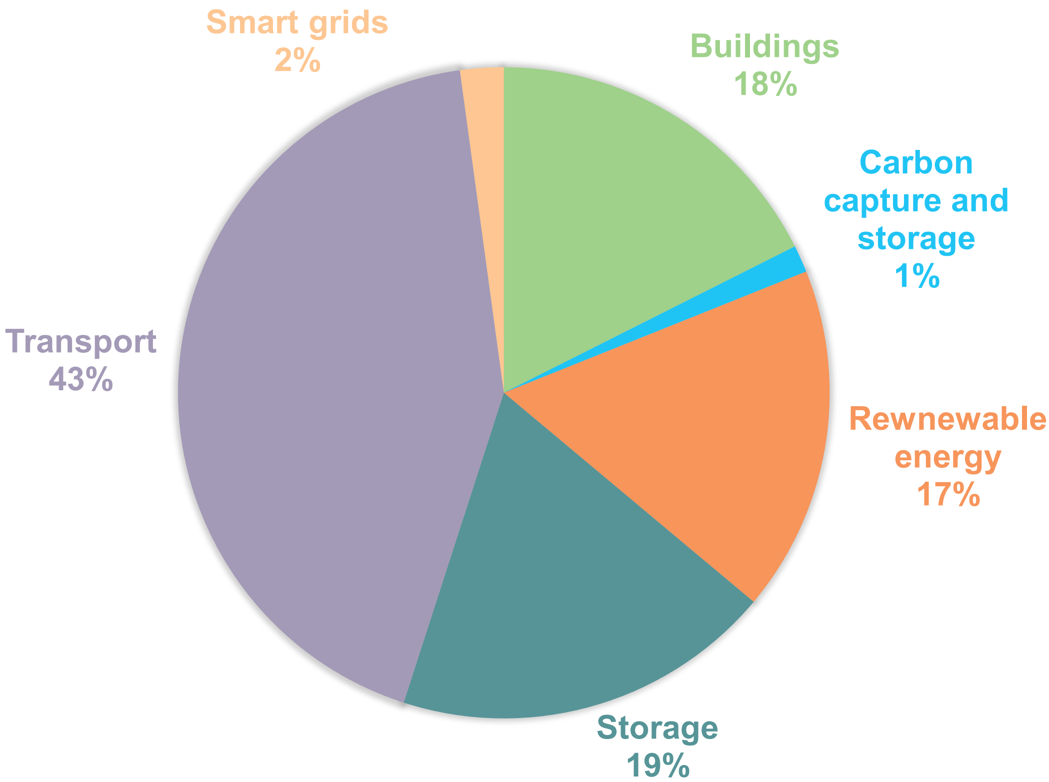
Japan files the largest number of high-value CCMT patents in Asia and is one of the top 3 low-carbon innovators in the world. It has particularly high levels of innovation in low-carbon transport (see figures 10 and 11). This is unsurprising given that Japan is already a leading car manufacturer alongside the United States and Western Europe. In addition to low-carbon transport, there are high levels of patenting activity in energy storage and efficient buildings.

Figure 10. **Top Innovators in CCMTs**



Sources: European Patent Office (2015).

