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Resources-energy-development nexus and its implications for achieving the SDGs in Asia

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Abstract. Growing modern economies are built on a variety of resources, and transitioning to the type of societies that are targeted by the Sustainable Development Goals (SDGs) will require a dramatic increase of clean energy (SDG 7) and resources consumption (SDG 12). At the same time, they must be provided within the limits of local environments, with a consideration of the balance of local and global impacts and benefits. Based on mineral production and reserves data for Asian countries, and the predicted requirements of minerals for clean energy technologies for their climate mitigation policy (SDG 13), supply-demand balances are calculated under a variety of scenarios. The potential for supply restrictions of identified “critical” minerals in each economy is demonstrated. Policy issues related to transboundary governance of energy and material flows and their economic and environmental costs and benefits (across the supply chain) to achieve equitable opportunities for all, including for emerging resources such as deep ocean mining (SDG 14) are then discussed on the basis of the “nexus”. This “nexus” of resources and energy offers a different perspective on the overall implications for development than either goal individually, and this is the first such study to target the Asian region holistically.

Introduction

Resources and energy are critical inputs to nations – particularly in the phase of development and rapid growth that many Asian countries are going through at present. Resources are needed for basic infrastructure, as well as for the many advanced goods and services that modern economies utilize. Of the various inputs, the requirement for minerals and clean energy are two aspects that are vitally important for the future. Minerals are important for fundamental infrastructure, but metals particularly are becoming much more important for clean energy technologies, including renewable energy and alternative energy vehicles. Clean energy is another vitally important component. Energy itself is critical to all sectors of the economy and society, but establishing clean, renewable energy infrastructure is a key component of climate change mitigation and developing a stable basis for future development. The linkage between these two elements – the “nexus” – is thus an important area of research, which will be addressed in this paper.

It is, moreover, important to consider the nexus of resources and energy as a combined or overall picture of the system, rather than as two individual elements or separate systems. If the two systems are considered separately, then the solutions will omit critical connections and feedback, or will alternatively provide sub-optimal solutions. This paper therefore takes a holistic, system level perspective on these two systems, within the context of the sustainable development of Asia. While



broadly considering minerals for energy in the primary analysis at the global scale, the data is analysed at the level of a number of key countries in Asia, as well as the ASEAN region. Further work is ongoing to expand this to give greater levels of detail to the assessment.

Methodology

This study first evaluates the energy-resource nexus within the context of Asia's historical and prospective growth scenarios. Scenarios from the International Energy Agency (IEA) [1] and others will be used as a basis to evaluate requirements for energy in the future. In particular, the clean energy requirement will be focused on, with regards to the need for minerals to provide these technologies. Similar studies at a global level have been undertaken by the authors in the past [2, 3], but this will be the first known study examining Asia as a whole.

Modelling will involve top-down analysis of the economic requirements for energy and minerals, as well as a bottom-up evaluation of the material intensity of new energy technologies. Mineral reserves and production estimates will be developed on a country-by-country basis, with a focus on the availability within Asia. Together, these models will provide an indication of the potential for scarcity (economic or physical) to become a problem for achieving sustainable development within Asia.

1.1. Clean energy requirements for Asia

Each of the countries considered in the Asian region in this study has a target or Nationally Determined Contribution (NDC) under the Paris Climate Agreement. The specific targets are not quantified at this point, but instead the IEA's Energy Technology Perspectives (ETP) Beyond 2 Degrees Scenario (B2DS), which aims to effectively achieve the Paris Target of below 2°C global temperature rise by the end of the century is taken as a proxy [4]. Further examination on a country-by-country basis will be undertaken in the near future. The requirements for clean energy in Asia – notably the expected expansion of photovoltaics (PV) and wind power are modelled here. The resulting requirement across the regions and countries of: ASEAN, Brazil, China, European Union (EU), India, Mexico, Russia, South Africa, United States (USA), other OECD and other non-OECD; are shown in Figure 1.

