Assessment of Renewable Energy Potentials in Asia toward a Decarbonized World

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Abstract

A decarbonized global society will require expanded deployment of renewable energy in Asia more than in any other region due to its large population and fast development compared to other world regions. Thus, the possibility of a decarbonized society in Asia depends first on the availability of renewable energy resources, which, in turn, depends on geographic and climatic conditions along with the status of technologies. This paper presents estimates of two major renewable resources, solar and wind, in terms of energy potentials from a model using georeferenced data. The outcomes are compared with current energy demand in Asian countries, and are discussed with respect to some of the gaps to be filled to secure the expansion of the region's renewable energy supply.

Key words: Asian region, energy potential, onshore wind, solar PV

1. Introduction

The Asian region has considerable requirements for renewable energy to help displace fossil fuels, increase energy security and prevent dangerous climate change. The region is home to close to half of global greenhouse emissions (UNEP, 2019), 40% of global energy consumption and 46% of fossil fuel consumption (UNDESA, 2021). Replacing such amounts of fossil fuels will require a scale-up of renewables in the future. Currently, solar PV and onshore wind represent the major renewable resources, besides conventional hydropower, that have the largest prospects for fulfilling energy demand while contributing to decarbonization.

The past two decades have seen unprecedented growth in the solar PV and wind power industries in the Asian region. The installed capacity of solar and wind power in the region, grew from just 9.6 GW and 66 GW, respectively, in 2011, to over 331 GW and 332 GW, respectively, in 2019 (IRENA, 2021a). China alone increased its installed solar power capacity during that period (2011–2019) by more than sixty-fold, and that of wind power by around five-fold (IRENA, 2021a). This progress has been supported by advances in technological performance and production, which have led to significant cost reductions. In 2020, the costs of electricity supply from solar PV and onshore wind power (global-weighted average) were 0.057 and 0.039 $/kWh, respectively. This is equivalent to a reduction of 85% and 56%, respectively, compared to the cost back in 2010 (IRENA, 2021b). Also, several policies have complemented the expansion of these technologies, and schemes for financially supporting the adoption of these technologies are in place in several countries.

Decarbonization of the supply and demand of energy poses multiple questions about the feasibility of deploying renewable energies at large scale. If renewable energies are the centerpiece of a decarbonized society, are these resources plentiful enough to fulfill current and future energy demands? What are the geographic and technological gaps that need to be addressed to enable a widespread, large-scale deployment of these energy resources? In addition to these questions, other issues exist that are related to the feasibility of implementing the relevant technologies with respect to economic performance, policy, institutional capability and social acceptability, among other factors. This paper limits its focus to the first set of questions (related to geographic and technological aspects), and will bring up some of the key factors related to other aspects.

This paper explains the value of renewable energy for achieving the decarbonization of energy use in the Asian region, with respect to the availability of energy resources. For this, the paper first presents the available

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renewable energy resources, namely solar PV and onshore wind power, estimated using a model with georeferenced data, and expressed as technical energy potentials. It then explains the value of renewable resources in the context of current energy demand.

2. Model for Estimating Renewable Energy Potentials

This study is based on a model for estimating the availability of solar and wind resources as energy potentials at the global scale using georeferenced data. This model is documented in Silva Herran (2012) and has been applied for global assessments (Silva Herran et al., 2016). The model's outputs are used in integrated assessment models evaluating global GHG emission mitigation scenarios (Fujimori et al., 2017; Dai et al., 2016). The estimates presented in this paper use updated values for technology parameters (conversion efficiency and capacity density). The paper also analyzes the energy potentials of 13 countries and regions, in contrast to the previous study which considered only three Asian countries, with the remaining countries aggregated into three regions, with no analysis with respect to national electricity consumption levels.

The model includes as inputs the georeferenced datasets (as gridded data) on climate (solar radiation, wind speed), geography (elevation, slope) and land features (protected areas, land cover), along with parameters related to the techno-economic features of the technologies assumed in the model and restrictions for land suitability (i.e., type and fraction of land available for installing solar or wind power technologies). The model combines multiple georeferenced datasets and assumptions from the parameters, and calculates estimates of energy potential by country after accounting for geographic, land use and technical restrictions. The model also considers distance to the closest urban area to account for visibility restrictions on wind turbines.

