Whose land is it anyway? Energy futures land use in India

Mohan, Aniruddh

Wuppertal Institute for Climate, Environment and Energy

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Whose land is it anyway? Energy futures & land use in India

Aniruddh Mohan

Abstract

Modelling studies which project pathways for the future of energy in India currently have several implicit assumptions with regards to the social, institutional, and political changes necessary for energy transitions. This paper focuses on the specific question of land use change required for realising ambitious clean energy targets. Demand for land is likely to be a critical question in India's energy future given the challenges with land acquisition in the country as a result of high population density and significant rights enjoyed by landowners. Yet, there is a lack of literature relevant to India which makes a quantitative assessment of the land use impacts of different types of low carbon technologies. I calculate and compare the land requirements in India of ground based solar photovoltaic (PV) power, nuclear power, and wind energy. All three types of technologies are expected to grow substantially as a share of India's electricity mix in the coming years. The analysis suggests that land demands of ground based solar PV are likely to be substantial compared to wind energy and nuclear power, and some policy suggestions are provided which may help mitigate that challenge.

Keywords
land use; India; energy futures

1. Introduction

In India, the world's third largest carbon emitter, renewable energy is receiving great attention as a solution to both climate imperatives and the challenge of energy poverty. India has high potential for deployment of solar energy to meet its electricity needs given the high solar insolation in the country (Khare et al., 2013). Indian Prime Minister Narendra Modi has announced a domestic goal of increasing renewable energy to 175 gigawatts (GW) by 2022, of which solar photovoltaic (PV) would make up 100 GW and wind power 60 GW. Of the 100 GW target for solar power, 60 GW is to be ground based solar while 40 GW will be rooftop solar. Several reports have however questioned the land based targets for deployment of solar energy, particularly citing challenges related to financing, grid connectivity and distribution, and last but not least, land area (Khare et al., 2013; NITI Aayog et al., 2015; Patil, 2017). Similarly in the case of wind energy, land acquisition has been highlighted as the biggest challenge to private companies operating in the sector (Rajaram, 2012; Siraj, 2015). Alongside the growing push for renewable energy sources in India, is also a simultaneous push for nuclear energy, which remains an important and growing part of India's energy mix and an integral part of India's clean energy targets to tackle climate change(Mohan, 2016). Nuclear power projects in India have however faced significant delays due to local protests at plant locations.

The main challenge in India with respect to land availability for large power projects is to do with the acquisition of land. There are several legal difficulties with the process for land acquisition for large scale infrastructure projects such as power plants as the current land acquisition laws provide significant privileges and protection to landowners. The current

National Democratic Alliance (NDA) government has been attempting to amend the existing land acquisition bill but has had no progress with this agenda in the upper house of parliament. India continues to have a high degree of conflict over land and over 60% of all conflicts documented are to do with land acquisition by the government (Tata Institute of Social Sciences and The Rights and Resources Initiative, 2016). Furthermore, 15% of all land conflict in the country is linked to power projects and in Central India the figure is as high as 33% (Tata Institute of Social Sciences and The Rights and Resources Initiative, 2016). Demand for land is likely to be a critical question in India's energy future given the high population density in the country and significant rights enjoyed by landowners. Targets for expanding clean energy which is a major focus of Indian energy policy, should take into account considerations over land use and the differences between different types of energy generating technologies. There is however a lack of literature relevant to India which explores this issue and which can serve as a guide to policymaking and further research.

In this paper, I calculate the land use implications of solar power in terms of m^2/GWh. To put this number in perspective and facilitate comparison with other energy sources likely to play a significant role in India's energy future, I also estimate the land footprint of future nuclear power reactors in the country and the land footprint of wind energy. Previous studies in other countries have made important advances in bringing the debate on land use and electricity generation to light, but have certain shortcomings when applied to India, as I highlight. This paper will try and bridge those deficiencies and provide policymakers and researchers with up to date estimates of future land use claims by low carbon power sources in India. Finally, some policy suggestions are provided that flow from the analysis.