Figure 11. **Japanese Climate Change Mitigation Patents**



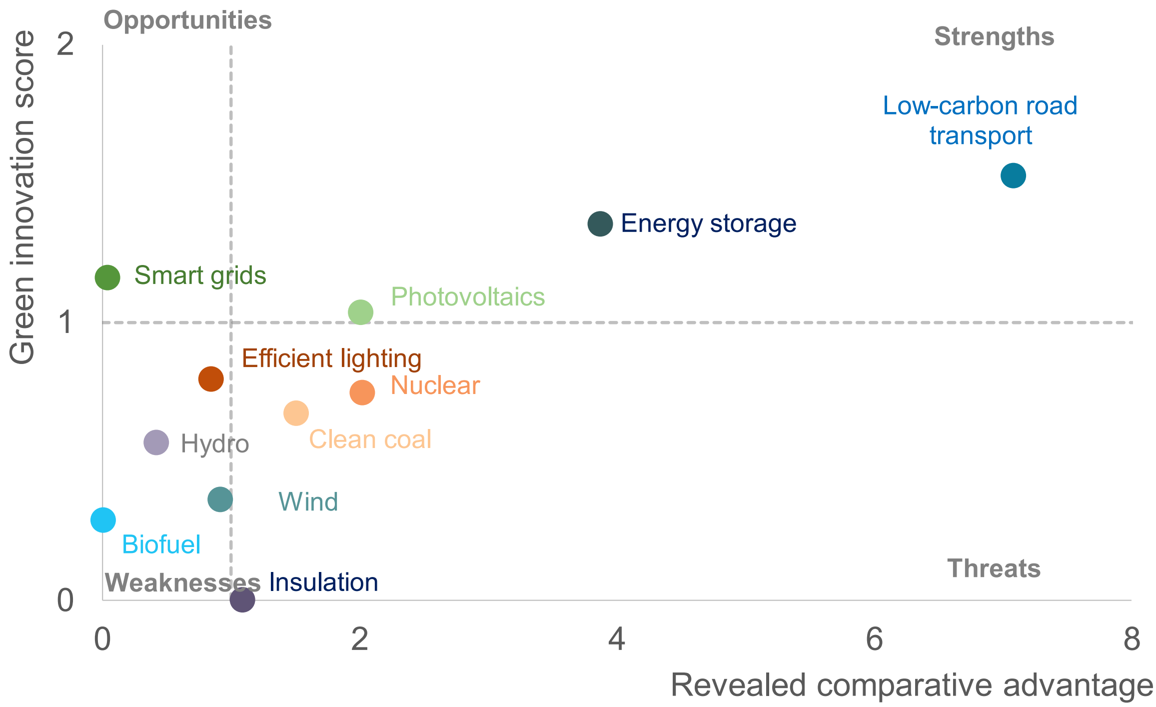
Note: 2012 data.

Sources: European Patent Office (2015).

Based on an assessment of Japan's GIS and RCA across CCMTs, the country is well-positioned to capture value from the design and export of low-carbon transport, energy storage and photovoltaics (figure 12). Japan's share of low-carbon road transport exports is seven times higher than the world average share, indicating a strong and highly entrenched comparative advantage. Japan also has the opportunity to develop its smart grid sector by focusing on capturing global market share through exports and building manufacturing capacity. However, it faces competition from South Korea. Both South Korea and Japan have strong innovation for smart grids, but are yet to develop their export markets, suggesting that they may be future competitors in this technology.

Similarly, Japan's nuclear technology is at risk of being overtaken by China's due to Japan's relatively low levels of innovation and the effects of the Fukushima incident on public opinion for nuclear. Overall, while Japan is in a strong position for low-carbon growth and has consolidated its position in low-carbon road transport and energy storage, it must ensure that aging industries are well-prepared for competition from emerging economies.

Figure 12. **Japan's Performance across CCMTs**



Notes: 2012 data. Sources: United Nations Commodity Trade Statistics Database (UN Comtrade 2015); European Patent Office (2015).