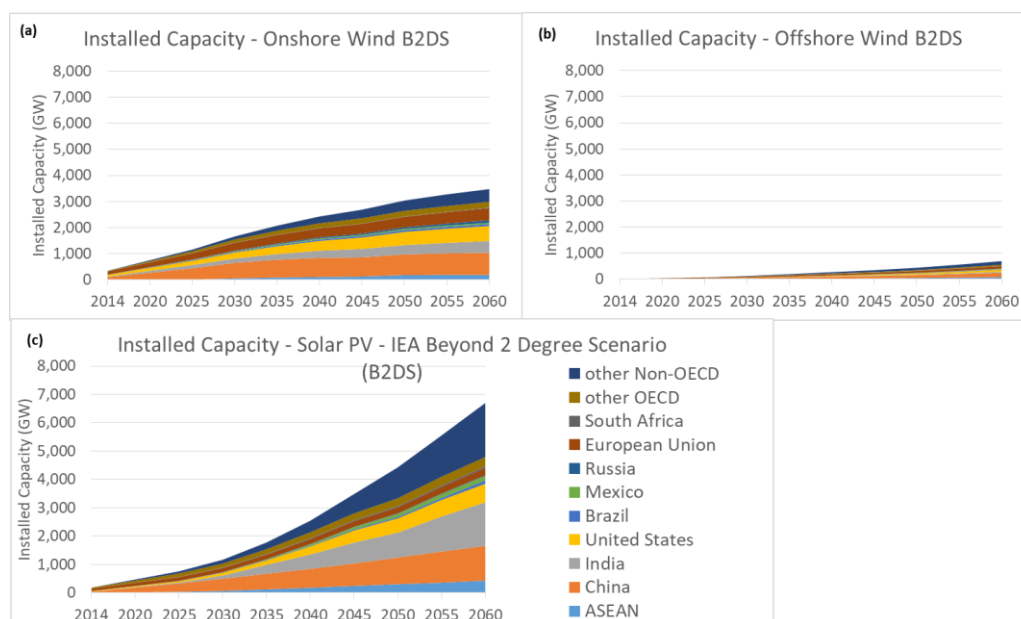


Figure 1. Modelled installed capacity under the Beyond-2 degree Scenarios of the IEA-ETP (a) Onshore Wind; (b) Offshore Wind; and, (c) PV

It is apparent that PV is expected to dominate the expansion of these three forms of renewable energy, with onshore wind power the second most prevalent. In terms of regions, India is expected to have the greatest increase in PV, followed by an already-dominant China.

Figure 2 then shows that wind and solar power are expected to produce nearly half of the electricity generated in 2060 – a dramatic increase from current levels. Even though the major Asian regions examined explicitly by the IEA – ASEAN, China and India – have a lower expected 2060 electricity generation from wind and PV (34%, 38% and 44% respectively), these are still obviously important sources of electricity. Considering the requirement for alternative energy in the transport sector, Figure 3, shows that under the B2DS there is a significant increase in electrification of transport, whereas there is no significant uptake of hydrogen in these identified areas. Figure 4 then shows that there for these regions, the expansion of renewables and other low-carbon technology is anticipated, with most non-CCS or non-renewable technologies eliminated by 2050, and a significant expansion of nuclear power in the mix.