2. Literature Review

There is limited life cycle analysis of land use by different electricity generation technologies that is pertinent to India. A scan of the literature on life cycle land use analysis of energy technologies in India reveals a neglected and under-studied field. Perhaps as a result, modelling studies which project pathways for the future of energy in India currently have several implicit assumptions over land use and land availability for large scale energy infrastructure projects. For instance, the TERI-WWF study into a 100% renewable energy scenario for India estimates a grid connected solar PV build up of up to 1200 - 1400 GW. The report notes that land availability will be a considerable constraint in the build up of solar PV in India and estimates that an installed solar capacity in this range would require land equivalent to 1% of the solar hotspots in the country (TERI and WWF-India, 2013, p. 23). However, there is little further debate on what the implications of this challenge for energy policy should be. Similarly, questions over land availability and impacts are conspicuous by their absence in the Lappeenranta University of Technology report on a renewable energy future for India by 2030 which estimates 727 GW of solar PV build up in the country but does not contain any discussions about the challenges of land acquisition for such a gigantic build up of solar power (Breyer et al., 2016). The Indian government sponsored think tank National Institution for Transforming India (NITI) Aayog has also released a report into renewable energy pathways to 2030 for India which analyses possibilities for rapid renewable energy deployment in the country. The report notes land availability as a major challenge to a dramatic scale up of renewable energy (NITI Aayog et al., 2015). Considerable sections in the report are devoted to policy options for land acquisition and planning for land availability but there is no comparative analysis of land use claims by different types of clean energy technologies (NITI Aayog et al., 2015).

The most notable analysis of comparative land use claims in India is by Mitavachan and Srinivasan (2012) who compare the respective land footprint of nuclear, solar PV, hydro, and coal power. Their data for nuclear energy land use is based on two studies that they cite as references. The first is the study by Jacobson (2009) that compares energy technologies in the United States and includes a section on nuclear power. The second set of numbers for nuclear energy land use presented by Mitavachan and Srinivasan (2012) is based on a seminal study by Fthenakis and Kim (2009) which compares the life cycles of different energy technologies. Both Fthenakis and Kim (2009) and Jacobson (2009) however use numbers relevant to the United States for their nuclear power land use calculations and therefore these studies cannot provide an accurate reflection for Indian nuclear energy land use. There are three reasons for this. Firstly, laws regarding siting of nuclear power plants are extremely unique to countries. Some countries require extensive exclusion zones that significantly increase the land area required while others do not. Secondly, their calculations for the nuclear fuel cycle, particularly the front end of the nuclear fuel cycle – fuel extraction, conversion, enrichment and fabrication - are once again unique to the United States. Out of the 21 nuclear reactors currently operating in India, 17 are Pressurised Heavy Water Reactors (PHWRs) which use natural uranium as fuel and for which enrichment is therefore not a consideration. Third, the numbers used in their analysis for the back end of the fuel cycle by Fthenakis and Kim (2009) for instance, particularly waste disposal, are drawn from a calculation of the percentage of land a particular reactor would require from the total area of the Yucca Mountain repository and are relevant to an open fuel cycle.

India's fuel cycle is however closed, which means that most of the spent fuel is reprocessed and that in turn significantly reduces the area required for waste disposal. Given these differences in the nuclear reactor siting and fuel cycle process between India and the United States, the numbers used by Mitavachan and Srinivasan (2012) are not representative of the land use claims of nuclear energy in India. Mitavachan and Srinivasan (2012) also do not include wind power in their study despite the strong prospective growth of wind energy in the country.

3. Methodology

My assessment of land use is from direct metrics of life cycle land transformation, i.e. the land area used to generate electricity as well as land use associated with the fuel cycle process. Land transformation from the power plant site is calculated by dividing the total land area of the reactor site (m^2) by the expected total electricity produced by the plant over its lifetime (GWh) using Equation 1 below. CF is the capacity factor of the power plant, h/y is the number of hours per year, and y is the expected number of years of operation.

$$\text{Land Use } \{\frac{m^2}{GWh}\} = \frac{Land\ Area}{Net\ Rated\ Capacity(GW) * (h/y) * CF * y}$$

Equation 1: Land Use from Power Plant Site

Land use from the fuel cycle process is also calculated in terms of m^2/GWh and therefore the total land use of a particular energy generating technology is simply the summation of the land use at the reactor site and that of the fuel process.

For Solar PV, I have chosen an upcoming solar park project of 1000 MW in Rajasthan for the comparative analysis in this paper. The choice of the state of Rajasthan is because this state is listed by the Ministry of New & Renewable Energy (MNRE) as having the highest potential in the country for future growth in solar energy according to a report by the National Institute of Solar Energy (2014), and currently has one of the highest amounts of installed capacity of solar PV power in India. It is as a result, a useful example to estimate land use claims by future solar power projects in the country.