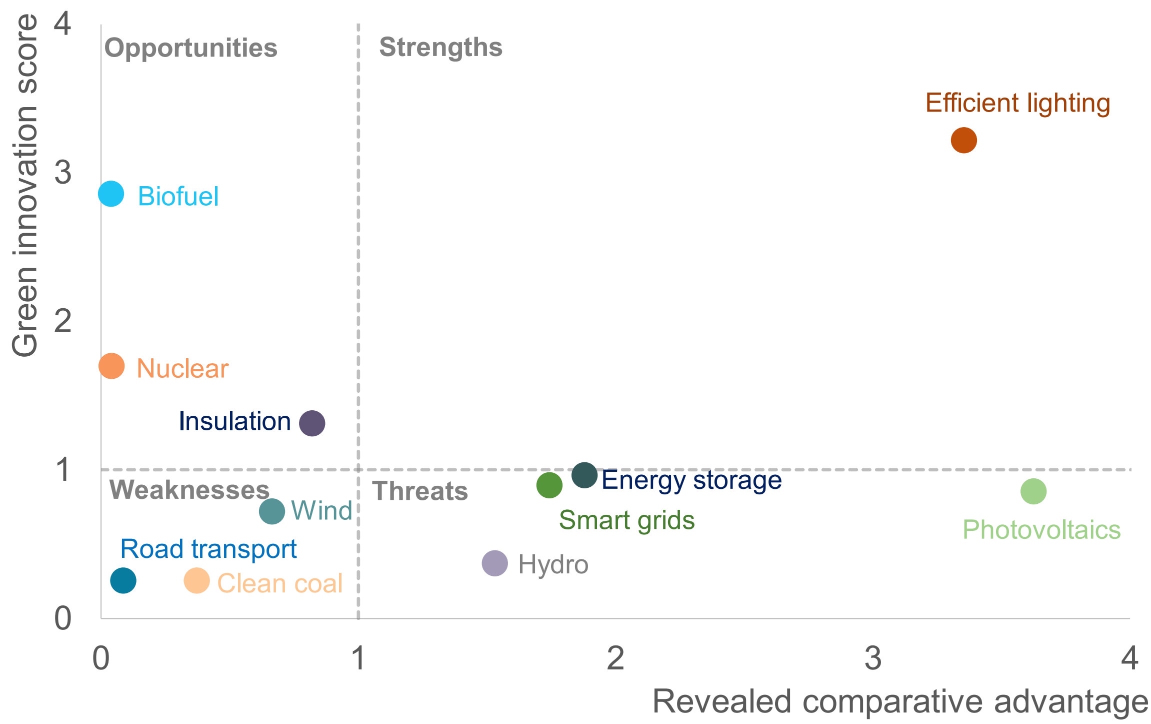
4.1.3. China's Low-Carbon Economy

Economic growth has severely compromised the quality of the environment in China. In 2014, the Ministry of Environmental Protection announced that 44 percent of China's groundwater was deemed to be of poor quality, 20 percent of farmland was contaminated, and that only three out of 74 monitored cities met official air quality standards in 2013. Underpinning these trends is the fact in 2006 China became the world's largest CO_2 emitter (Ho & Wang, 2014).

The government has made substantial efforts to control pollution. China's success is particularly visible in renewables. It has achieved the world's largest wind power capacity, has plans to triple solar power, and multiply nuclear capacity six-fold by 2020 (Ho & Wang, 2014). Officials have committed to ensuring renewables account for 20 percent of the energy mix by 2030 and aim to reduce carbon intensity by 17 percent (Albert and Xu 2016).

Analysis of the China's GIS and RCA scores (figure 13) suggests that it is an exporter more than a specialist innovator in CCMTs. Unlike developed Asian countries such as Japan and South Korea, China is not yet a frontier innovator in CCMTs. China is an early adopter of CCMTs and engages in relatively high-levels of manufacturing and export.

Figure 13. **China's Performance across CCMTs**



Notes: 2012 data.
Sources: UN Comtrade (2015)*; European Patent Office (2015).*

The competitiveness analysis shows that China has a particularly strong position in efficient lighting where it has both an innovation and export specialization (figure 13). Opportunities for China include insulation, biofuels and nuclear. Nuclear power is an opportunity where China can potentially overtake Japan. China has high levels of innovation in nuclear technology but still needs to consolidate its export position. Nuclear is one of the most difficult technologies in which to compete given its complexity and high up-front costs. Given the China's size, government support, and access to capital, it could be well-placed to lead in this CCMT.

China's share of photovoltaic exports is three and a half times higher than the world average, indicating a strong and highly entrenched comparative advantage. Its share of smart grid and energy storage exports is also almost double that of the global average. However, in all of these technologies, despite being a specialist exporter, it is not a specialist innovator. For certain technologies, this is a risk because once the technology paradigm changes, China's market will become outdated and it will lose export share. However, the magnitude of this risk is uncertain because China may have the ability to quickly adapt to the technology paradigm thereby making its market relatively resilient.