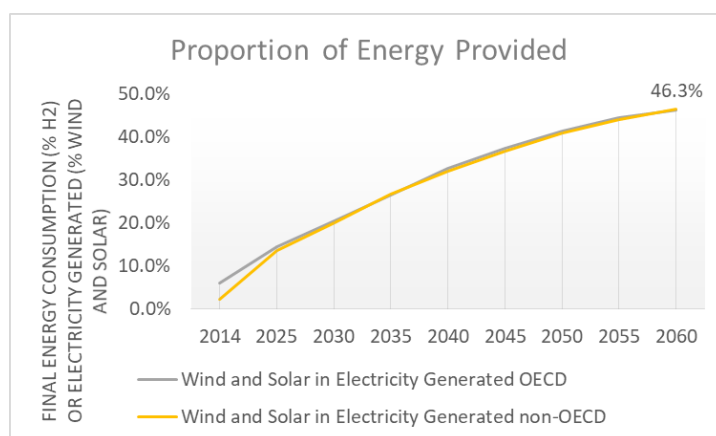


Figure 2. Wind and solar power in total generated electricity

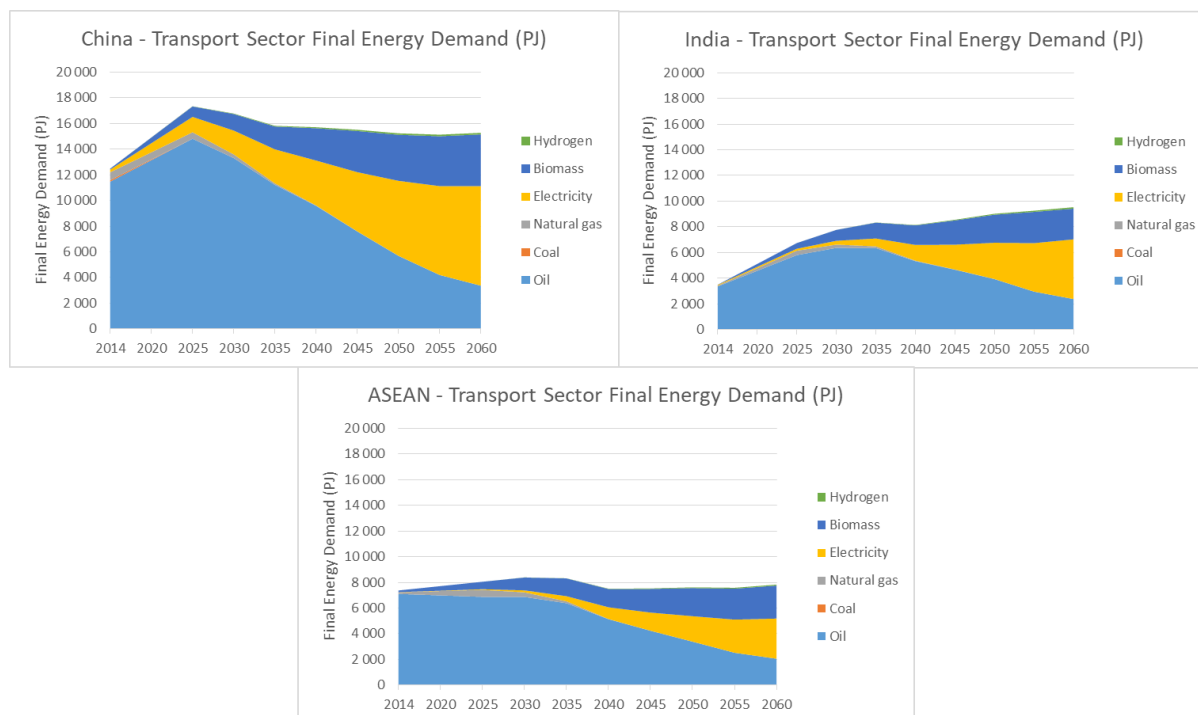


Figure 3. Transport sector final energy demand for key Asian countries and regions

Combined, these figures indicate that it is important to consider the requirement for minerals to produce these technologies – notably, it is important to evaluate the PV and wind power technologies, which have a significant requirement for critical metals.