For nuclear power, I have selected the project site for two twin prospective new Indian PHWRs at a site in Gorakhpur, Haryana with an upcoming solar park in Rajasthan, India. As mentioned before, PHWRs constitute the majority of India's currently operating reactors as well as the majority of reactors currently under construction in the country. The selection is therefore a good representative of the current and future nuclear energy production process in India. Data for the land use in the case of the Gorakhpur reactor site is also readily available. To improve on the Indian numbers for nuclear energy in particular compared to previous studies, I use India specific data for the nuclear plant site; remove enrichment considerations from the life cycle assessment as Indian PHWRs use natural uranium as fuel; and use the French closed fuel cycle as a useful estimate for land use claims of reprocessing and fuel disposal. These three steps enable a more accurate estimation of nuclear energy’s land footprint in India. For uranium mining and fuel fabrication, I employ numbers from previous international studies in the absence of India specific data.

In the case of wind energy, no project specific data is available for the existing wind farms in the country. However, the National Institute of Wind Energy in India estimates the average energy density of installed wind energy capacity in India to be 6 MW per square kilometre as per its latest annual report (National Institute of Wind Energy, 2016). This figure is comparable to other countries. For instance, the National Renewable Energy Laboratory (NREL) in the United States assumes an energy density of 5 MW per square kilometre (Lopez et al., 2012).

4. Data

4.1 Data for Solar PV

The land use calculations for solar PV are straightforward as there is no fuel cycle to be considered. Analysis of the solar parks recently allocated in India provides a straightforward estimate of the land area required for solar PV installations. The rated power capacity of the power project site along with the total land area for the project can be used to derive a relevant figure for comparison. The Ministry of New & Renewable Energy (MNRE) (2015) released guidelines for the development of solar parks that identify the land required for various solar projects along with their rated capacity.

A total land area of 2000 hectares has been identified for the 1000 MW project in Jaisalmer Phase I, Rajasthan according to the MNRE report (2015). These numbers are used to derive an appropriate conversion to m^2/GWh as per Equation 1. The calculations are shown in the Appendix. The estimated land use is 456.6 m^2/GWh.

4.2 Data for Nuclear Energy

Calculations for land use of nuclear energy are not simply restricted to the plant site but must account for the entire fuel cycle which includes uranium mining, fuel fabrication, reprocessing and waste disposal. As India's PHWRs use natural uranium as fuel, the front end of the fuel cycle involves uranium mining, milling and fuel fabrication. No enrichment or conversion is required. The back end of the fuel cycle involves reprocessing and waste disposal.

4.2.1 Uranium Mining & Milling

Uranium for India's PHWRs can either be supplied from indigenous uranium that is mined by the Uranium Corporation of India Limited (UCIL), mostly through its mines in Jharkhand, or through imports of uranium from Canada, Russia and Kazakhstan. The Environmental Impact Assessment Report notes that the Haryana Atomic Power Project will be served by indigenous fuel (Nuclear Power Corporation of India Limited (NPCIL), 2013, p. 339).

UCIL operates 7 mines currently in the country, 6 of which are underground and 1 is an open pit mine according to the latest joint report on global uranium mining and production by the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (2016). For this study, I have assumed that the uranium for the PHWRs under consideration will be served by an underground mine. Exact data for total land area covered by the mines, tonnes of ore produced per day and grade of the uranium ore (% of U_3O_8) were requested by the author from UCIL on several occasions. However, UCIL refused to divulge such information.

Furthermore, in the lower house of Parliament, the Prime Minister's Office has declined to provide an answer to the amount of production of uranium ore per day from the mines, citing issues of public interest and security (DAE, 2014a).

To estimate the area displaced I have therefore used a study by Schneider et al (2013a) who undertook a thorough assessment of primary data relating to several mines across the world. Other estimations for uranium mine and milling land use also exist but either fail to specify which type of mine they refer to (Fthenakis and Kim, 2009) or their estimations are not relevant exclusively for underground mines (Finch, 1998; Poinssot et al., 2014).

