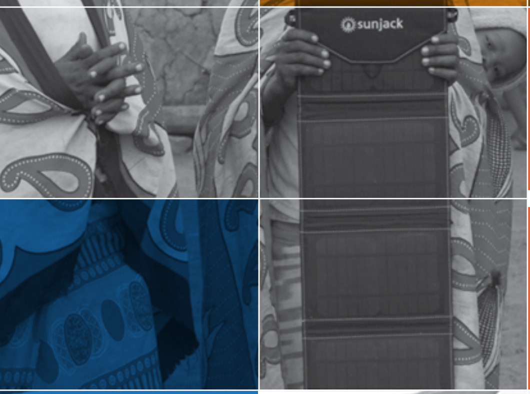

AN ENERGY REVOLUTION IS POSSIBLE

Friends of the Earth International

AN ENERGY REVOLUTION IS POSSIBLE

Full report

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Other photos page 6 Babawale Obayanju - COP20 March for System Change And Not Climate Change, 2014, Lima; page 8 Paul Glendell - Offshore wind farm; page 16 Luka Tomac - Global Day of Action, 2011, Durban; page 19 Babawale Obayanju - COP20 March for System Change And Not Climate Change, 2014, Lima.
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Project outline

Introduction

This report is the technical report that supports Friend of the Earth International's summary report with recommendations and general analysis, also entitled 'An energy revolution is possible'. To obtain a copy of this report please visit www.foei.org

What is the aim of this analysis?

The aim of this analysis is purely to calculate an investment cost of providing several regions of the developing world with 100% renewable electricity, and to compare those amounts with the gross concentrated wealth of the world's richest individuals, in order to highlight the need for economic and climate justice.

All values are in 2014 US dollars unless otherwise specified.

It is important to note that the investment cost, representing the additional investment in renewables over and above what will occur anyway, does not represent the economic cost to society. Investments in power generation are paid back over time through sales of electricity. Friends of the Earth International believe that access to energy is a basic human right and a necessary condition of a dignified life.

Greenpeace's Energy [R]evolution 2015[1] has analysed in detail the entire costs of continuing to rely on fossil fuel energy up to 2050, compared to switching to 100% renewables. They have found that overall, the cost to society of the 100% renewables option is cheaper than continued fossil fuel dependence. For while renewable power may be more capital-intensive than fossil fuel power, which also has ongoing fuel costs. The savings in avoided fuel costs pay off the higher upfront investment in renewables.

We have calculated for 100% renewable energy (electricity generation) by 2030 to demonstrate that an energy revolution to tackle climate change is achievable and the financial means exist.

What is the baseline scenario?

The International Energy Agency's (IEA) World Energy Outlook 2014 (WEO 2014)[2] has been used as the base data set underlying this analysis. The IEA is considered one of the most authoritative bodies on global energy issues, working as an entity of the Organisation for Economic Co-operation and Development (OECD), which are collectively the wealthiest countries on the planet. They collect data on energy use and project future trends for the entire globe.

The World Energy Outlook 2014 projects that globally, $20 trillion of investment is required in power generation and transmission infrastructure to 2040 to meet future power demand.

What countries are being considered?

The IEA supplies data in the WEO 2014 in country groupings classified by geographical regions and membership of OECD, with individual data provided for a handful of major countries.

We are interested in non-OECD countries for our analysis. The countries/country groupings for which the IEA provides data are shown in Figure 1.

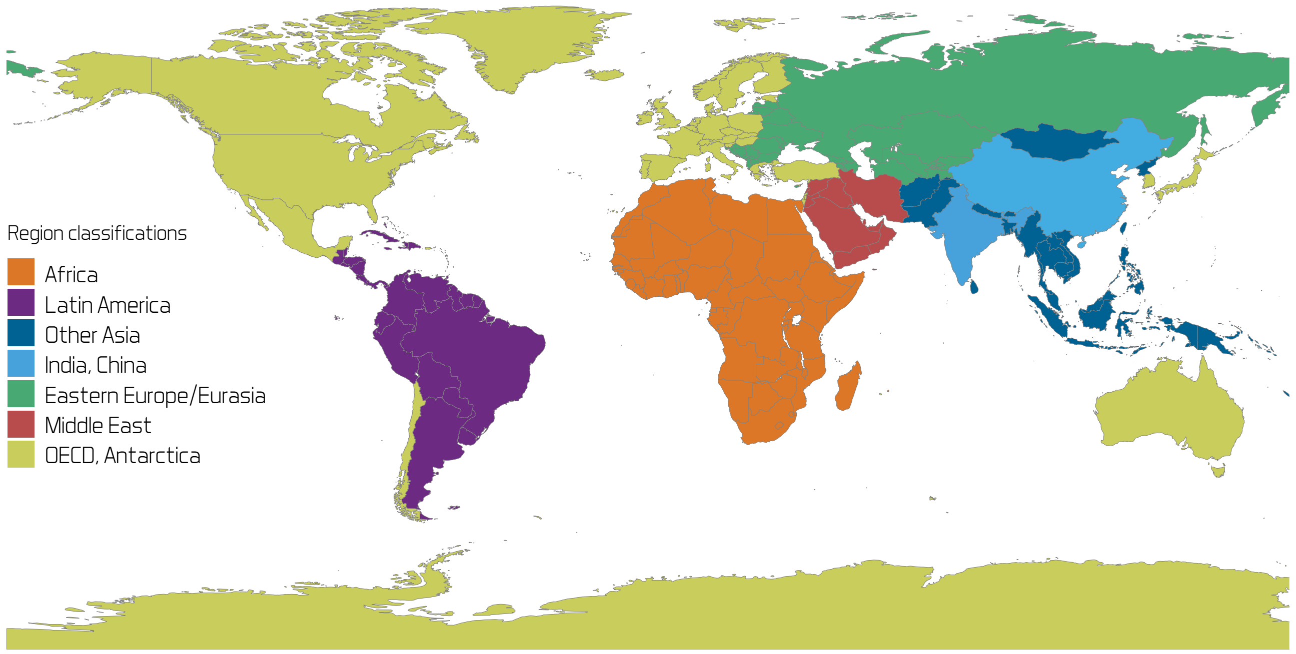

Figure 1 WEO 2014 non-OECD country groupings. Further specificity is provided for OECD country groupings and selected major countries but is omitted here for simplicity.

This analysis chooses to focus on Latin America, Africa and 'Other Asia' - non-OECD countries Asia (also excluding China and India). A full list of every country in each region studied in this analysis is provided in Appendix I. Note that as Chile and Mexico are members of the OECD, the IEA includes its data in the OECD Americas grouping, so we are not including Chile and Mexico in our analysis.

THE WEALTH OF **THE RICHEST**
782
PEOPLE
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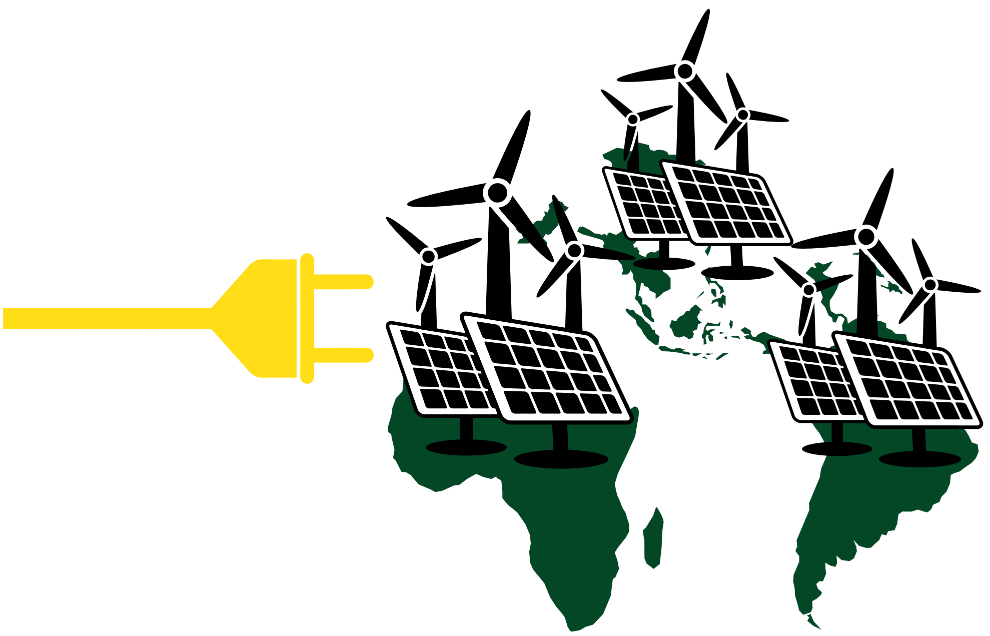
HALF THE WORLD
WITH 100%
RENEWABLE
ENERGY
BY 2030



What wealth data are we using?

The 782 wealthiest individuals on the planet (many CEOs of major corporations) hold personal fortunes of around $5.15 trillion. This research calculates the price tag of providing a large portion of the global south with 100% renewable energy (predominately wind, solar and energy storage) for the purpose of comparison with this and other figures of concentrated wealth.

The wealth data used in this report has been sourced from Deborah Hardoon, 'Wealth: Having it all and wanting more: Data and Calculations', Oxfam[3], 2015 and Forbes Billionaires 2010-14 lists.[4]

This report is purely comparative and demonstrative. It is not a policy position on expropriation of wealth or how this particular wealth should be used to power this particular energy revolution. Rather the stark nature of the numbers is to demonstrate just how rampantly unequal our current system and society are, and it is essential that this inequality change if we want a sustainable planet and society. The findings of this report demonstrate the need to create a climate safe future by addressing inequality caused by the economic system and corporations in order. The findings also clearly demonstrate that an energy revolution is possible – and much needed.