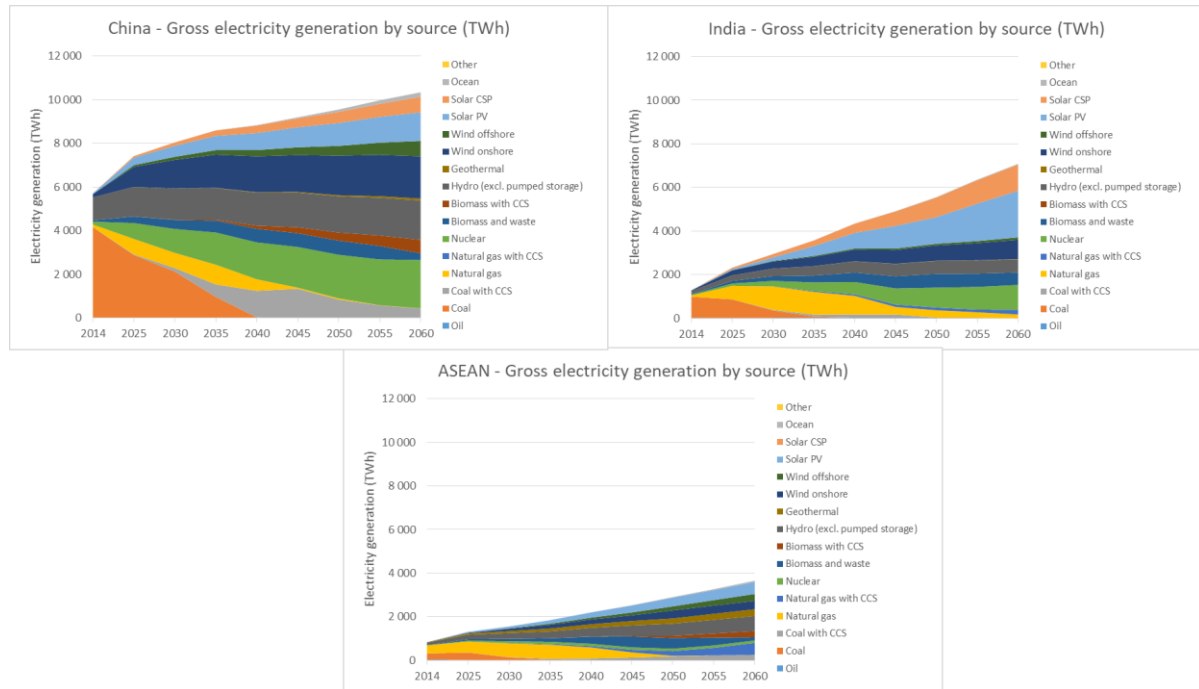


Figure 4. Gross electricity generation by source in the IEA B2DS scenario for selected Asian countries / regions

1.2. Minerals requirements for clean energy

In order for the clean energy requirements to be met, the technologies required must be manufactured. Importantly, each of these technologies requires minerals for functionality, some of which are considered to be “critical” – that is, to be essential for the purpose without appropriate substitutes and with the potential for supply risks to occur. For example, neodymium and dysprosium are used in magnets for the generators in wind turbines [5] or motors in electric vehicles, while photovoltaic panels (PV) may use silver, cadmium, tellurium and gallium, among others [6]. Estimates of the material intensity of these critical functional minerals are utilised to examine the demand requirements and the potential for national level risks of supply disruption.

Often there are alternative technologies utilised for the same technology group – for example, PV could be silicon-based or thin-film types, while there are alternatives for wind turbines that do not use rare earth magnets [7]. There are variations in the material intensity within the same technology sub-group, but more extensively between the sub-groups of technologies. The scenarios used here, assume a steady mix of alternative sub-technologies within each broad renewable energy category, as well as a 1% (year-on-year) improvement in material intensity for each energy technology application, reflecting the fact that some technologies are still in their infancy, while advances in production methods and components seek to reduce the amount of expensive minerals used. The mix of noted technologies is shown in Table 1, with the overall percentage of new installed capacity for thin-film type solar cells (CIGS/CdTe) and permanent magnet wind power generators (PMG). The proportion of CIGS and CdTe cells is assumed to be equal, with the remainder of solar installations being conventional silicon-based cells. Table 2 shows the assumed initial material intensities, as well as the final material intensities after a progressive improvement as described below. By multiplying these

material intensities by the projected required installed capacity, the total requirement for each mineral can be calculated on an annual and cumulative basis.

Table 1. Proportion of key technology sub-groups in new installed capacity

Technology	Sub-Type	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
PV	CIGS	1%	4.5%	7.5%	10.5%	12.5%	14%	14.5%	15%	15%	15%
	CdTe	1%	4.5%	7.5%	10.5%	12.5%	14%	14.5%	15%	15%	15%
	Silicon-based	98%	91%	85%	79%	75%	72%	71%	70%	70%	70%
Wind	PMG	10%	15%	18%	20%	23%	25%	28%	30%	30%	30%
	Non-PMG	90%	85%	82%	80%	77%	75%	72%	70%	70%	70%
Fuel Cells	PEMFC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
	SOFC	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%

Table 2: Material intensities of technology sub-types at beginning and end of period

Technology	Mineral	Technology Sub-type	Material Intensity (t / GW)	
			2014	2060
PV	Indium	CIGS	23	14.5
			7.5	4.7
			45	28.3
	Tellurium	CdTe	97.5	61.4
			85	53.5
	Silver	All	80	50.4
	Copper	All	4,000	2,519
Wind	Dysprosium	PMG	198	124.7
	Neodymium		27.7	17.5
	Copper	Onshore	3,000	1,889
		Offshore	6,000	3,778