Schneider et al (2013a) estimate the underground mine land use as 196 m^2/tU which includes both mining and milling operations. In terms of m^2/GWh, this comes out to 4.2 m^2/GWh from the mining and milling process. Full calculations are shown in the Appendix and is based on data provided by the DAE on fuel burn-up in Indian PHWRs (DAE, 2014b). This result of 4.2 m^2/GWh is an order of magnitude lower than the estimations of Fthenakis and Kim (2009) but comparable to other studies as shown in Table 1. The difference is to do with the variations between open pit, in situ, or underground mining.

Source	**Mining Land Use** (m^2/GWh)	**Milling Land Use** (m^2/GWh)	**Total Land Use** (m^2/GWh)	**Mine type**
(Fthenakis and Kim, 2009)	30	10	40	None specified
(Finch, 1998)	0.3	1.2	1.5	Open pit mine
(Eliasson and Lee, 2003)	0.15	2.09	2.2	Underground

Table 1: Reviewed estimates of mining and milling/refining land use.

4.2.2 Fuel Fabrication

Refined uranium must be converted to UO_2 pellets to be used as fuel in the PHWRs. The DAE handles the fuel fabrication process for nuclear power reactors operating in India through the nuclear fuel complex located at Hyderabad in the south of the country. Land use intensity numbers for fuel fabrication specific to India are unavailable as no such data has been made publically available by the DAE. Estimations can however be drawn from other studies. Schneider et al (2013b) for instance estimate the land use as 13 x 10^{-3} m^2/GWh. A study of the French nuclear fuel cycle produces an estimate of 0.93 m^2/GWh (Poinssot et al., 2014). In the absence of Indian data, I employ the higher number of approximately 1 m^2/GWh.

4.2.3 Project Site

Fortunately, estimations for the project site are available specific to the Indian reactors in question. This is especially important as the nuclear plant site contributes to the bulk of the area required for a land use assessment of nuclear power plants and countries vary in their laws regarding the need for an exclusion zone and buffer area. The Nuclear Power Corporation of India Limited (NPCIL) has published the approved environmental clearance obtained from the Ministry of Environment, Forests, and Climate Change (MOEFCC) for the Gorakhpur site. The total area approved, which will include the four PHWRs, surrounding facilities, mandatory exclusion zone and township, is 608.4 hectares (MOEFCC, 2013). The total rated capacity of the Gorakhpur site is 2.8 GW given that there are four 700 MW reactors planned for the site. The appropriate calculations for a conversion into m^2/GWh using Equation 1 are shown in the Appendix. The land use for the project site comes out to be 7.3 m^2/GWh.

4.2.4 Reprocessing and Waste Disposal

The Indian nuclear fuel cycle is closed, i.e. most of the spent fuel is reprocessed and waste volume is minimised. This is similar to the French fuel cycle studied by Poinssot et al (2014) but different to the American fuel cycle studied by Fthenakis and Kim (2009). The study of the French closed nuclear cycle therefore provides a better analogue for Indian calculations. Poinssot et al (2014) estimate the French fuel cycle reprocessing and waste disposal footprint as approximately 4 m^2/GWh and 13 m^2/GWh respectively and I use these numbers in the absence of publically available data specific to the back end of India's fuel cycle.

4.2.5 Total Nuclear Energy footprint

The total land footprint of the energy produced by the PHWRs is simply a summation of the land use by the entire fuel cycle and reactor site. This is shown in Table 2. The total land use comes out to be 29.5 m^2/GWh which is almost 1/3rd the estimate of 85 m^2/GWh used by Mitavachan and Srinivasan (2012). Using data more relevant to India therefore significantly affects the final land footprint estimate of nuclear energy production in the country.

Nuclear Energy Production Cycle	**Land Use (m^2/GWh)**
Power Plant Site (Gorakhpur)	7.30
Mining & Milling	4.2
Fuel fabrication	1
Enrichment	-
Reprocessing	4
Waste disposal	13
Total	**29.5**

Table 2: Calculations for entire life cycle land use of the Gorakhpur Nuclear Power Plant

4.3 Data for Wind Energy

Calculations for the wind energy footprint can be made using Equation 1 and the latest estimate of wind energy density in the country of 6 MW per square kilometre provided by the National Institute of Wind Energy in India (National Institute of Wind Energy, 2016). However, in the case of wind farms, the land taken up by the turbine towers and additional infrastructure such as roads is usually only 1-10% of the total land area and the remaining land can continue to be used for other purposes such as grazing, agriculture, and recreation (Fthenakis and Kim, 2009). For the purpose of this study I assume the land area actually disturbed to be 3% of the total in line with estimations made by Phadke et al. (2012). The calculations are shown in the Appendix. The land use of wind power comes out to be 142.7 m^2/GWh.