Some of the key figures used in this report for comparative purposes are: The combined wealth of the worlds' richest 53 people is equal to approximately $1,501 billion or $1.5 trillion. The combined wealth of the world's richest 32 people is equal to $1,165 Billion or $1.16 trillion.

Billionaire	Wealth 2014	Origin of wealth *Forbes*	Country
Bill Gates	76000	Microsoft	United States
Carlos Slim Helu & family	72000	Telecom	Mexico
Amancio Ortega	64000	Zara	Spain
Warren Buffett	58200	Berkshire Hathaway	United States
Larry Ellison	48000	Oracle	United States
Charles Koch	40000	diversified	United States
David Koch	40000	diversified	United States
Sheldon Adelson	38000	casinos	United States
Christy Walton & family	36700	Wal-mart	United States
Jim Walton	34700	Wal-mart	United States
Liliane Bettencourt & family	34500	L-Oreal	France
Stefan Persson	34400	H&M	Sweden
Alice Walton	34300	Wal-Mart	United States
S. Robson Walton	34200	Wal-Mart	United States
Bernard Arnault & family	33500	LVMH	France
Michael Bloomberg	33000	Bloomberg LP	United States
Larry Page	32300	Google	United States
Jeff Bezos	32000	Amazon.com	United States
Sergey Brin	31800	Google	United States
Li Ka-shing	31000	diversified	Hong Kong

Table 1 Wealth of the worlds 20 richest people in 2014 (in millions). Source: Deborah Hardoon, "Wealth: Having it all and wanting more: Data Summaries" (2015), Oxfam & "The World's Billionaires" (2010-2014 list), Forbes

What type of energy transformation do we envision?

This report outlines the costs of meeting predicted energy demand with 100% renewable energy to certain parts of the global south. While the technical feasibility of this vision is important, it is imperative that renewable energy policy is guided by certain principles which guarantee a just and sustainable energy system for all.[5]

Energy is a necessary condition for a dignified life. We need energy for fuel and electricity to cook our food, to have habitable homes and workplaces in hot and cold places, to ensure that everyone has access to basic services like health and education, to communicate and travel and to share and access information via the internet. Yet according to the IEA, nearly 1.3 billion people – or one fifth of the world's population – do not have access to electricity.

The current global energy system – the way we produce, distribute and consume energy – is unsustainable, unjust and harming communities, workers, the environment and the climate. This is fundamentally an issue of corporate and elite interests outweighing the rights of ordinary citizens and communities.

When we refer to 100% renewable energy in this report we envision it prioritises and adheres to the following principles:

1. Provides energy access for all as a basic human right

Access to energy is a basic human right and a necessary condition of a dignified life. Everyone will have access to sufficient sustainable, clean, safe, affordable, reliable and appropriate energy to meet their energy requirements for a dignified life. This means adequate energy for:

- lighting, heating and cooking
- ensuring clean water supplies for adequate sanitation
- ensuring access to essential public services like hospitals and schools
- pumping water for irrigation and to run small-scale agricultural industries and other small businesses
- communication, entertainment, and climate-safe recreation.

2. Climate-safe and based on locally-appropriate, low-impact technologies

Energy will be generated from climate-safe sources with low social and environmental impacts. This means no energy sources that:

- are high carbon or produce significant quantities of other dangerous greenhouse gas emissions through their production, combustion, distribution, or the direct or indirect land use change that they give rise to abuse the rights of local communities and Indigenous Peoples
- result in deforestation or forest degradation
- result in the production of toxic waste
- result in significant air, land or water pollution
- deplete non-renewable resources.

Energy technologies will also be appropriate to the needs of the communities who are using them and to their local and regional environmental, economic, social and cultural contexts.

3. Under direct democratic control and governed in the public interest

Energy is a common good. In a just energy system energy infrastructure and resources are therefore under direct democratic control. Decisions about the production and use of energy:

- are democratic, participative, open and accountable
- prioritise social outcomes, including energy access, fairness, environmental sustainability, and dignified work
- are governed by the principle of subsidiarity, with decisions delegated to the most local and least centralised level possible, while also allowing for sub-regional, national and regional planning and coordination
- give adequate power to all directly-affected groups to influence decisions, including energy users, energy sector workers, and people who are excluded from energy systems
- respect the rights of communities to define their energy needs and how these needs are met in accordance with their cultures and ways of life, as long as these choices do not have destructive impacts on other people and communities.

4. Ensures the rights of energy sector workers, and their influence over how their workplaces are run

Workers involved in all aspects of the energy system are assured of their basic rights, including the right to freedom of association and collective bargaining, a living wage, safe, secure and dignified work, and influence over how energy infrastructure is developed and run.

5. Ensures the right to free, prior and informed consent and rights of redress for affected communities

The construction of new energy infrastructure will be done on the basis of the free, prior and informed consent and appropriate compensation / remuneration of affected communities and will respect the other rights of Indigenous Peoples and affected communities, and customary law. The same holds for the extraction of any material inputs needed to build energy infrastructure and develop and produce energy technologies.

6. As small-scale and decentralised as possible

Energy infrastructure, including supply and distribution, will be decentralised as much as possible. This is the case where energy solutions come from local opportunities at both small and community scale, and where energy is generated at or near the point of use, and either connected to a local distribution network system, supplying homes and offices rather than the high-voltage transmission system, or as stand-alone systems entirely separate from the public network.

Decentralisation will help ensure energy access for people in remote and rural areas; will facilitate subsidiarity and community or local ownership and control; and will reduce energy wastage in distribution because energy and heat will be produced close to the point of use. Some large-scale renewable energy infrastructure such as large-scale wind or concentrated solar energy may be needed to complement decentralised supply to large towns and cities and essential public services and infrastructure. However, decision making over any such large-scale infrastructure will be subject to the democratic and participative decision-making process set out above, and subject to rigorous testing to ensure that measures to reduce energy dependence have already been exhausted and that the end use of the energy produced has high social importance or value.

7. Ensures fair and balanced energy use, reduced dependence and minimum energy waste

Energy use is broadly fair and balanced globally and within countries, economical, and with minimum energy waste.

8. Reduces energy dependence

Reducing energy dependence and energy consumption does not have to mean a drastic reduction in living standards for ordinary people, although it will have to mean limits on excessive energy use from very energy-intensive activities. Increasing energy efficiency and regulating energy-intensive industries: Reducing energy dependence also necessitates efforts to increase energy efficiency. The IEA estimates that four fifths of the potential to reduce energy demand in the buildings sector and half of the potential to reduce demand in industry remains untapped.

Some of the most important energy-savings options include improving heat insulation and building design, improving the efficiency of electrical machines, replacing old electric heating systems with renewable heat production, and reducing energy consumption by goods and passenger vehicles. It is important to recognise however, that energy efficiency does not automatically lead to reduced energy demand or reduced energy dependence overall.

The transformation of our energy system will also require us to look at energy-intensive industries such as aluminium, steel, chemicals, cement and car production and ask what place these industries have in a sustainable economy and how they need to be transformed at their core, not just improved with energy-efficiency measures. Hence, while energy efficiency is important, it is not a solution by itself. Energy-savings measures must be integrated into a far bigger rethink of how to completely transform our economies towards sustainability and away from energy dependence.

What electricity consumption are we projecting?

Per-capita electricity consumption varies significantly across the countries being considered here, and of course would vary significantly amongst the population of individual countries as well. This analysis focuses on electricity only, and does not extend to other forms of energy consumption such as transport and heating. Electricity consumption is closely correlated with economic growth and income levels. Any future projections must entail a set of assumptions around the scale and type of economic activity and population growth. It raises questions of equity within and across societies. What changes in policies and societal priorities could change the projected outcomes?

We use the WEO 2014 projections of future electricity consumption – also referred to as electricity or power demand – by region as our baseline, as an internationally-recognised standard, and seek to determine how that same level of demand might be met using renewable energy. We note that the IEA projections of per-capita energy use for 2030 still have some parts of the world remaining at relatively lower levels of energy usage. However, any other modelling was beyond the scope of this study, and as noted above, we believe a 100% renewable energy future must prioritize access to energy for all, community control and reduced energy dependence. Furthermore, this report aims to highlight existing inequality by providing a high level comparison of renewable energy investment costs against figures of concentrated global wealth.

What would a fully renewable energy system look like?

Renewable Energy Technologies

There are a range of technologies available to provide reliable renewable electricity, outlined below. This report seeks to predict the cost of a 100% renewable energy system. The energy mix presented is based on regional renewable energy generation capacity factors, however it is only a general overview that represents one possible scenario. It is the right of communities and in some cases, governments and other stakeholders, to determine their own locally appropriate renewable energy mix.

Variable renewables - vast resources, different characteristics

Power from the wind and the sun are set to become the primary energy sources for society in the 21st century. The potential from these resources is vast, eclipsing many times over humanity's entire current energy use. As their availability does change with the weather, a different set of strategies is required (as compared to fossil fuels) to ensure these sources can meet our needs.

Wind power

Wind power is one of the most mature renewable energy technologies. Wind power has been installed in over 80 countries, with 370GW of cumulative global capacity as of 2014[6]. While it is variable, as power output fluctuates with wind speed, it can be used day or night and usually follows reliable patterns on a seasonal average basis.

Solar photovoltaics (PV)

Solar PV is a fast-maturing renewable energy technology. As of 2014 it had reached 178GW of global capacity[7]. While solar PV performs best in direct sunlight, it is also able to produce some power from diffuse sunlight when clouds cover the sky. PV's modular nature allows it to be used at any scale from tiny panels producing enough power for a few small lights in a remote village, to utility-scale installations covering entire fields. Obviously solar PV can only generate electricity during the day unless coupled with batteries or other storage, and also follows reliable seasonal trends.