The technologies assumed in the model for solar PV are multi-crystalline panels mounted as arrays on rooftops or as solar farms in empty land plots with a fixed inclination angle. For onshore wind, the technologies assumed are large-scale horizontal axis turbines grouped in wind farms, turbine height of 80 meters and rotor diameter of 90 meters. The main equations used to estimate the technical energy potential are listed below. Details on the calculations can be found in the author's manual (Silva Herran, 2012) and relevant publications (Silva Herran et al., 2016).

$$Q_{PV} = A_G * r_{LC\_PV} * n * q_{rad} / Interv$$
$$Q_{Wind} = A_G * r_{LC\_Wind} * \rho_{cpc} * cf_{turb} * 8760$$

Q_{PV}: technical energy potential of solar PV [MWh/yr]
Q_{Wind}: technical energy potential of onshore wind power [MWh/yr]
A_G: area of grid cell [km^2]
r_{LC}: land suitability factor for each land cover type [-]
n: conversion efficiency of solar panels [-]
q_{rad}: annual average energy flux as solar radiation over inclined panel [MWh/km^2/yr]
Interv: factor accounting for spacing between adjacent panels [-]
cf_{turb}: annual average capacity factor of wind turbine [%]
ρ_{cpc}: capacity density of wind power farm [MW/km^2]

The input data sets and main assumptions are listed in Table 1 and Table 2, respectively. The conversion efficiency of the solar panels is assumed to be 20%, and capacity density of the wind turbines, 10 MW/km^2.

Table 1 Input data sets used in the assessment.

Data set	Remarks {resolution}	Reference
Solar insolation	Monthly average solar insolation on horizontal surface {1 arc degree}	NASA LaRC (2008)
Wind speed	Monthly average at 50 meters above ground {1 arc degree}.	NASA LaRC (2005)
Land cover	17 types according to IGBP classification {0.5 arc-minute}	USGS (2005)
Elevation	Land altitude and ocean depth {0.5 arc-minute}	NOOA (2005), Hastings and Dunbar (1999), GEBCO (2006)
Slope	Meters of change in vertical direction per 100 meters {0.5 arc-minute}	Burrough and McDonell (1998)
Wilderness areas	Areas away from human activities (6 km from roads and settlements, larger than 400,000 ha) {0.5 arc-minute}	The Sierra Club and World Bank (1993)
Landscape angle	Angle between horizontal plane and landscape line within 30 km {0.5 arc-minute}.	Ikegami (2009)
Optimal inclination angle	Inclination angle of PV panels corresponding to optimal insolation rate {0.5 arc-minute}.	Ikegami (2009)
Distance to urban area	Distance to the closest urban area {0.5 arc-minute}	Silva Herran et al. (2016)
Protected areas	Terrestrial and marine protected areas {0.5 arc-minute}	IUCN and UNEP (2009)

Table 2 Assumptions for land exclusions and land suitability.

Assumptions	Wind: onshore	Solar PV
Exclusions		
Elevation [m above sea level]	> 2000	> 2000
Slope [%]	> 3	> 3
Wilderness and protected areas	Excluded	Excluded
Land suitability factor (r_{LC}) [%]		
Forest, mixed forest, woody savannas	0	0
Savannas, grasslands, open shrublands	50	5
Croplands, cropland/natural vegetation mosaic	30	5
Urban and built-up, closed shrublands	0	5
Barren or sparsely vegetated	50	2.5
Water bodies, wetlands, snow/ice	0	0

3. Renewable Energy Potentials and Their Contribution to Energy Demand

The estimated technical energy potentials for solar PV and onshore wind in Asian countries are presented in Table 3. Given that solar and wind resources are directly related to the surface area available for installing solar panels and wind turbines, respectively, the energy potentials can be expressed as densities in terms of each country's total surface area to give a clearer comparison among countries. Figure 1 shows the energy potential densities, equivalent to each energy potential divided by the country's surface area and expressed as a ratio to the world value (which is estimated from the same model used in this analysis). These estimates should be viewed as the result of a set of assumptions based on "central values" for the parameters used in the model. Assuming upper or lower values for the parameters, which are within a range of plausible values, will influence final outcomes by increasing or decreasing the results (a "sensitivity analysis" would demonstrate the range of outcomes from assuming a different set of values for the parameters, but such an analysis is left for another study).

The results for solar PV show that a considerable quantity of resources exist in India and China, given their large surface areas. These two countries alone account for two thirds of all the solar resources in the Asian region. Thailand and Indonesia also have significant amounts of solar resources. From the results of the energy potential density, it becomes clear that considerable solar resources (larger than the world average) exist in Singapore, India and Thailand. In contrast, countries such as Japan, Malaysia and Indonesia, have relatively small potentials as a result of an annual regime of low insolation, and large areas restricted for installation of solar panels (such as forests and protected areas).