1.3. Minerals supply

On the supply side, minerals can be provided primarily via three routes: imports, primary domestic production and secondary production (recycling). The primary production at the mining stage is limited to the geological occurrence and discovery of ores that can be technically and economically mined within acceptable impacts to environment and society. This is therefore a source of significant variability between nations. In the current study, the most recent reported reserves of minerals, along with historical production data, are used to produce potential scenarios for future mineral supply. The primary production is estimated using a Hubbert peak method, whereby historical production and reserves are used to fit a peak-curve. This is undertaken on a country-by-country basis, with the overall results used in the case of ASEAN. Alternative methods can be used to try to estimate how

production will grow in the future – for example previous work has taken the approach of using a constant production or considering either linear or exponential trend growth [8]. In this paper, the cumulative material requirement is compared to the Hubbert peak curve, while annual consumption is compared to the constant production from 2016, in order to give potentially useful comparisons, as described in the results. The use of reserves (as opposed to resources in the nomenclature of economic geology) is sometimes considered controversial, as it only considers the minerals that are well-known and known to be economically extractable. However, it is argued here that the use of reserves gives perhaps a lower bound on availability rather than an upper bound.

1.4. Minerals supply-demand balance

The requirement for minerals to fulfil the needs of clean energy, and the available domestic supply from primary sources are used to find an initial supply-demand balance. This balance is calculated annually and as a cumulative figure over the period of the projections. This balance gives an initial idea of the domestic capability of fulfilling clean energy technology needs and an indicator of potential supply risk. The two alternative supply streams of recycling and imports are not considered in this paper, but will be added to the model in future.

1.5. Induced atmospheric emissions change

The expansion of mining to fulfil the required minerals needs of the global clean energy transition will lead to a subsequent growth in the emissions from mining. For selected minerals, the estimated increase in emissions is calculated based on an evaluation of the Australian minerals industry emissions reported in the National Pollutant Inventory (NPI) [9]. This is presented across a wide range of emitted substances, and in the current paper does not take into account the variation in production techniques or ore characteristics across the global industry. It also does not include the processing, smelting and refining of these minerals through to usable metals – although this work needs to be undertaken for better understanding of the lifecycle impacts.

2. Results

The mineral requirements for the selected countries / regions of Asia to provide the projected installed capacity of PV and wind power are shown in Figure 5 and Figure 6 respectively, with comparison to the global production in 2016. It is readily apparent that for PV, the requirement to expand thin-film PV panels is likely to lead to increased demand significantly beyond the 2016 production levels except for cadmium. For CIGS technology, the projected deficits would occur between 2025 and 2030, whereas for CdTe the deficit in tellurium may come sooner. Silver is required for all PV types, and may face supply problems around 2025.

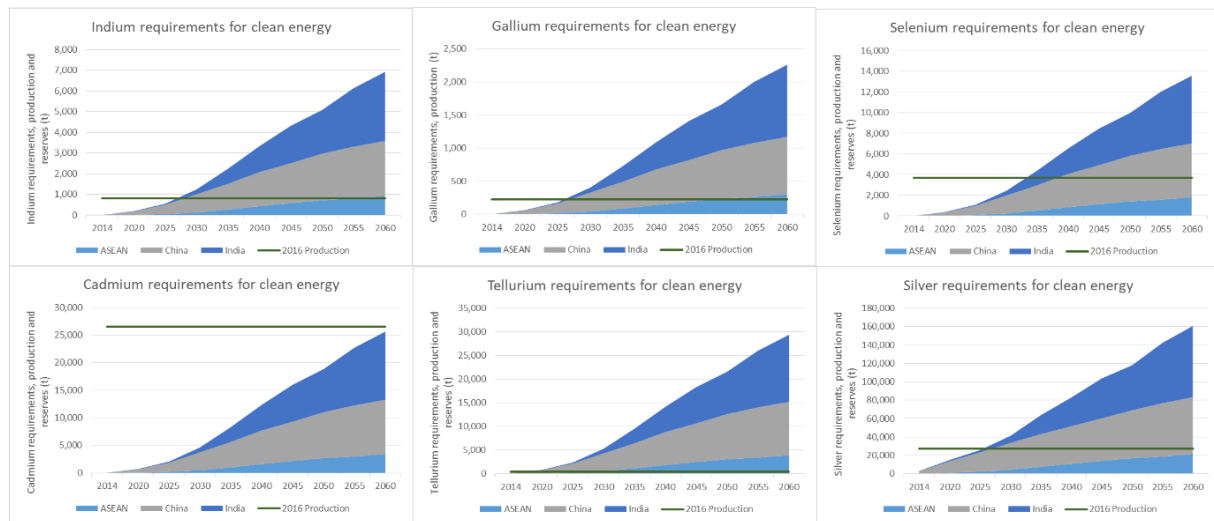


Figure 5. Annual requirements for minerals for PV in selected Asian countries / regions compared to global 2016 production