Concentrating solar power (CSP)

CSP is a different method of using the sun's energy to generate electricity. It uses combinations of mirrors to concentrate sunlight to heat fluids to high temperatures, which is then used to run steam turbine cycles similar to those used in conventional fossil and nuclear power plants. Some CSP technologies use molten salt as the operating fluid which can then be stored for later use in insulated tanks, thereby integrating very high efficiency energy storage into the power plant. CSP requires direct sunlight to operate, and while sunlight is only available during the day, plants with integrated storage can operate at night and through cloudy periods. CSP is a less mature technology and therefore more expensive than solar PV and wind, though with great potential to reduce in costs in the future.

Storage - an essential complement to wind and solar

There are many ways of storing energy for later use. This analysis will use the characteristics and costs for several representative energy storage technologies, however it is entirely possible and likely that with future technological development, other types of storage will become available and cost-effective. While CSP-integrated thermal storage is useful in areas that have a high enough direct sunlight resource for CSP, the other technologies listed here can be used in different situations.

Batteries

A range of battery technologies for use with renewables are maturing and reducing in costs. Recent analysis of current trends suggests batteries will cost $250/kWh (or less) by 2020, and $150-200/kWh by 2030[8,9]. These costs could be realised earlier and reduced further, but these assumptions are used as a conservative expectation for this analysis. Battery systems, similar to solar PV, are modular and scaleable – they can be sized to supply a single dwelling, a community, a large commercial factility, or be integrated into the electricity grid. They are well-suited to the decentralised energy model that will likely play a large role in the global south. There are also a range of types of batteries using different materials at various stages of development, with many offering great potential.

Pumped Hydro Energy Storage (PHES)

Pumped Hydro Energy Storage (PHES) is the most widespread form of grid-scale electricity storage world-wide, and is a mature technology. It consists of simply pumping water up an upper reservoir with excess/cheap electricity, and later using this water to generate power with standard hydro turbines, released to a lower reservoir or body of flowing water, or even the ocean in the case of saltwater PHES.

Conventional large hydro dams rivers to create very large reservoirs – capable of holding enough water to generate power for weeks to months. Unlike this, PHES systems built to store enough water several hours worth of generation are much smaller. The reservoirs can be artificially constructed with shallow walls without damming an existing water catchment, and can be sited to avoid ecologically sensitive areas. A system capable of providing 500MW of power for 10 hours, with 100 metres height difference between reservoirs, would need an upper reservoir 30 metres deep and 1km in diameter (if a circular footprint is used).

A review of PHES technology and status in 2014 found that system costs of well-sited PHES facilities could be in the order of $200-300/kWh[10]. Costs will vary from site to site due to different topographical and civil engineering issues, but this still means that the more affordable PHES sites offer a cheap, large-scale energy storage solution with relatively low environmental impact.

Other renewables - dispatchable but more resource limited

The renewable energy sources in this section are generally limited due to geographic and ecological constraints. They are not directly dependent on the daily availability of sun or wind to provide power (though hydropower and bioenergy do depend on seasonal weather patterns). They can draw on reserves of potential energy (subterranean heat, stored water or stockpiled biomass) to generate power on demand – dispatchable power.

Geothermal power

There are a range of different methods for using the heat naturally created within the Earth's core for useful purposes. In areas where the local geology allows relatively easy access to high temperatures, usually along geological fault lines, geothermal electricity has been generated for decades. For example, 25% of Iceland's electricity comes from geothermal power, though as they also use geothermal heat directly to heat buildings, it accounts for 66% of Iceland's total primary energy use[11]. In parts of the world which have suitable resources (Figure 2), there is the potential to significantly expand the use of geothermal power. Geothermal power can reliably generate electricity constantly, regardless of weather or seasons.

Hydro

Hydro power from large mega-dams causes severe ecological and social problems. Hence this analysis explicitly chooses to consider a future without building any more large hydro dams, which we consider included in the definition of dirty and harmful energy. The continued use of existing hydro facilities has been factored in to help meet demand as a generator of last resort, as it is often used in conventional power markets today.

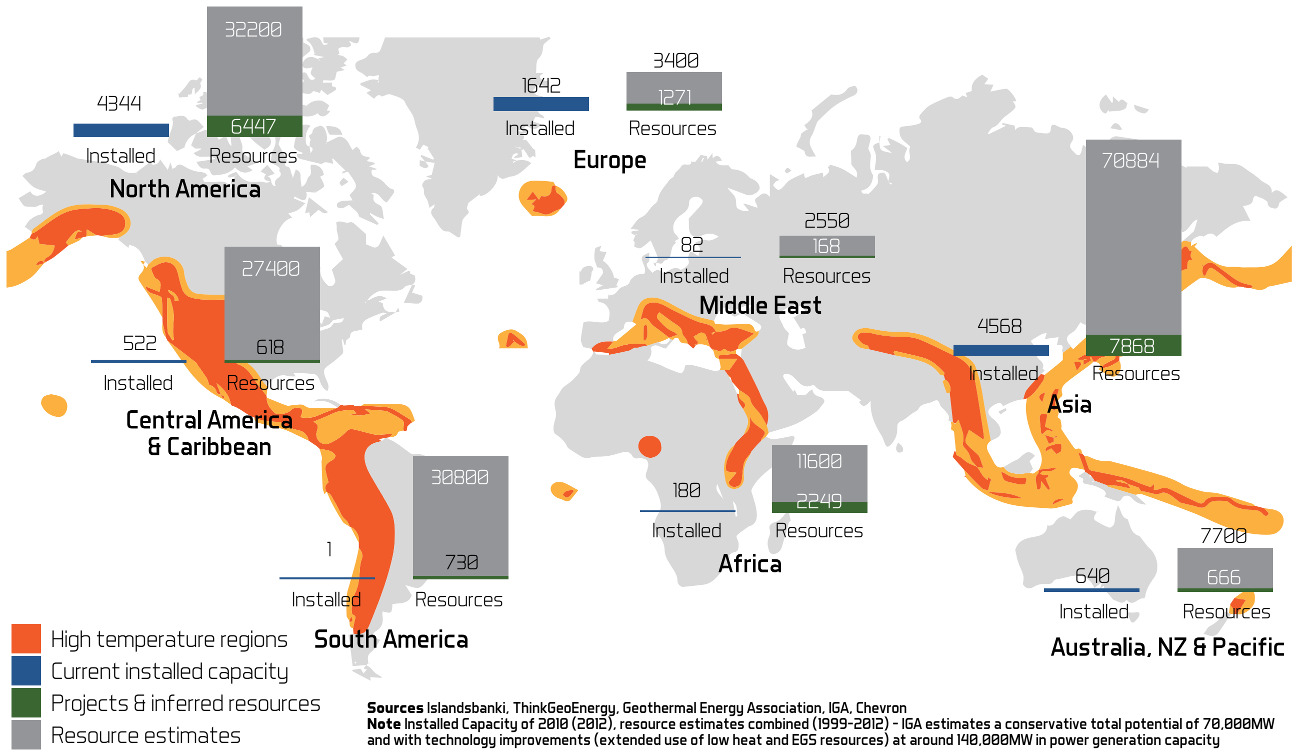


Figure 2 Geothermal power globally, installed and potential. Source: ThinkGeoEnergy[12]

Bioenergy

Due to a range of ecological and social reasons, we do not see bioenergy as an energy source to be used extensively for power generation. We have not factored in any more bioenergy than the small amounts projected by the IEA in each region. There is a small role for bioenergy alongside existing hydro to meet the final few percent of electricity demand, helping to get through particularly low periods of wind and solar.

It should be noted that in many rural parts of the developing world, biomass from traditional sources – woodcutting, animal dung etc – is already the main source of energy for heat and cooking. The use of wind and solar power to mostly replace traditional bioenergy use will help to reduce overall levels of biomass harvesting.

A Note on Energy Source versus Energy System

Although we have listed several energy sources which are renewable and could be part of a sustainable and just energy future, we reiterate that our planet and its people need a much bigger transformation than merely a switch of the energy source. Only considering an energy source switch, rather than a deeper energy system transformation, involves some serious pitfalls. Some of these pitfalls to be mindful of include[13]:

1. Corporations will try to define what constitutes 'renewable energy',
2. Construction of renewable energy infrastructure could drive land grabbing, enclosures,
3. Human rights abuses and environmental destruction, land grabbing, environmental destruction and human rights abuses from raw material extraction for renewable energy infrastructure,
4. Greenhouse gas emissions from the rollout of renewable technologies,
5. Poor environmental and labour standards in renewable energy technology manufacturing,
6. The renewable transition becoming a Trojan horse for energy privatisation,
7. Lack of public consent for renewable energy.

These pitfalls can be addressed and avoided only if the transition to renewables is carried out fairly, in a consultative manner, with a whole of supply chain approach to social and environmental sustainability.

How would it work?

The main question arising when considering how a country could run primarily on renewable electricity is variability – how to use power sources which depend on the wind and sun to meet electricity demand which depends on human patterns of behaviour. A variety of studies from all over the world have looked at this very question[14]. They have generally found that renewable energy can provide most or all of a country or region's electricity needs, by using a number of strategies:

1. Using a portfolio of different types of renewable energy technologies, which have different production characteristics.
2. Generating more electricity than is required to make sure that there is enough even at times of low production.
3. Using energy storage.
4. Connecting renewable power plants across a wide geographical area, taking advantage of different weather patterns.
5. Changing how electricity is used to better fit with production from renewables.
6. Using power from non-weather dependent dispatchable sources.

What can we learn from analyses of high penetration renewables scenarios?

In recent years there have been a number of very detailed studies into how electricity systems can operate with high penetrations of renewables. These have modelled the production and consumption of electricity on an hourly basis across many years of data, using actual electricity demand data from existing grids. Meteorological models providing wind speed and solar radiation data have allowed the teams to model the power output of new wind and solar installations that would need to be built to provide electricity in their high-penetration scenarios.