The results for onshore wind energy reveal that the energy potential of the entire Asian region is similar to that for solar PV, but it is distributed very differently across the region. Around half of the onshore wind energy resources in the Asian region are in China. Other regions with important amounts of wind resources are in other Southeast Asia, other South Asia and India. In terms of energy densities, only the countries in other South Asia and Other East Asia have values larger than the world average. In the latter group of countries, Mongolia contributes the most to this outcome. Besides these two regions and China, all the other regions have smaller wind energy potential densities compared to solar energy.

Solar and wind energies produce electricity, therefore, it is important to evaluate their energy potential with respect to electricity consumption. Figure 2 shows the estimated energy potentials of each region plotted against the electricity demand in year 2018 (both values are plotted in logarithmic scale for ease of evaluation). The figure indicates that regions with values above the equality line (bold diagonal line in the plots) have higher amounts of the energy resource (either solar PV or onshore wind) than the electricity that is consumed at present. Conversely, regions with values below the equality line indicate higher consumption than the available resource.

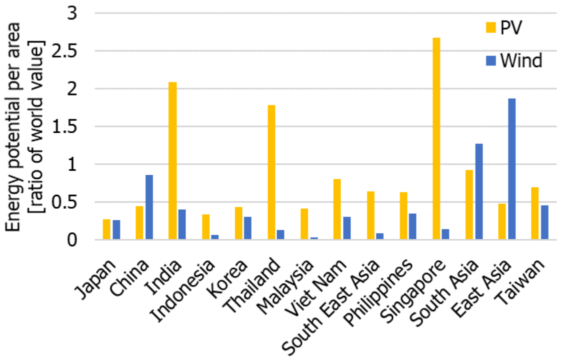

Fig. 1 Density of technical energy potential in terms of each country's surface area, expressed as the ratio to the world value (3,740 TWh/yr/km^2 and 3,360 TWh/yr/km^2 for PV and onshore wind, respectively). World values estimated from the same model are applied in this study.

Table 3 Technical energy potential for solar PV and onshore wind, and electricity demand in Asian countries and the world (TWh/yr).

Region	Code	Energy potential [TWh/yr]		Electricity demand in 2018 [TWh/yr]
		PV	Wind	
Japan	JPN	392	347	946
China	CHN	15,662	27,100	6,002
India	IND	24,625	4,319	1,157
Indonesia	IDN	2,439	404	252
Korea	KOR	168	106	531
Thailand	THA	3,433	233	188
Malaysia	MYS	518	29	153
Viet Nam	VNM	985	343	193
Other Southeast Asia	XSE	2,683	345	35
Philippines	PHL	731	360	83
Singapore	SGP	6	0	50
Other South Asia	XSA	6,638	8,203	206
Other East Asia	XEA	3,044	10,606	18
Taiwan	TWN	97	56	247
Asian region total		61,422	52,454	10,061
World		506,452	455,219	22,226

Other Southeast Asia includes Brunei, Cambodia, Myanmar and Timor Leste. Other South Asia includes Afghanistan, Bangladesh, Bhutan, Maldives, Nepal and Pakistan. Other East Asia includes Korea DPR and Mongolia.

The solar PV potentials, showed in Figure 2a, can supply at least 10% of the electricity demand, and at most more than 100 times larger electricity amounts. In regions that include less developed countries, such as other East Asia (which includes Mongolia and North Korea), other Southeast Asia (which includes Laos, Cambodia and Myanmar) and other South Asia (which includes Sri Lanka and Afghanistan) have solar resources more than ten times larger than their electricity demand. In contrast, in the industrialized countries of the Asian region, the available potential is only a fraction of the demand due to high energy consumption per capita and relatively low annual insolation rates. It is also worth noting that countries with small solar energy potentials are in a surplus condition (for example Malaysia and Vietnam). Moreover, the largest potential, located in China, is only a few times larger than the electricity demand in that region.

The energy potential of onshore wind, shown in Figure 2b, can cover between 0.6% (Singapore) to around 600 times (other East Asia) the current electricity demand. Similar to solar resources, low income regions possess large resource surpluses compared to their electricity demand. Also, middle income regions, such as Indonesia, Thailand and Vietnam, have resource levels similar to their demand, while industrialized regions have limited resources (around 20%–40% of electricity demand, or less in the case of Singapore).

The analysis above suggests that the supply of electricity from solar and wind resources can be an opportunity for low-income regions, as they have large surpluses that could be provided to other regions with high energy demand and small renewable energy potential, in particular to industrialized regions such as Japan or Korea.