Overall, the GIS and RCA statistics suggest that innovative capacity will not be the immediate driver of success in China's low-carbon economy, and could be an area to build on. China's success in the low-carbon economy may be more due to its comparative advantage in exports and the benefits of returns to scale rather than innovation in the short to medium-term. On some technologies, such as wind, our data may not give a clear picture of true success as it does not account for domestic scale.

In China's case, it is especially important to note that the GIS and RCA are only two dimensions of competitiveness in the low-carbon economy. Domestic scale is an important third dimension which is not represented in this SWOT analysis. There are agglomeration benefits associated with domestic scale that are likely to be significant for China.

5. Conclusion

The world is undergoing a low-carbon transition. Countries have committed to the terms of the Paris Agreement, which has sent signals to the markets to transition to low-carbon products. The effects of pollution and threats of climate change have galvanised consumers to increasingly demand environmentally-friendly alternatives such as electric vehicles, efficient lighting and cleaner forms of energy. Foreseeing this change, Asian countries have played a critical role in the low-carbon economy. Many have tried to strategically place themselves as leaders by being early adopters of a low-carbon growth strategy. Examples include South Korea which was amongst the first countries to adopt a Green Growth Strategy in 2009. For Asia, climate policy has also been industrial policy, as evidenced by China's five year plans which identify specific low-carbon sectors for increased investment (Stern 2010)

This paper explores the extent to which to which Asia has been successful in its efforts to build low-carbon competitiveness. It shows that Asia is a specialist innovator and exporter in climate change mitigation technologies. Its top low-carbon economies are Japan, South Korea and China who are also all individually, specialist innovators and exporters in low-carbon goods. Asia's most competitive climate change mitigation technologies are efficient lighting, energy storage, photovoltaics and low-carbon road transport. The implications of these results are that Asia is well-placed to capture global value from the design and export of low-carbon goods.

It is also worth mentioning that there are stark regional disparities within Asia. Once South Korea and Japan are removed from the sample, 'Developing Asia' is no longer a specialist innovator or exporter in climate change mitigation technologies. Developing Asia's level of export and patenting activity in low-carbon technologies is roughly equal to the world average, which puts it neither in a position of weakness nor strength according to our framework. However, it can easily use this neutral position to build specialisation by implementing policies to further incentivise a switch to low-carbon technologies.

However, it is important to emphasize the limitations of the analysis. Developing Asian countries may excel in competitiveness metrics that are not reflected in this analysis. For example, India performs well at process-innovation which is not captured by patent data and China has large domestic scale and the ability to quickly adopt new technologies, which can increase its level of competitiveness in the global low-carbon economy. Our analysis focuses on frontier innovation and export specialization, which are just two dimensions of low-carbon competitiveness. Nevertheless, they are important dimensions in light of the value that accrues from IP rights and export activity. They also meet the conditions of competitiveness metrics by being based on internationally-comparable data and covering sectors that are traded/tradeable (Durand & Giorno, 1987).

More research is needed to deepen our understanding and corroborate the initial findings of this paper. Future research can focus on developing a method that not only captures frontier innovation through patent data, as done in this paper, but also process-related innovation. Researchers can also focus on other indicators of low-carbon competitiveness such as investment and the rate of adoption of new technologies. Another avenue for future work is to explore in-depth the implications of this study's high-level results through case-studies and study the role of policy in deepening a region's export or innovation specialisation.

References

ADB. (2015). *Managing the Transition to a Low-Carbon Economy: Perspectives, Policies and Practices from Asia*.

Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268–281.

Balassa, B. (1965). Trade liberalisation and revealed comparative advantage. *The Manchester School of Economics and Social Studies.*, *33*, 99–123.

Capozza, I. (2011). Greening Growth in Japan. *OECD Environment Working Papers*, (28), 0–41. https://doi.org/10.1787/5kggc0rpw55l-en

Dechezleprêtre, A., & Calel, R. (2012). Environmental policy and directed technological change: evidence from the European carbon market. *Centre for Economic Performance, Working Paper LSE*, *dp1141*.