Several of these studies have been used to inform the assumptions for this study.

Using a combination of strategies to provide 100% renewable electricity for Europe

Rasmussen et al (2012)[15] used a similar method modelling hourly demand, solar and wind output, across 27 European countries. They then sequentially analysed how using a number of different strategies could increase the proportion of demand that can be met by variable renewables. They assumed unconstrained transmission in their scenarios.

Storage with overgeneration

Trying to meet 100 TWh/yr of demand by generating exactly 100 TWh/yr of renewable electricity is very difficult, as it would require that every unit of electricity generated in excess of demand at one time is stored, potentially for a long time, for eventual later use. Rasmussen et al show that combining the use of storage with overgeneration – that is, generating more renewable electricity than demand – dramatically reduces the amount of storage required to achieve a fully renewable system. Figure 3, taken from the Rasmussen et al paper, shows this clearly. With an average Variable Renewable Energy (VRE) generation of 1.25 times annual average demand, the amount of storage required drops by over 80%.

Storage size

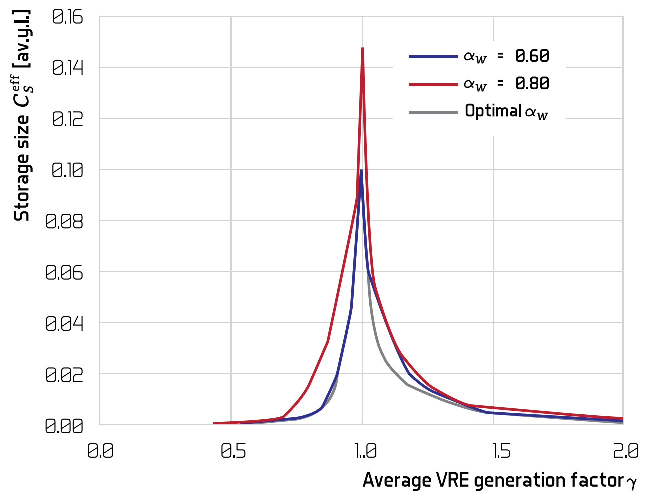


Figure 3 Storage results from Rasmussen et al. α_W refers to the proportion from wind of total renewable generation, with solar as the remainder.

The next stage of analysis looked at what size of storage is most useful. For the European scenario studied, it was found that a storage size equivalent to 6 hours of average demand was sufficient to smooth out most variability over the day/night cycle. Beyond this size there were strongly diminishing returns. A system with 25% overgeneration and 6 hours of storage was capable of meeting 97% of annual demand. The last 3% is due to rare periods when both solar and wind generators have low output for a number of days in a row, and providing short-term storage capable of meeting all of these possible scenarios would be difficult, hence the diminishing returns. However it should be noted that this 'optimum level' of 6 hours storage is for the scenario with 60% wind / 40% solar in Europe, as Europe generally has a good wind resource but a poor solar resource. The authors note that if the grid was trying to run primarily on solar energy, more storage would be needed, up to 12 hours for a 100% solar grid. This is because storage plays a more important role for smoothing the day/night cycle of solar, whereas wind power blows both day and night and storage smooths this production out over a shorter timescale.

Dispatchable renewables

There are of course other renewable electricity technologies which can flexibly generate power on-demand, such as hydropower, biomass combustion and geothermal. However the scale of these technologies is more limited than that of wind and solar, due to the need for specific geography in the case of hydro and geothermal, and competition with other demands in the case of biomass. These technologies have a role to play in a renewable energy future by balancing wind and solar, and will likely be mostly used in enabling the final few percent of a 100% renewable grid to be achieved. Hydro power systems are often used today as the 'generator of last resort' in power grids with bid-in power markets, where hydro generation is used on rare occasions when conventional generators are struggling to meet peak demand. Due to the many ecological and social problems caused by hydropower from large scale dams this analysis chooses to consider a future without building any more large hydro dams.

Rasmussen et al next took into account the electricity currently provided by existing hydro power systems in Europe, equivalent to 4.6% of the annual demand. When this was included in the model, essentially meaning that solar, wind and storage only needed to provide 95.4% of demand, the fully renewable system was achieved more easily, requiring only half the amount of overgeneration.

The final results for the pan-European renewable grid modelled are given in Table 2.

Parameter	Value
Annual average demand	3240TWh/year
Renewables overgeneration	112%
Storage size	2.22 TWh (6 hours of average hourly demand)
Optimal wind/solar proportion	60% / 40%
Demand met with wind/solar/storage	95.4%
Demand met with seasonal hydro	4.6%

Table 2 Characteristics of pan-European 100% renewable electricity system from Rasmussen et al (2012)

The significance of increased transmission

In the regions of the developing world looked at in this analysis, existing transmission interconnections between countries are unlikely to be as available as Europe. The studies referenced below find that

- while better transmission to link up wide geographical regions does help enable renewables to meet more of electricity demand,
- even with no or low levels of transmission it is still possible for renewables to meet a large portion of demand (in the absence of other strategies like storage and overgeneration), and
- the incremental benefits of significantly enhanced transmission links are relatively small, with diminishing returns.

Becker et al (2014)[16] modelled a high penetration of wind and solar photovoltaic power in the lower 48 states of the USA, divided into 10 regions specified by the U.S. Federal Energy Regulatory Commission. Rodriguez et al (2014)[17], performed a similar analysis across 30 European countries. These specifically looked at effect of geographic dispersion by considering individual member countries or regions, with and without various levels of transmission.

These studies did not include storage in their analysis, and assumed that at times when renewable generation is insufficient, flexible (dispatchable) generation can be used to meet the shortfall – much like fossil gas turbines are used today. The amount of electricity generated from wind and solar was specified as equal to the grid demand, on an annual average basis – which is actually a worst case scenario for sizing a renewable grid (see Figure 3). However as no storage was employed, at times when wind and solar production was in excess of grid demand it was wasted, while at times when it was less than grid demand backup power was used. The key variable being sought was "what proportion of grid demand can be met by wind and solar over a whole year". The results are given in Table 3.

Level of transmission interconnection between countries/regions	Proportion of annual demand met by renewables Rodriguez et al (Europe)	 Becker et al (USA)
Zero interconnections*	67-80% (average 76%)	70-77%
Existing interconnections	79%	
Double existing interconnections (x2.1)	82%	
Unconstrained interconnections	85%	82%

*Range of results for individual FERC regions or European countries

Table 3 Results of Rodriguez et al (2014) and Becker et al (2014)

These results are useful for understanding the benefits of linking up renewables over a large geographical area via transmission interconnection. These studies indicate that the incremental improvements in investing in greater transmission are part of the solution to creating renewable electricity grids. However it is instructive that 67-80% of demand can be met by renewables without storage or overgeneration in the absence of a large transmission grid in the European study – each country was modelled as its own separate grid. A theoretically unconstrained transmission grid increased this by only 9 percentage points to 85%. The U.S. study had broadly similar findings.

Another finding worth noting is that preliminary results of an Australia-wide renewables modelling study indicates that clustering wind farms in 4 main areas across the continent provides a similar benefit (in terms of diversity of resource) to wind farms scattered individually[18]. This suggests that the benefits of geographical diversity can be gained with a targeted approach to transmission.

Differences in the developing world

There are important ways in which the renewable electricity future in the developing world may be quite different from that in Europe and the United States. These include:

- The regions of the world that this study focuses on have different solar and wind resources.
- Developing countries may not have, presently or in the future, an extensive transmission grid.
- Demand management and current reliability.

Renewable resource comparison

On the first point, a high level look at global solar and wind resources on the maps on the following pages gives some insight. Figure 4 shows average wind speeds across the world, which correlates with power output of wind turbines. Figure 5 shows solar resource measured as Global Horizontal Irradiation (GHI). GHI is a measurement of both direct sunlight and diffuse sunlight – scattered sunlight which is present even with cloud cover – which is useable by solar photovoltaics, as falling on a plane horizontal to the Earth's surface. Figure 6 shows Direct Normal Irradiation[19], which measures only the direct portion of sunlight, as falling on a plane which precisely tracks and matches the angle of the sun over the course of the day. DNI is the relevant resource to consider for Concentrating Solar Power plants. These maps have been created with data supplied by Vaisala/3Tier, a global renewable energy consulting company[20].

The windspeed data shows that the developing regions considered in this study have generally a similar or worse wind resource than Europe and the contiguous United States. The regions close to the equator have a very poor wind resource, while it is generally better away from the equator. The solar data shows that these same developing regions considered have generally a superior solar resource to Europe and the US. Even South-East Asia and other equatorial regions which have a somewhat lower DNI resource due to cloud cover still receive enough total GHI to have a comparable or higher solar potential to southern Spain. Away from the equator the solar resource is comparable or significantly higher than the south-west United States.

This suggests that the regions in this study will benefit from a higher share of solar in their renewables mix than wind, a reversal of the results of the European and US studies.

Large grids or small?

In Africa there exists today a large number of transmission interconnections between countries across the continent (see Figure 6). However it is possible and indeed likely that rural parts of the world without any grids currently may need to 'leapfrog' conventional fossilised electricity grids, and use small-scale micro-grids with localised renewable energy sources. This approach has great potential because renewables, particulary solar PV, are modular so can gradually be added to as a community is able to afford more energy. The concept of 'climbing the solar ladder'[21] envisages communities starting with solar lanterns to replace kerosene lamps, to small solar panel & battery systems able to provide a house with energy after dark, to community –level microgrids also able to power labour-saving machines such as grain milling, sewing machines and other enterprises that will generate income.

When it becomes more affordable there are benefits to joining an electricity network with more diverse generation, and the potential to aggregate storage. It is likely that the renewable future of the regions in this study will have a more significant role for micro-grids than that which exists in developed nations today, but still incorporate large-scale and decentralised grid-connected power sources, especially to supply large urban areas with electricity (note that small-scale renewable generation can also be grid-connected). It is not within the scope of this study to specifically prescribe how the mix between these options will play out.