However, the energy potentials estimated in this study only include major geographic, technical and ecological restrictions, and lack any representation of economic or social restrictions (besides visibility restrictions in the case of onshore wind). Solar and wind resources are abundant, but they will remain with little or no value unless measures are in place for deploying them. What matters is how much of that resource can be utilized after accounting for, and overcoming, restrictions imposed by compatibility with the environment, development agendas and societies' values.

The outcomes of this study are subject to the assumptions and datasets adopted, which involve several uncertainties. The outcomes are compared to other estimates from global models for the Asian region. The solar PV potential is slightly smaller than that reported in another two studies (61 PWh/yr compared to 74–130 PWh/yr) (de Vries et al., 2007; Pietzcker et al., 2014), presumably due to the different solar resource datasets used, as well as lower values assumed for land suitability (50%–90% across land cover categories). For onshore wind energy, the potential is larger than that reported in other studies (52 PWh/yr against 2–47 PWh/yr in other studies) (de Vries et al., 2007; Bosch et al., 2017). Again, differences in the resource dataset have an effect, while higher values for capacity density (10 MW/km^2 in this study in contrast to 4–5 MW/km^2 in other studies) may play an important role. An important limitation of this study is the coarse spatial resolution of the datasets used when compared to single country studies. For example, an assessment of Japan using national-scale datasets (MOEJ, 2022) suggests that the energy potential of solar PV (3,222 TWh/yr) is considerably larger than in this study (392 TWh/yr). For onshore wind, this study's estimate (347 TWh/yr) is smaller than that of the national-scale study (686 TWh/yr). These differences may result from the high spatial resolution of the national-scale study (0.5 km for solar radiation, wind speed and land cover), which may allow areas of intense solar radiation and wind speeds to be accounted for that are overlooked in global datasets (~121 km resolution for solar radiation and wind speed). It must be noted that the datasets of these studies are dated. Therefore, the outcomes are likely to be affected by changes in recent decades in land cover patterns (such as urbanization and agricultural land expansion), and in resource flows due to climate change. For instance, some studies have reported an impact from

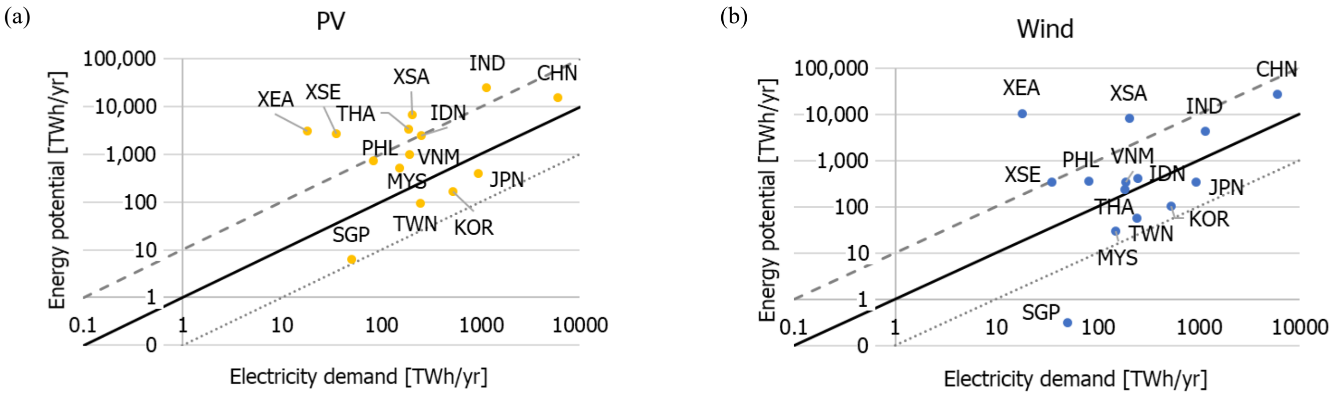

Fig. 2 Comparison of estimated energy potential with electricity demand (as of 2018) in each region: a) solar PV; b) onshore wind. The bold line indicates equal values for energy demand and energy potential; the dashed and dotted lines indicate energy potentials ten times higher and ten times smaller than electricity demand, respectively. The code names of countries and regions are explained in Table 3. Based on energy demand data from UN energy statistics pocketbook (UNDESA, 2021).

climate change on solar PV and wind power generation in Europe (Jerez et al., 2015; Tobin et al., 2014).