5. Discussion & policy suggestions

The comparative land use life cycle assessment of nuclear power, wind energy, and solar PV in India shows that nuclear energy enjoys significant advantages over both solar PV and wind power with respect to land transformation, as shown in Figure 1. Per GWh of electricity generated, nuclear power requires 6% the land area of solar PV and about 1/5th the land required by wind power, even when the land use impact of the entire nuclear fuel cycle is taken into account.

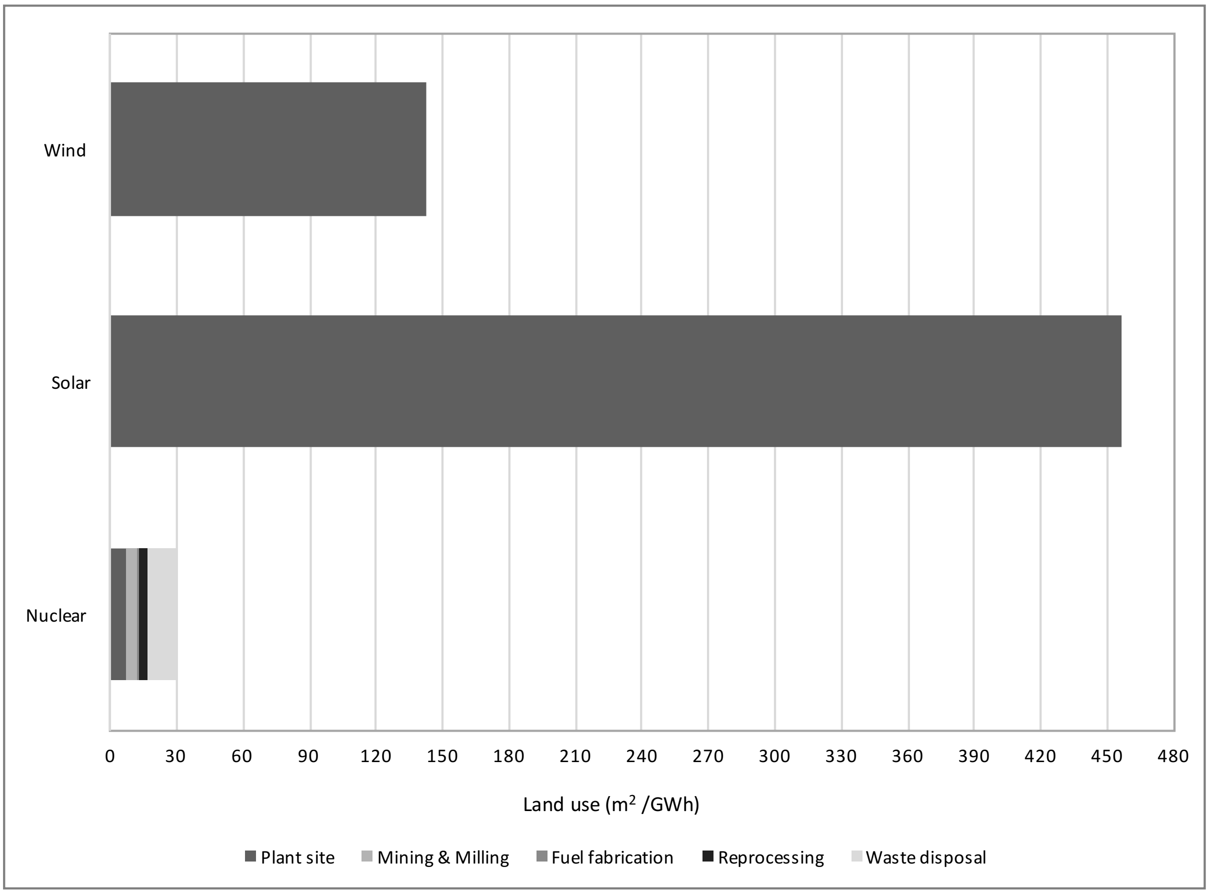

Figure 1: Comparative estimates for land use of wind energy, solar PV, and nuclear power in India

The analysis suggests that land demands of solar PV in particular are likely to be substantial and merit careful consideration in mainstream energy policy debates in India. The final comparative results between nuclear energy and renewable energy land use in India is actually comparable to other studies (DiPippo, 1991; Fthenakis and Kim, 2009; McDonald et al., 2009; MIT, 2006), which also conclude in their specific cases that nuclear energy performs significantly better than renewable energy sources with respect to land transformation.