Significant investments in new and upgraded transmission will be required both for a renewable and a fossil fuel future. Out of the $20 trillion the IEA projects will be spent on all new power infrastructure worldwide to 2040, $8.7 trillion of this is on transmission alone. The IEA estimates only 4% of this is needed specifically to integrate renewables into the grid[22]. Estimating whether or how much extra transmission would be required in a fully renewable future would also need to account for transmission investments that would have occurred anyway – to connect new fossil and nuclear power plants, and supply buildings and communities that are not currently on the grid with new connections. The complexity of this exercise is beyond the scope of this study, and as such we do not include any extra transmission costs in our results.

Reliability expectations and demand management

Many parts of the developing world that are connected to the electricity grid today do not receive power with the same reliability as a grid in more developed countries, which are typically tightly regulated to ensure greater than 99.99% of demand is met. In contrast, rolling blackouts are a commonly used method of 'demand management' in developing countries, with particular towns, or parts of cities, receiving power only on some days, or for limited hours per day. The electricity grids are less likely to be well-maintained, increasing the occurrences of unexpected power outages. Increased use of decentralised renewable energy is likely to offer a significant improvement in the current situation in many places.

'Demand management' is a practice often discussed in developed countries in the context of dealing with extreme situations for the electricity grid – dealing with the highest peak demand by arranging for some industrial facilities to temporarily shut down, or timing hot water systems and pool pumps only to operate at off-peak times. Using strategies like these to time-shift electricity demand by a few hours will likely play an important role in a renewable future, by using more power at times of high wind and solar output, and using less at times of low output. It may be that in developing countries demand management is easier to implement due to different existing expectations of the availability of grid electricity.

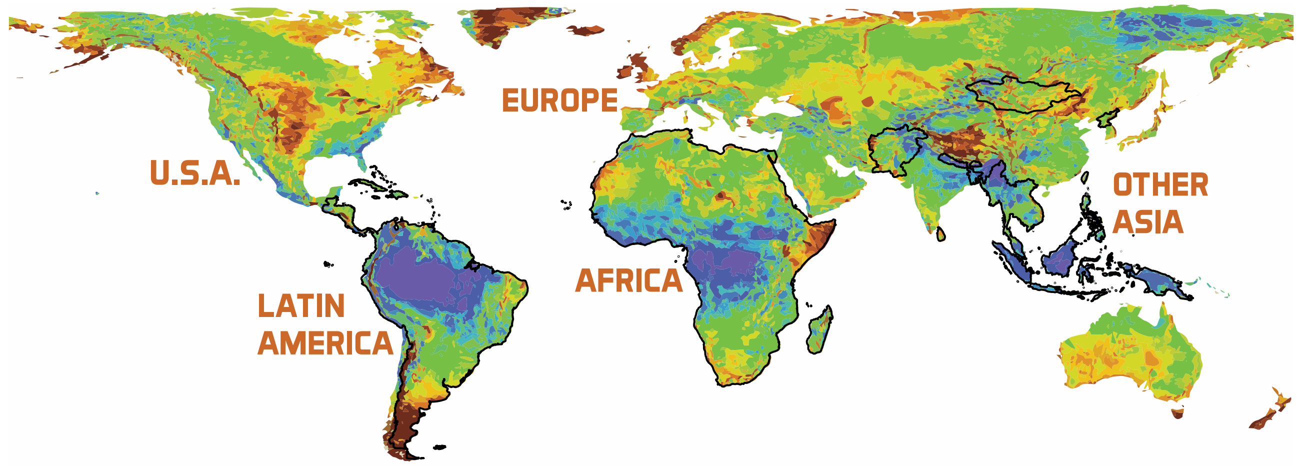


Figure 4 Windspeeds at 80m height above ground. Blue is lowest resource, red/brown is highest. World regions relevant to this study outlined in black. Sources: see note 20

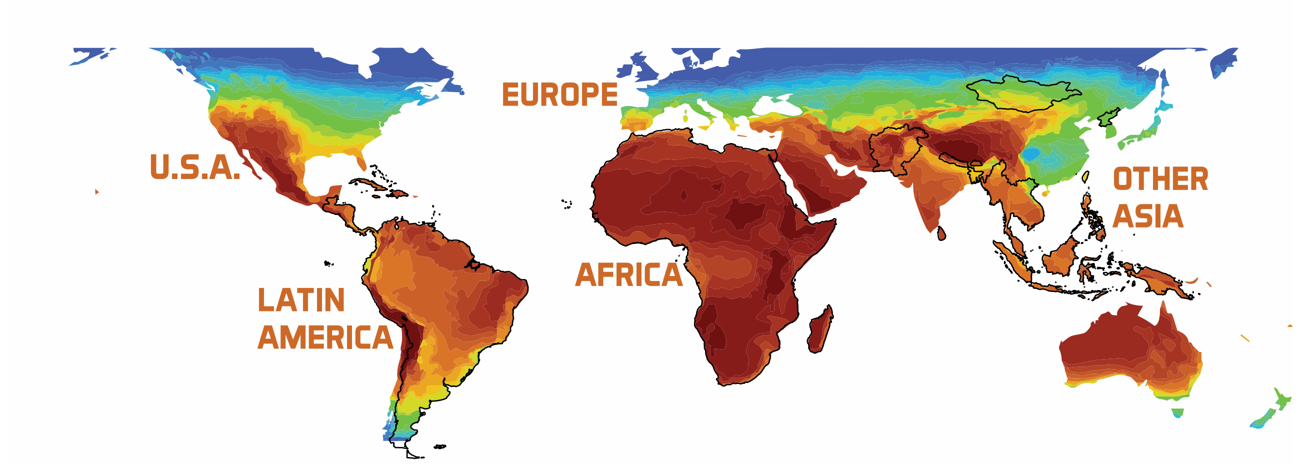


Figure 5 Solar Global Horizontal Irradiation (GHI) resource. Blue is lowest resource, red/brown is highest. World regions relevant to this study outlined in white. Sources: see note 20

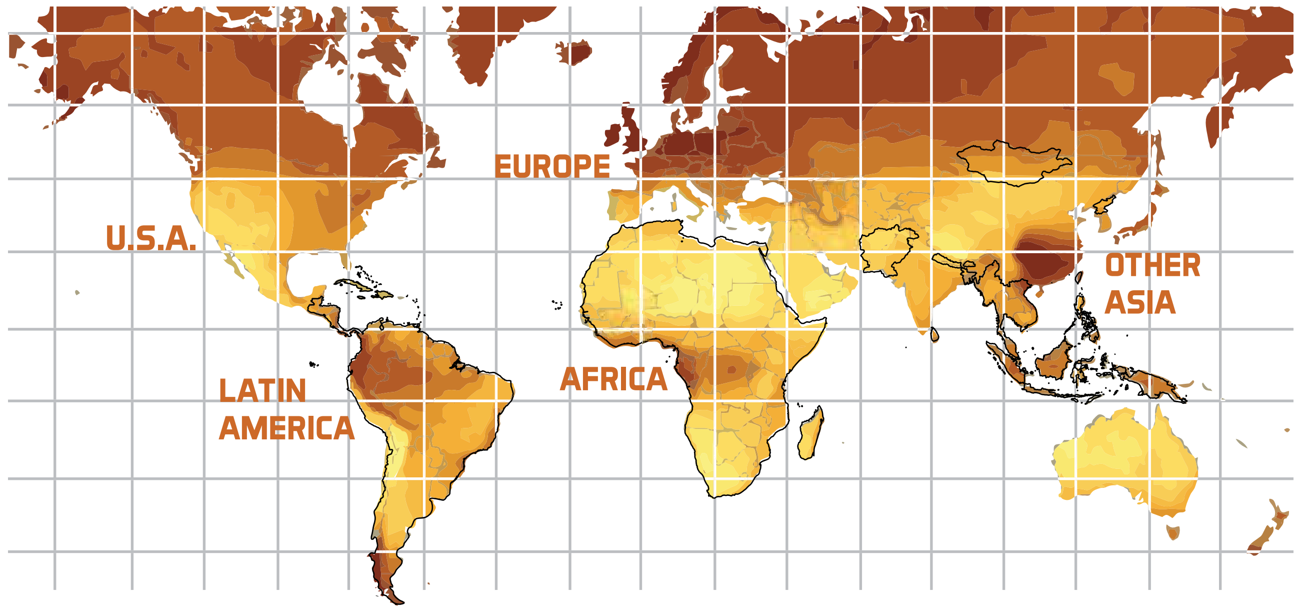


Figure 6 Solar Direct Normal Irradiation (DNI) resource. Dark colours are lowest resource, light is highest. World regions relevant to this study outlined in black. Sources: see note 19

Methodology

Detailed hourly modelling is beyond the scope of this study. Based on principles derived from the results of the European and US studies, and making conservative assumptions, we specify a high-level 100% renewable electricity generation scenario for several regions of the developing world.

Detailed results and calculation steps can be found in Appendix II.

General assumptions and methodology

Generation and demand

Demand for each region is calculated based on projected electricity demand in the WEO 2014[23]. The WEO also gives electricity generation for each region[24], which for 2012 is 12-22% greater than demand in the regions considered. This would be due to a number of factors, primarily

- Own consumption in fossil and nuclear power plants, which have significant parasitic loads due to pumping and compressing heat transfer fluids.
- Losses in transmission and distribution networks.

Wind and solar PV technologies do not have the parasitic loads associated with fossil and nuclear power stations as their energy conversion mechanisms are simpler and more direct. Some transmission and distribution losses will remain, though are expected to reduce over time as network investment improves efficiency, and decentralised renewables are able to generate power close to the point of consumption.