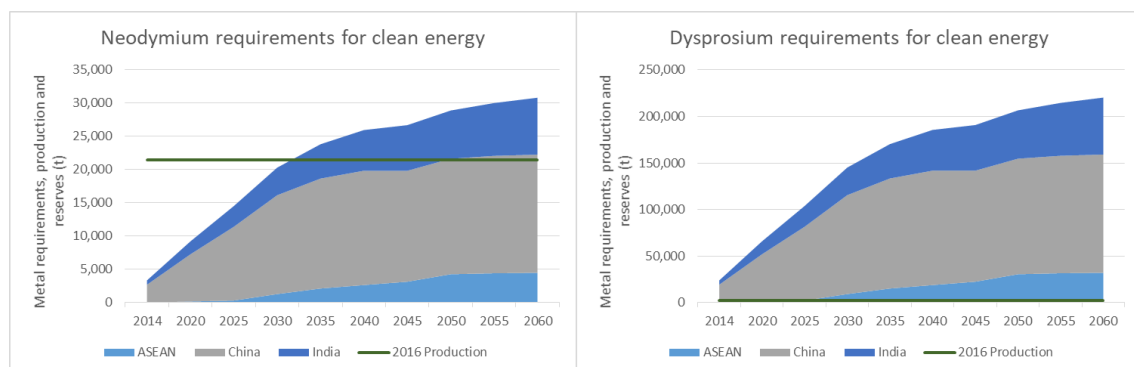


Figure 6. Annual requirements for minerals for wind power in selected Asian countries / regions compared to global 2016 production

For wind power, the requirements for dysprosium appear to be the most challenging, with near-term shortages if wind power is rolled-out with PMG technology. In the case of copper (Figure 7), which is required for all the considered technologies, there is no immediate concern of absolute shortages, but it should be noted that the competition between Asia and other areas of the world for supply, and the competition with other uses of copper, could bring supply risks closer.

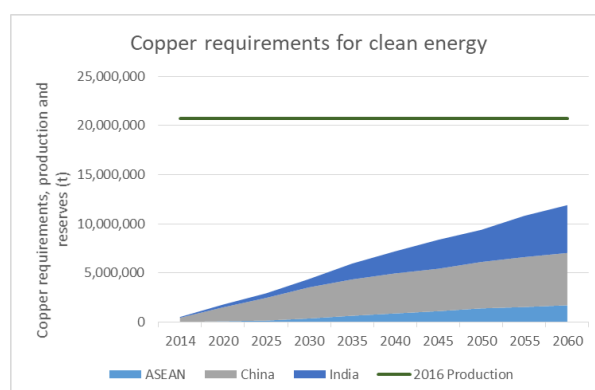


Figure 7. Annual requirements for copper for wind power and PV in selected Asian countries / regions compared to global 2016 production