The notably high land transformation numbers for ground based utility solar PV may suggest that a higher percentage of future solar build-up in India should be achieved through rooftop solar panels. While rooftop solar is currently more expensive than ground based PV, it removes the obstacle of land acquisition for large solar parks. Industry experts have also argued that long term sustainable growth in the solar sector in India will have to be achieved through decentralised rooftop PV instead of centralised, utility scale projects (Engelmeier et al., 2014). Strong support from the government for this sector may therefore be prudent not just financially but also in terms of challenges with land use change. Another possibility to mitigate the land acquisition problem is to also focus on smaller scale projects of 50 – 100 MW for solar PV near demand centres and where land acquisition for sprawling solar parks may be a challenge.

For wind energy, improving capacity factors which continue to be low compared to other countries and upgrading to more powerful turbines already in operation globally such as 6 MW turbines from the current maximum in India of 2.5 MW – 3 MW, will help further reduce the pressure on land by potentially increasing energy density up to 10 MW per square kilometre, which has been achieved in Europe (European Environment Agency, 2009). One of the advantages of wind energy is the dual use nature of land, and policies to encourage dual use for solar PV parks in India has been suggested and could significantly alleviate the land acquisition challenge for solar power (Harinarayana et al., 2014).

It is to be noted that land transformation is only one aspect of the impact of land use, the other being land occupation (Fthenakis and Kim, 2009). Land occupation refers to the time period over which a given piece of land returns to its original state, measured as a product of land area (m^2) and time (year) (Fthenakis and Kim, 2009). Precise calculations for estimating land occupation of different types of energy generation technologies are beyond the scope of this paper given that estimating the time needed to restore a land to its original state is complex and sensitive to the type of ecosystem disrupted and under consideration. Clearly however, in the case of land occupation, nuclear power plants occupy the land for longer than solar PV and wind energy power plants due to longer operating duration as well as time needed for decommissioning and returning the land to its original state. Construction times are also significantly longer for nuclear power plants.

6. Conclusions & recommendations for further work

This paper has attempted to address the gap in the literature with regards to a life cycle land use assessment of different low carbon technologies in India by comparing prospective nuclear reactors, an upcoming solar power park, and wind energy.

Particularly in the case of nuclear power, a more accurate picture can still be drawn, and is hampered by unavailability of specific data for nuclear power in the country. Information on India’s civilian nuclear programme is very difficult to access as India’s civilian programme still remains linked to its military weapons programme and there is a prevailing culture of secrecy and unaccountability (Ramana, 2009).

Apart from unavailability of data, calculations for land use intensity of nuclear energy production in India are also complicated by the differing types of reactor designs and type of fuel used. Some Indian PHWRs are now being tested with slightly enriched uranium as fuel (IAEA, 2011) which has an impact on land use, as it will necessitate calculations for the land area used by enrichment facilities. On the other hand, if a nuclear reactor in India uses imported uranium, as 13 of the 21 currently operating reactors do (DAE, 2015), there is no land footprint associated with mining operations in the country. Last but not least, data from France's nuclear programme has been used for reprocessing plants. Nuclear reactors in France are however Pressurised Water Reactors (PWRs), while in India most of the reactors are PHWRs as discussed. Fuel burn-up rates in PHWRs are less than that in PWRs and as a result lead to larger spent fuel volumes. This has implications for the size of reprocessing plants required and associated land use. The small contribution of reprocessing to the overall life cycle footprint for nuclear power however suggests that this would not change the results significantly.

In the case of ground based solar PV, many of the large projects are located in remote areas which have high potential for solar irradiation but are far away from where the majority of electricity consumption takes place. This means that power producers or grid operators have to then build transmission lines to evacuate power from the site of generation to distribution centres as well as build secondary infrastructure such as approach roads. This has further implications for land use which should be further evaluated. One important factor that has also been overlooked so far in future energy studies for India is the lack of a government policy for disposal of end-of-life PV panels (Weckend et al., 2016). It is estimated that the country may have to deal with up to 300,000 tonnes of solar waste cumulatively by 2030 (Weckend et al., 2016), which has implications for the cost of solar PV as well as land use change. PV waste related regulation is therefore an urgent need in the country.