For our renewable scenario analysis, this generation in excess of demand is assumed to reduce by 50%, such that the final electricity generation requirements are 6-11% greater than the underlying demand across the regions studied. This new generation requirement is considered to be the final gross electrical demand for the purposes of our analysis.

Variable renewables verus dispatchable renewables

Rasmussen et al showed that combined with some dispatchable renewables (hydro), variable renewables (solar and wind) combined with storage could meet 95% of demand. For our regions we will be satisfied with variable renewables meeting less than 90% of demand. Dispatchable renewables – hydro (only capacity already existing in 2012), geothermal and bioenergy will make up the remainder. While on the timescale of minutes to hours CSP with storage can be considered dispatchable, as its output is inherently dependent on the solar resource it is considered a variable renewable along with wind and solar PV for our analysis.

Renewables overgeneration

The final scenario in Rasmussen et al required a renewables generation of 112% of annual demand.

Our scenarios will consider a renewables generation equal to 130% of annual demand. This excess overgeneration is a conservative assumption to allow for the fact that there will be real-world differences in renewable resources, transmission constraints and load profile between the regions we are studying, and the European scenario in Rasmussen et al.

Storage

Rasmussen et al modelled 6 hours of storage as the optimum for their European scenario. This scenario also found that approximately 60% of generation from wind was optimal due to the good wind resource and relatively poor solar resource of Europe. Their results of other mixes with higher solar shares find that more storage is required for scenarios with a higher proportion of solar, up to 12 hours of storage for a 100% solar grid.

As the regions of focus in our study generally have a better solar resource and similar-to-worse wind resource than Europe, our scenarios use more solar and more storage – detailed in the following regional-specific analyses.

This storage is not specified in terms of scale or technology, as we are not specifying in detail the nature of these future renewable electricity supply systems. As discussed, a generic cost of $200-$250/kWh of storage capacity has been used. This could be off-grid batteries, grid-connected batteries, utility-scale storage such as pumped hydro energy storage or other storage technologies.

The only exception is that CSP plants have been assumed to have 6 hours of storage integrated into them[25]. This has been accounted for in calculating remaining storage requirements.

Off-shore wind and large versus small-scale solar PV

The IEA costings matrix[26] allows for separate costings and annual capacity factor for offshore vs onshore wind, and large-scale vs small/building scale solar PV.

Offshore wind is more expensive than onshore wind but can generate at higher capacity factors due to better wind resources offshore. We have assumed that 15% of wind power in each region is offshore.

Large-scale solar PV will generally be grid-connected, while small-scale solar PV may or may not be grid connected. We assume that one-third of solar PV in our regions is large-scale, with the remaining two-thirds small scale – except for Other Asia where the assumption is 20%/80% large-scale/small-scale.

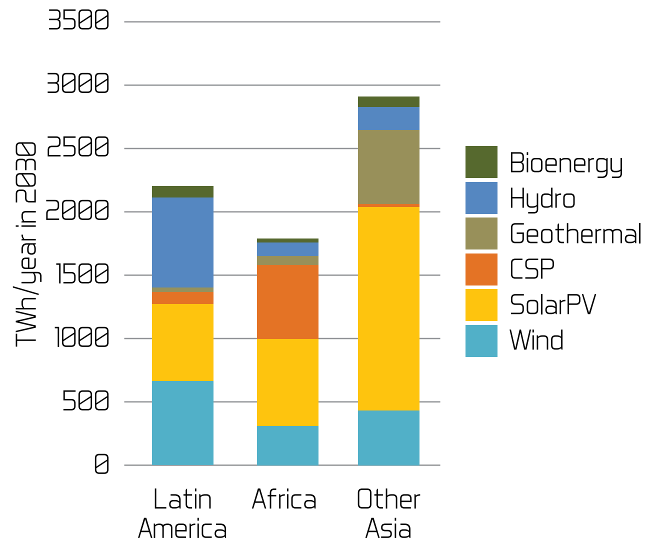


Figure 7 2030 generation by technology under 100% renewables scenario

Region-specific assumptions and analysis

The high level generation mix results are shown in Figure 7. The following pages outline the analysis for each region separately.

Renewable energy resources in Africa

Africa - solar resource

The continent of Africa has overall an excellent solar resource. Even in the equatorial regions which experience higher cloud cover, the solar GHI resource is among the best on the planet (see Figure 5 and Figure 8). Outside of this equatorial band, in most of the northern and southern areas of the continent, the DNI resource (most relevant to CSP technology) is among the best on the planet (Figure 6).

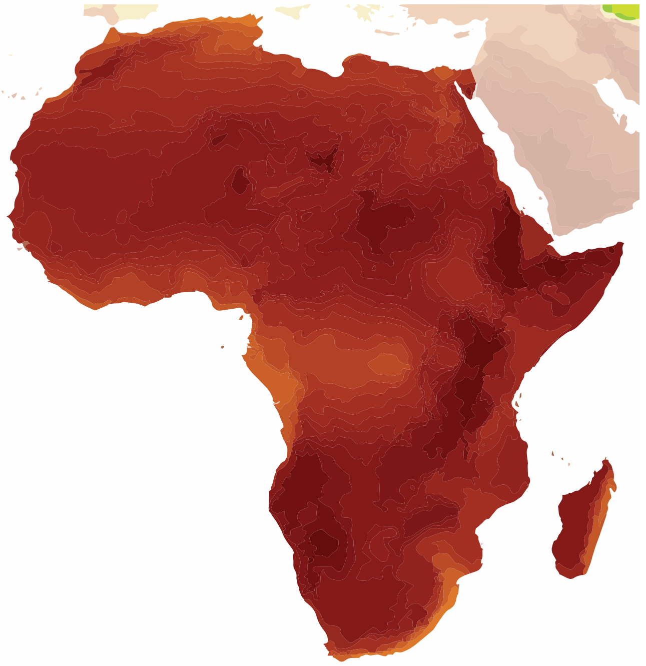


Figure 8 Solar energy resource (GHI) for Africa. Sources: see note 20

Africa - wind resource

Like most continents, Africa has both regions with very high and very low wind power potential. Coastal areas in the far east, north-west and southern parts of the continent have particularly good wind resources (as well as pockets of the Saharan desert and northern Madagascar), while much of the equatorial part of the continent has quite poor average wind speeds.

Africa - geothermal and hydro power

Geothermal in Africa is likely to be located primarily in the Rift Valley region. Some parts of the continent have already tapped into hydro potential significantly, while other areas have not.

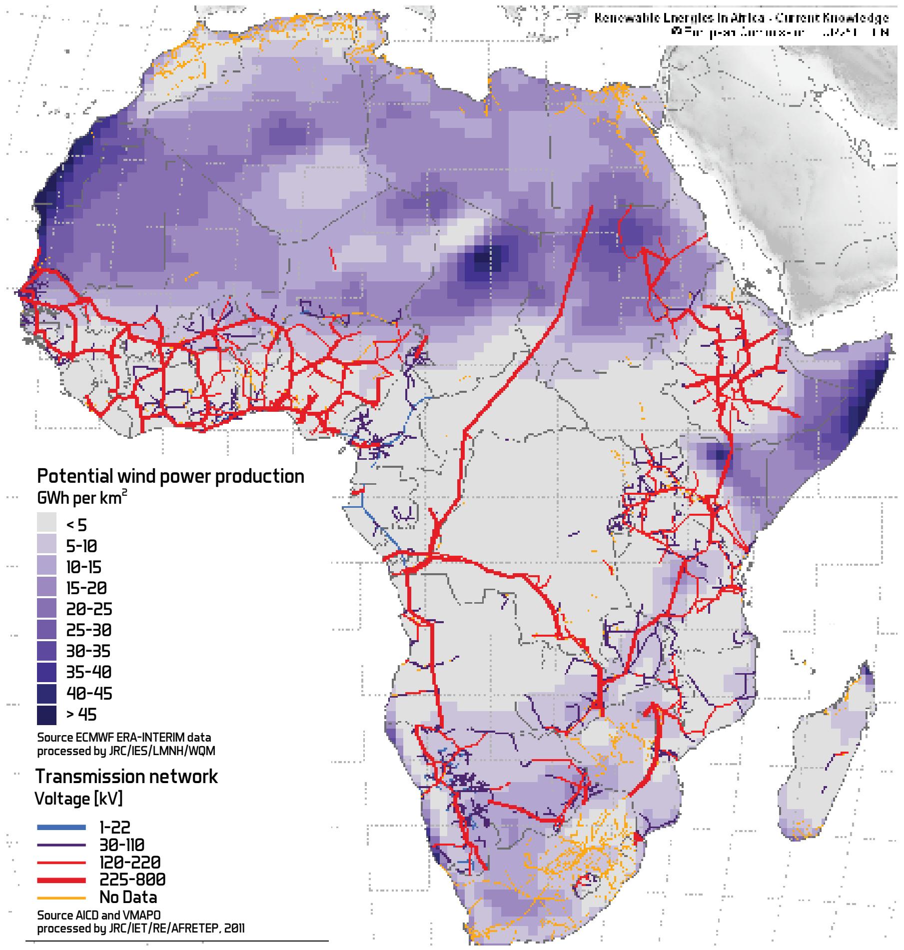


Figure 9 Potential wind power production for Africa, also showing existing transmission lines. Source: EC JRC[27]

What a renewable energy future for Africa could look like

The vision of a renewable energy future for Africa in this analysis is detailed in Table 4 and Figure 10, and would broadly consist of:

- Solar PV distributed across the continent, in standalone systems, microgrids and grid-connected installations.
- Some wind power, starting in southern African countries which already have stronger grids, as well as some in the more remote eastern and north-western parts of the continent which will require further transmission links.
- CSP with storage in the northern and southern parts of the continent, providing important flexible balancing power to electricity grids.
- Use of the existing hydro dams, an increase in geothermal capacity and a small amount of bioenergy to provide 12% of electricity from non-weather dependent renewable resources.
- Storage equivalent to 10 hours of average demand.