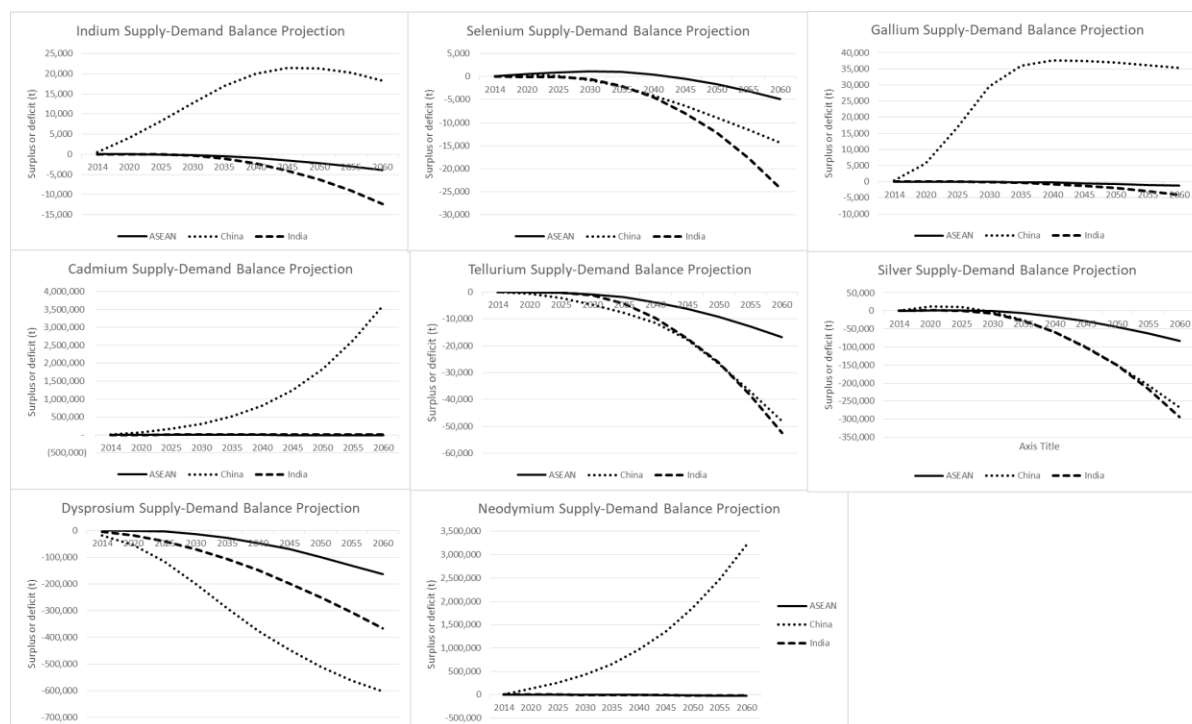


Figure 8. Cumulative supply-demand balance projections for the domestic primary production of critical minerals for clean energy in selected Asian nations / regions

Figure 8 shows the cumulative supply-demand balance projections for minerals under the Hubbert peak supply scenarios for providing the clean energy requirements of the B2DS. This shows a distinct difference when compared to the annual basis in Figure 5 and Figure 6, indicating that in certain minerals, each of the countries / regions has a domestic cumulative surplus for some period of time – for example, neodymium, cadmium, indium and gallium in China, cadmium and silver in India, silver and selenium in ASEAN.

Figure 9 shows the resulting change in emissions across the period, assuming that global demand for rare earths, copper and silver for clean energy was to be met. It is apparent that not only is the requirement for minerals increasing, which will lead to great waste production and energy requirement in the sector, but that despite a decline in CO₂ emissions, there is likely to be a significant increase in localised atmospheric pollutants. The increase varies from around 8 times for acetaldehyde, through to 24 times for chlorine compounds and sulfuric acid. While these are just indicators of some of the potential emissions, it is also important to note that there would be further supply chain emissions, and that the location of these emissions shifts are equally, or more, important than just the change in emissions, as these emissions tend to have local environmental (and health) impacts.