While this paper has focused on three low carbon electricity technologies, namely solar PV, wind power, and nuclear energy, there is also a need for further analysis of other low carbon technologies which have an important future role in India such as hydropower and biomass. Land occupation times for various technologies also require further evaluation, with consideration of the different types of ecosystems needing to be restored.

A comparison of energy technologies on the basis of just one metric, i.e. land use, is insufficient to fully justify policy decisions but is nonetheless an important metric to be considered in India. As highlighted previously, land acquisition has been cited as the major barrier to clean energy growth in the country. Quantitative debates on land use change will also have to be balanced against qualitative factors, such as public perception of risk and favourability towards certain technologies; importance of facilitating energy access in remote, rural areas; and ensuring equitable incomes for land sold. Large scale energy transitions will have to be socially validated (Miller et al., 2013). Current debates over energy futures in India are circumscribed modelling and technical studies with implicit social and sustainability assumptions that need unpacking. Lack of open engagement with social and sustainability dimensions such as land use change risks alienating conversations over energy futures from societal debates. Energy modelling studies cannot be a black box with hidden assumptions and dependencies (Pfenninger, 2017). Rigorous and transparent attention to practicalities such as land availability, grid stability, consumer behaviour, labour markets, and second-degree infrastructure needs in studies of energy futures will go a long way in ensuring that long-term energy pathways attest to the burden of proof of viability required, for them to be relevant in real world policy debates.

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Appendix

The land use for the solar power plant site can be calculated using Equation 1. The capacity factor used for solar power is 20% as per the estimates from the report into the performance of solar power parks in the country (Sharma, 2011). Plant lifetime is also accordingly derived to be 25 years. The Rajasthan solar power park under consideration has a total land area of 2000 hectares and a rated capacity of 1000 MW, i.e. 1 GW. Therefore as per Equation 1:

$$\text{Land Use } \{\frac{m2}{GWh}\} = \frac{2000000}{1*(8760/1)*0.20*25} = 456.6$$

Schneider et al (2013a) estimate the underground mine land use as 196 m^2/tU. To convert this into m^2/GWh for India, I use the information provided by the Department of Atomic Energy (DAE) in Parliament relating to the natural uranium fuel cycle in the 700 MWe PHWRs. According to the DAE, 24 kg of UO_2 (Uranium Dioxide) is required as fuel to produce 1 GWh of electricity assuming a capacity factor of 85% for Indian PHWRs (DAE, 2014b).

The weight fraction of U in UO_2 is the mass of uranium divided by the mass of uranium dioxide. Uranium has a mass of 235 g/mole while UO2 has a mass of 270 g/mole. The mass of uranium divided by the mass of UO2 (238/270), i.e. 0.8815 as the weight fraction of U in UO_2. 24 kg of UO_2 is therefore, (24*0.8815), i.e. 21.16 kg of U.

Given that 0.196 m^2 produces 1 kg of uranium, to produce 21.16 kg of U we would need (0.196*21.16), i.e. 4.2 m^2 of land area.

Land requirements for the reactor site can therefore be similarly calculated using Equation 1. The total rated capacity of the Gorakhpur site is 2800 MW or 2.8 GW given that there are four 700 MW reactors planned for the site. The total plant area according to environmental clearance is 608.48 hectares, i.e. 6084800 m^2. The plant lifetime is estimated at 40 years while the capacity factor is assumed at 85%. Therefore as per Equation 1:

$$\text{Land Use} \left\{\frac{m2}{GWh}\right\} = \frac{6084800}{2.8*(8760/1)*0.85*40} = 7.3$$

Calculations for the wind energy footprint can be made using the estimate of wind energy density in the country of 6 MW (0.006 GW) per square kilometre (10,00,000 m^2) provided by the National Institute of Wind Energy in India (National Institute of Wind Energy, 2016). The capacity factor assumed is 20% and plant lifetime as 20 years (IRENA, 2012). Using Equation 1:

$$\text{Land Use} \left\{\frac{m2}{GWh}\right\} = 0.03 * \frac{1000000}{0.006*(8760/1)*0.2*20} = 142.7$$

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