Dechezleprêtre, A., Glachant, M., & Ménière, Y. (2011). What Drives the International Transfer of Climate Change Mitigation Technologies ? Empirical Evidence from Patent Data What Drives the International Transfer of Climate Change Mitigation Technologies ? Empirical Evidence from Patent Data Abstract. *Grantham Research Centre on Climate Change and the Environment and Centre for Climate Change Economics and Policy*, (16), 1–30.

Dechezleprêtre, A., & Martin, R. (2010). Low carbon innovation in the UK: evidence from patent data. *Centre for Climate Change Economics and Policy Grantham Research Institute on Climate Change and Environment Policy Paper*, (April).

Dechezleprêtre, A., Martin, R., & Mohnen, M. (2013). Knowledge spillovers from clean and dirty technologies: a patent citation analysis.

Durand, M., & Giorno, C. (1987). Indicators of international competitiveness: conceptual aspects and evaluation. *OECD Economics Studies*, (9), 147–182.

Eleanor Albert and Beina Xu, C. on F. R. (2016). China's Environmental Crisis. Council on Foreign Relations. Retrieved from http://www.cfr.org/china/chinas-environmental-crisis/p12608

EPO. (2015). Patstat Database. European Patent Office.

Fankhauser, S., Bowen, A., Calel, R., Dechezleprêtre, A., Grover, D., Rydge, J., & Sato, M. (2013). Who will win the green race? In search of environmental competitiveness and innovation. *Global Environmental Change*, *23*, 902–913.

Hidalgo, C. A., Klinger, B., Barabasi, A.-L., & Hausmann, R. (2007). The Product Space Conditions the Development of Nations. *Science*, *317*(5837), 482–487. https://doi.org/10.1126/science.1144581

Ho, M. S., & Wang, Z. (2014). Green Growth for China: A Literature Review. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2537838

HSBC. (2009). A climate for recovery. *HSBC Global Research*.

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate Change 2014: Impacts, Adaptation and Vulnerability (Fifth Assessment Report of Working Group II of the Intergovernmental Panel on Climate Change)*. Geneva, Switzerland.

Mimura, N. (2008). *Asia-Pacific Coasts and Their Management*.

OECD. (1998). The Global Environmental Goods and Services Industry.

Ricardo, H., & Hidalgo, C. (2010). The building blocks of eocnomic complexity. *Proceedings of the National Academy of Sciences*, *106*(26), 10570–10575.

Statistics Korea. (2012). Korea's Green Growth: Based on OECD Green Growth Indicators, 56. Retrieved from http://www.oecd.org/greengrowth/Korea's GG report with OECD indicators.pdf

Stern, N. (2010). China's Growth, China's Cities and the New Global Low-Carbon Industrial Revolution. *Policy Brief, Grantham Research Institute, London School of Economics.*

UK BIS. (2011). Low carbon and environmental goods and services database. Department for Business, Innovation & Skills.

UN Comtrade. (2015). International Trade Statistics Database.

WHO. (2016). Global Urban Ambient Air Pollution Database. Retrieved from http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

Yoshida, F., & Mori, A. (2015). *Green Growth and Low Carbon Development in East Asia*.

Appendix

The following climate change mitigation technologies have been included in this study, listed by the EPO (2015) classification:

Y02 – Technologies or applications for mitigation or adaptation against climate change

Y02B – buildings
Y02B10 - renewables integration
Y02B20 - lighting
Y02B30 - heating/AC
Y02B40 - appliances
Y02B50 - elevators/escalators
Y02B60 - own energy
Y02B70 - end-user
Y02B80 - insulation
Y02B90 - other buildings

Y02C – CCS

Y02E - energy
Y02E10 - renewables
- Y02E101 - geothermal
- Y02E102 - hydro
- Y02E103 - sea
- Y02E104 - thermal
- Y02E105 - PV
- Y02E106 - thermal-PV
- Y02E107 - wind

Y02E20 - clean coal
Y02E30 - nuclear
Y02E40 - transmission/distribution
Y02E50 - biofuel
Y02E60_70 - storage

Y02T – transportation
Y02T10 - road transport
Y02T30 - rail transport
Y02T50 - air transport
Y02T70 - maritime transport
Y02T90 - other transport

Y04S - smart grids