RE source	TWh/yr in 2030	% of total	Notes
Wind	322	18%	Starting near today's grid, extending to better areas
Geothermal	72	4%	Primarily in Rift Valley region
SolarPV	677	38%	Extensive use of small scale microgrids
CSP	580	32%	In Northern and Southern Africa
Hydro	112	6%	No additional generation from 2012
Bioenergy	31	2%	Same as projected by IEA - WEO 2014

Table 4 Proposed renewable electricity mix for Africa

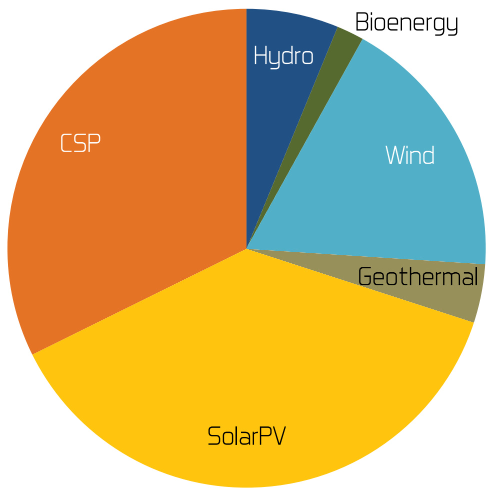


Figure 10 Proposed renewable energy mix for Africa

Latin America

Latin America covers South America, Central America and the Caribbean. As Chile is a member of the OECD it is excluded from this analysis.

Renewable energy resources in Latin America

Latin America - solar resource

As with Africa, the solar resource of South America is excellent. Most of the continent except for the southernmost region of Patagonia has a good solar GHI resource. The area with the highest DNI and therefore suitability for CSP is around the Atacama desert – taking in southern Peru, south-western Bolivia and north-western Argentina (see Figure 6).

Latin America - wind resource

The wind resource of Latin America varies extremely. Much of the Amazon, around the equator, has a very poor wind resource. There are pockets of good wind locations such as in Central America, the Caribbean and the northern coast of South America, and the eastern-most part of Brazil. This area of Brazil has over 7GW of wind power installed[28] across over 250 windfarms[29]. In addition, Patagonia – which covers a large area of the southernmost part of the continent, has an excellent wind resource.

Latin America - hydro power

Hydro currently dominates the Latin American electricity supply, accounting for 61% of total power generation. Of this hydro capacity, 59% is located in Brazil. If no new dams are built, by 2030 hydro will still contribute 32% of projected electricity generation.

Latin America - geothermal power

The parts of Latin America where the potential for geothermal power is greatest – the north-west of South America, Central America and the Caribbean – are also the areas with less hydro capacity. This is useful as geothermal power will be able to play a balancing role with the more variable renewable resources.

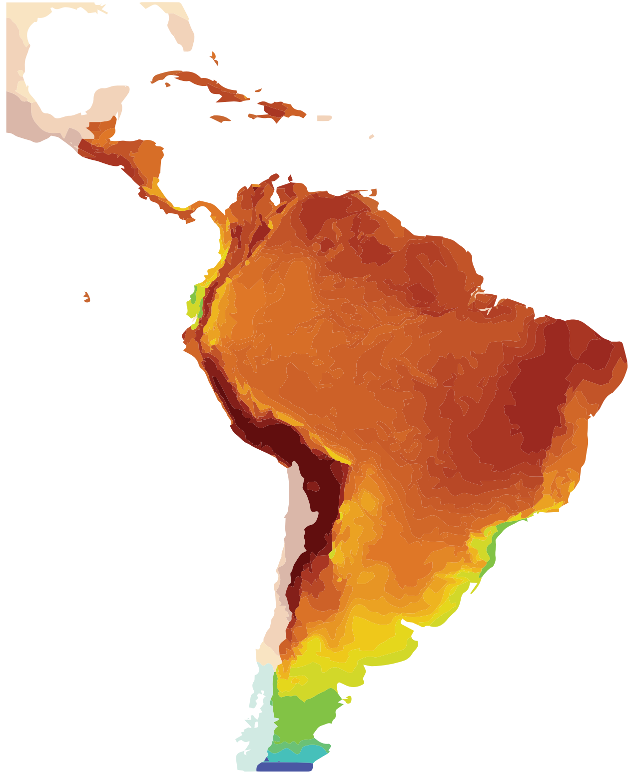


Figure 11 Solar energy resource (GHI) for Latin America.
Source: see note 20

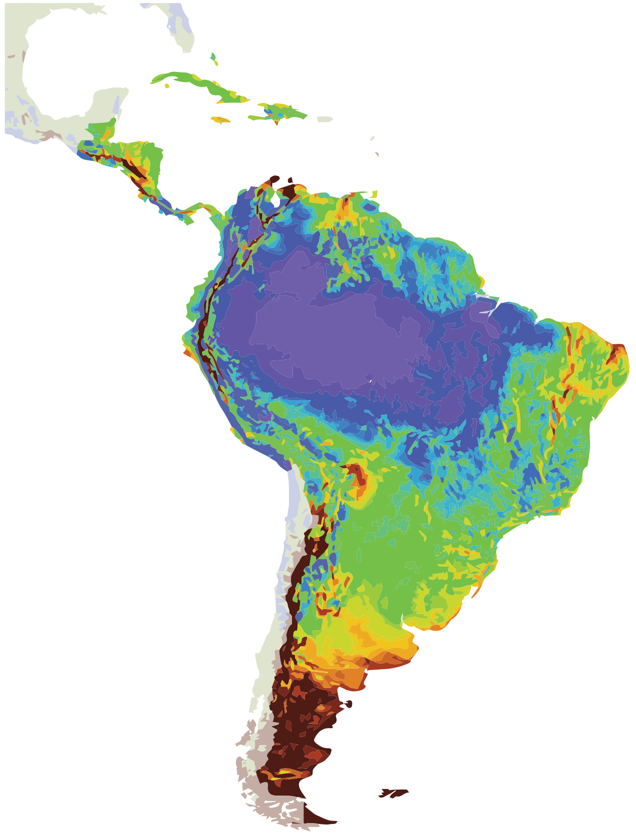


Figure 12 Wind resource (average wind speed at 80m height above ground) for Latin America.
Source: see note 20

What a renewable energy future for Latin America could look like

The vision of a renewable energy future for Latin America in this analysis is detailed in Table 5 and Figure 13, and would broadly consist of:

- Solar PV in covering rooftops in cities, and in small microgrids in remote parts of the continent.
- Wind power installed in the high wind speed regions.
- Some CSP installations in regions with high DNI, though likely limited by environmental factors in the Atacama region.
- Use of the large existing hydro systems, some increased geothermal capacity to provide 38% of generation from dispatchable renewable sources.
- Storage equivalent to 6 hours of average demand.

RE source	TWh/yr in 2030	% of total	Notes
Wind	679	31%	In Patagonia and other high wind speed areas
Geothermal	44	2%	Limited to a few areas
SolarPV	598	27%	Used widely at all scales
CSP	89	4%	Limited to a few areas
Hydro	702	32%	No additional generation from 2012
Bioenergy	92	4%	Same as projected by IEA - WEO 2014

Table 5 Proposed renewable electricity mix for Latin America

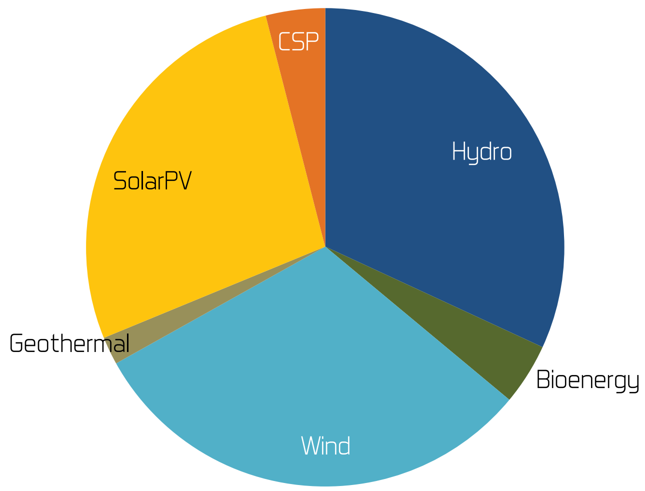


Figure 13 Proposed renewable energy mix for Latin America

Other Asia

'Other Asia' includes Asian countries except for OECD Asian countries, China and India. As can been seen in Figure 11 and Figure 12, it is not a contiguous geographic region as with Africa and Latin America, but covers a number of dispersed regions. The IEA also includes the many small Pacific island states in this analysis, for which they estimate data in aggregate, and are not all shown on these maps due to scale.

Renewable Energy Resources in Other Asia

Other Asia - solar resource

Pakistan and Afghanistan are the only countries in this region likely to be suitable for concentrating solar power (CSP), as the DNI map in Figure 14 shows. However most of the Other Asia countries have a good solar GHI resource, including the Pacific Islands that are not shown well on the map in Figure 11. Many people in this region live in isolated communities – whether on the Mongolian steppe or rural Afghanistan, or small islands in south-east Asia and the Pacific. It is envisaged that small-scale solar and battery microgrids will play a significant role in providing electricity access for these regions.