The trends in the renewable energy market in recent decades herald a continued expansion of the solar and wind industry, but, at the same time, give evidence of shortcomings arising from experience gained through large-scale deployment. One of these is compatibility with the environment. At the local scale, the introduction of large-scale solar and wind farms can disrupt local ecosystems, for example by obstructing migration routes of certain birds, and fragmenting the areas of influence of some wild animals. At the broad scale, the exploitation of raw materials, such as rare metals, needed for the construction of solar and wind technologies, is arousing concerns over the disruption and pollution of wild environments due to the expansion and intensification of mining activities. Moreover, the proper disposal and recycling of materials from many installations that will be decommissioned after the end of their operational life in the future poses an important challenge.

Another shortcoming observed from large-scale deployment of solar and wind energies, is the integration of fluctuating supply from these sources into the power system. Handling the variable supply will require multiple measures to balance the mismatch between supply and demand within hourly timespans. These measures include the use of batteries for storage, complemented with fast response power plants (such as natural gas turbines), trading of electricity among neighboring regions and demand-side responses. Implementing these measures in the Asian region is a fundamental challenge given the lack of experience and large reliance on thermal power plants. This is especially true in low income (such as Cambodia and Laos) and middle income (such as Thailand and Indonesia) countries where stability and reliability of the electricity supply are still far from accomplished. At the same time, tackling these issues along with promoting solar and wind power may bring benefits, as the growing demand from new users in residential, commercial and industrial sectors, can be covered directly with decentralized systems. These systems can incorporate smart metering and a more robust transmission and distribution network. Accordingly, they can enable direct implementation of demand-side response measures and balancing of the system through electricity supply among distant areas under grids that are newer and well-connected.

It also must be noted that the energy demand, especially that for electricity, in the Asian region will increase considerably in the near future. Increased access to electricity is expected for more than 100 million people currently lacking access to the service in the region (IEA et al., 2020). Also, continued growth in consumption is expected, driving energy consumption per capita upwards. Projections of energy consumption from integrated assessment models suggest an increase of 44%–92% in the Asian region (excluding Japan) by 2030 compared to 2010, in contrast to an increase of 26%–45% worldwide (COMMIT consortium, 2021; van Soest et al., 2021). Therefore, the balance between solar and wind energy resources and energy demand will change. Making use of novel technologies, infrastructure (such as high voltage transmission lines and electricity storage) and policies will be needed to foster the penetration of renewable energy at a pace that secures decarbonization without undermining the stability and affordability of the energy supply.

Assessments of renewable energy resources must also evolve to reflect the changes mentioned above. As new technologies emerge, assessments will need to include other schemes for electricity generation from solar and wind resources. Currently, assessments assume a single dominant technology. In the case of wind power, the assumed technology is a horizontal axis turbine. However, currently there are numerous technologies based on different schemes, such as vertical axis turbines and high-altitude turbines, that can harness electricity under conditions not possible with conventional turbines. For the case of solar PV, the assumed technology is a flat polycrystalline module mounted on a rigid frame, usually installed over a roof or an open plot of land. In contrast, several alternatives exist that generate power using panels mounted on walls or other surfaces, or that have a flexible structure, or that can be installed on croplands using an elevated frame with enough spacing so that plants can grow underneath.

Finally, it is necessary to verify the feasibility of these potentials in terms of their economic value and their compatibility with environmental and social conditions in the region. The economic aspect can be analyzed by means of supply-cost curves, which characterize the energy potential against the cost of the supply. The environmental aspect has been covered in this study by excluding wilderness and protected areas from the estimates, but it can be enhanced by studying the areas of negative influence of solar and wind power installations with more detailed datasets and restrictions (such as those related to migratory routes of birds). The social aspect can be approached by setting land suitability restrictions in relation to proximity to human settlements and by considering cases that present different levels and rationales for acceptability of expanding renewable energy installations.

4. Conclusion

Overall, this study showed that there are plenty of solar and wind resources in the Asian region, but they are unequally distributed among countries. The estimated technical energy potentials of solar PV and onshore wind in the region were 61,422 TWh/yr and 52,454 TWh/yr, respectively. These potentials are equivalent to six and five times the current electricity demand (as of 2018). There are surplus energy potentials in low-income countries, that can range from more than half to several times the current electricity demand in each respective country. These countries could balance the large deficits in high-income countries, where energy potentials only amount to 40% of current electricity demand.

Further analyses are needed to verify the feasibility of these energy potentials with respect to economic, environmental and social restrictions. Also, it is important to improve the present assessment to consider the evolution of technologies, as well as the lessons from continued deployment of large-scale solar and wind installations.

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