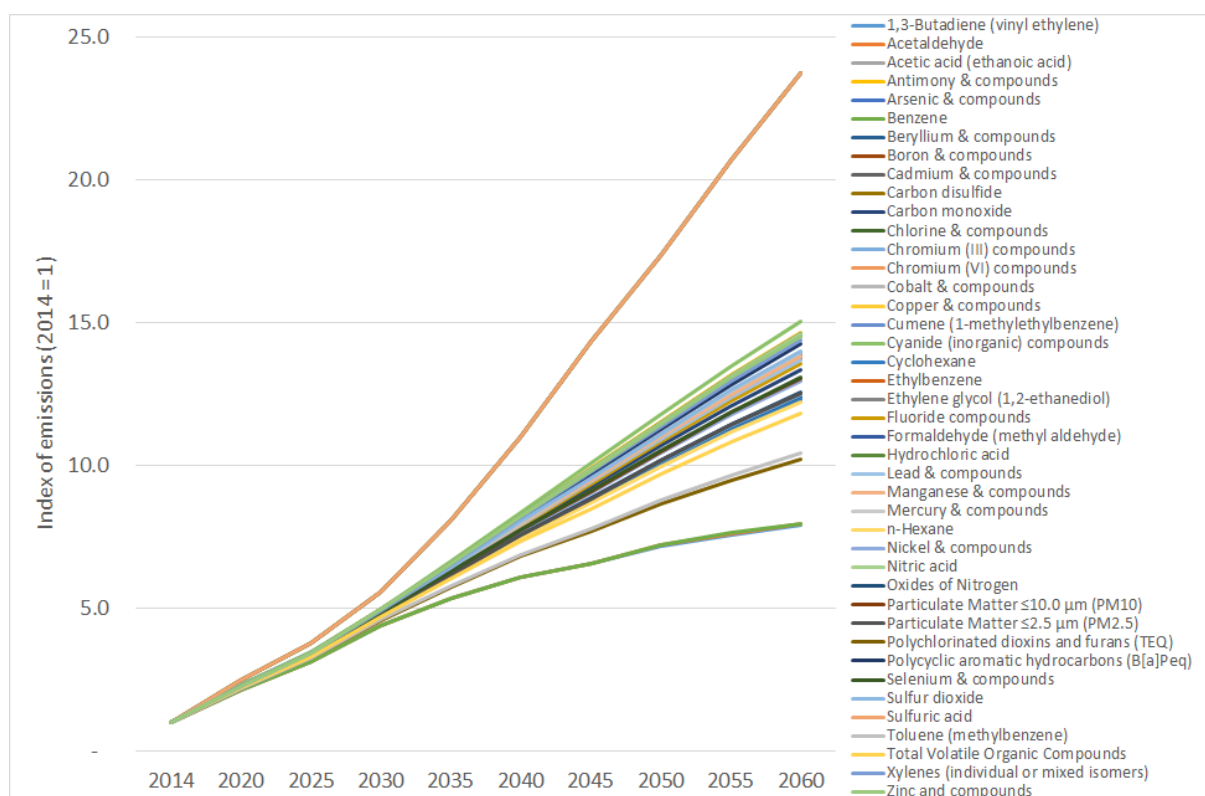


Figure 9. Index of non-CO₂ atmospheric emissions change from 2014 for the production of copper, silver and rare earths to meet global demand for clean energy

3. Discussion

The results presented in this paper, though only an initial examination across the selected regions of Asia presented by the IEA in their ETP scenarios, indicates that there are important concerns for clean energy provision from the perspective of minerals. It is important to note that a domestic supply deficit is not necessarily a problem, as most countries of the world require imports of some materials or products. However, it does leave these countries open to vulnerability with regards to the production of the relevant technologies. Within the world context, the same analysis shows that most metals will become problematic beyond 2030, with the exception of cadmium, neodymium and gallium, although this is reliant on the accuracy of peak minerals predictions. (Note that this currently disregards all other uses of these minerals apart from PV and wind power.) With regards to how countries could deal with these supply shortages, two immediate options (other than importing) are currently being considered within global resource-poor countries. One option is secondary supply (recycling), which is attractive both through the reduction of waste as well as the potential for retaining resources in circulation. An accurate assessment of this potential needs to first understand the material flows into various products, and where those products will ultimately be installed or utilized until their end-of-life. Currently, many countries in Asia – notably China and Japan – produce large quantities of manufactured goods for export to the rest of the world. This includes PV panels, wind turbines and components, and advanced clean energy vehicles. Retrieval of exported materials is highly unlikely, so the recycling potential must rely fundamentally on domestic consumption. With developing countries gradually improving their relative GDP comparative to developed countries, it is also likely that the physical trade in material goods will gradually shift. However, in the meantime this means that the stocks of secondary supplies of materials are relocated to developed countries that have the ability to install them more widely, and thus are enhancing their future position both with regards to energy security and resource security.

Conclusion

There are apparent potential scarcities in the provision of minerals for clean energy. Some of these will be limited to domestic scarcities, which might be overcome or reduced by imports or recycling. However, there are potential global level scarcities that would require either significant expansion in new primary production or substitute technology. The environmental and social implications of expanding mining are of key interest as the low carbon transition shifts from fossil fuel extraction towards a greater metal requirement. In developing Asia, the ability to implement new technologies needs to also examine the purchasing power as these countries develop. Moreover, a shift in the emissions profile, from CO₂ to localised pollutants, is an important consideration that should also incorporate an understanding of the specific locations where mining will be expanded, as these are the communities and environments that will be most affected. In this paper, only a sub-set of the supply chain of a selected group of minerals has been examined, but future work needs to address the full supply chain and the full list of minerals in more detail.

Acknowledgements

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