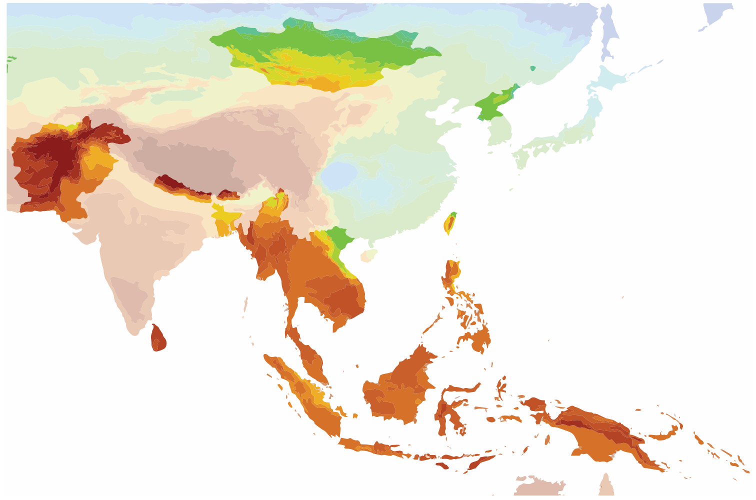


Figure 14 Solar energy resource (GHI) for Other Asia. Source: see note 20

Other Asia - wind resource

Much of South-East Asia, particularly Indonesia, has quite a poor wind resource (Figure 15), though Mongolia, Afghanistan and Pakistan have better wind. There is currently a small but growing wind industry in South-East Asia, though resilience to tropical storms is an issue. It is envisaged that wind power will not play as significant a role as solar in south-east Asia's energy mix.

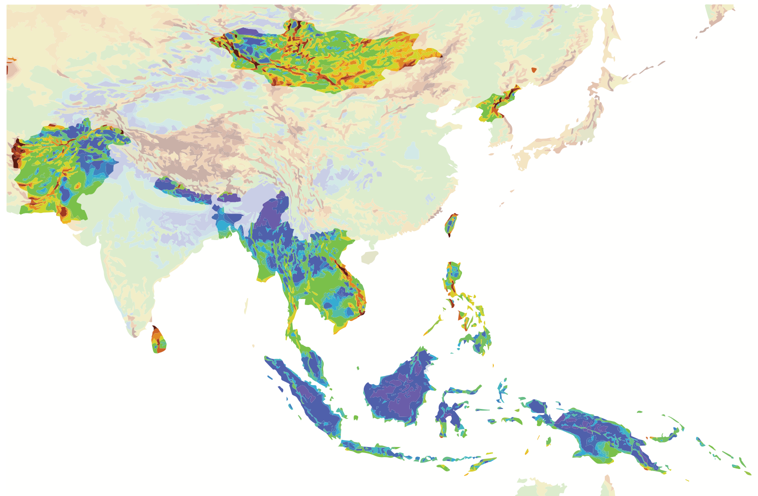


Figure 15 Wind resource (average wind speed at 80m height above ground) for Other Asia. Source: see note 20

Other Asia - geothermal

Indonesia, the Philippines and parts of the Pacific have large geothermal energy potential. It is expected that geothermal will play a significant role in the energy mix of these countries, where it can play a similar role to hydro in providing firm balancing power to variable renewables.

What a renewable energy future for Other Asia could look like

The vision of a renewable energy future for Other Asia in this analysis is detailed in Table 6 and Figure 16, and would broadly consist of:

- Extensive use of small-scale, microgrid solar PV across the whole region.
- Wind power mainly in Mongolia, Pakistan and Afghanistan, as well as the pockets of good wind resource in South-East Asia
- A small amount of CSP limited to Pakistan and Afghanistan.
- Widespread use of geothermal in Indonesia and the Philippines.
- Geothermal, hydro and bioenergy contribute 29% of annual demand.
- Storage equivalent to 10 hours of average demand.

RE source	TWh/yr in 2030	% of total	Notes
Wind	444	15%	More dominant in northern countries, limited in Indonesia and Philippines
Geothermal	582	20%	Pedominantly in Indonesia and Philippines
SolarPV	1593	55%	Used widely in small grids and standalone systems
CSP	33	1%	Pakistan and Afghanistan only
Hydro	175	6%	No additional generation from 2012
Bioenergy	84	3%	Same as projected by IEA - WEO 2014

Table 6 Proposed renewable electricity mix for Other Asia

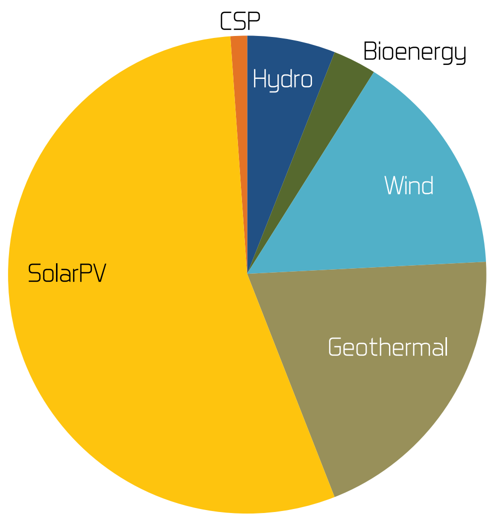


Figure 16 Proposed renewable energy mix for Other Asia

Costing results

Investment costs have been calculated for each of the regions, for providing the renewable electricity systems outlined.

The investment costs are for the additional renewable energy capacity over and above the renewable energy capacity that would be built anyway under the IEA New Policies Scenario.

As hydro capacity is assumed to remain constant from 2012, we have calculated the cost of the additional hydro that would have been built under the IEA New Policies Scenario, and subtracted this from final figures for each region. This is because it represents investment in renewable energy that would occur anyway, but in our scenario would be redirected from hydro to other renewables.

Data on cost and capacity factor (a measure of annual energy output per unit of capacity) have been sourced directly from the relevant sections of the IEA's input assumptions for the World Energy Outlook 2014[30]. Costs from the 450 Scenario have been used as they represent a more rapid decrease in the costs of renewable energy in a world which takes greater action to decrease the use of fossil fuels.

For simplicity, a linear progression of building of additional renewable capacity is assumed. This is slightly conservative because in practice an increasing growth curve would occur, meaning that more capacity is built later in the period when costs are lower.

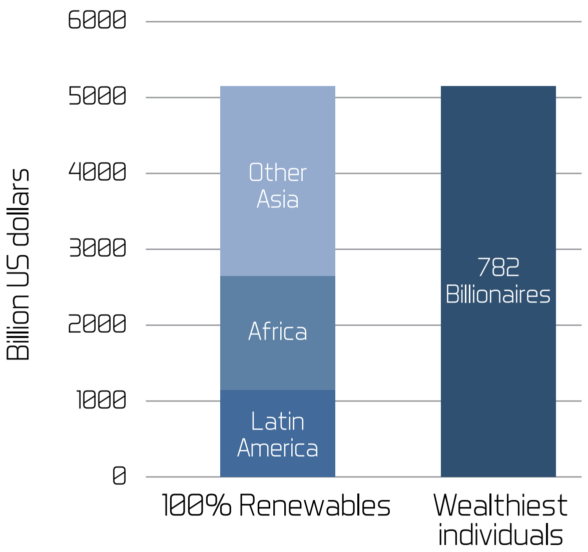


Figure 17 Additional investment costs for achieving 100% renewables by 2030, compared to combined wealth of the world's richest 782 billionaires in 2014

Region	Billion US dollars
Latin America	1501
Africa	1165
Other Asia	2482
TOTAL	**5148**

Table 7 Additional investment costs for achieving 100% renewables, by region - 2014 US Dollars

Appendix I - IEA regional classifications

The country groupings used in this study are based on those used by the IEA in the World Energy Outlook 2014. The main difference is that 'Other Asia' is a category we have narrowed down from the IEA's grouping 'Non-OECD Asia'. 'Other Asia' is 'Non-OECD Asia' minus China and India.

Africa
Algeria
Angola
Benin
Botswana
Cameroon
Republic of Congo
Democratic Republic of the Congo
Ivory Coast
Egypt
Eritrea
Ethiopia
Gabon
Ghana
Kenya
Libya
Morocco
Mozambique
Namibia
Nigeria
Senegal
South Africa
Sudan
Tanzania
Togo
Tunsisia
Zambia
Zimbabwe
Burkino Faso*
Burundi*
Cape Verde*
Central African Republic*
Chad*
Comoros*
Djibouti*
Equatorial Guinea*
Gambia*
Guinea*
Guinea Bissau*
Lesotho*
Liberia*
Madagascar*
Malawi*
Mali*
Mauritania*
Mauritius*
Niger*
Reunion*
Rwanda*
Sao Tome and Principe*
Seychelles*
Sierra Leone*
Somalia*
Swaziland*
Uganda*
Western Sahara*
South Sudan*
Somaliland*

Latin America
Argentina
Bolivia
Brazil
Colombia
Costa Rica
Cuba
Dominican Republic
Ecuador
El Salvador
Guatemala
Haiti
Honduras
Jamaica
Netherlands Antilles
Nicaragua
Panama
Paraguay
Peru
Trinidad and Tobago
Uruguay
Venezuela
Antigua and Barbuda*
Aruba*
The Bahamas*
Barbados*
Belize*
Bermuda*
British Virgin Islands*
Cayman Islands*
Dominica*
Falkland Islands*
French Guyana*
Grenada*
Guadeloupe*
Guyana*
Martinique*
Monserrat*
Saint Kitts and Nevis*
Saint Lucia*
Saint Pierre and Miquelon*
Saint Vincent and the Grenadines*
Suriname*
Turks and Caicos Islands*

Other Asia
Bangladesh
Brunei
Cambodia
Taiwan
Indonesia
North Korea
Malaysia
Mongolia
Myanmar
Nepal
Pakistan
Philippines
Singapore
Sri Lanka
Thailand
Vietnam
Afghanistan*
Bhutan*
Cook Islands*
East Timor*
Fiji*
French Polynesia*
Kiribati*
Laos*
Macao S.A.R.*
Maldives*
New Caledonia*
Palau*
Papua New Guinea*
Samoa*
Solomon Islands*
Tonga*
Vanuatu*

Appendix II – Detailed workings

W.1 Target Demand

The electrical demand we aim to meet is based on the IEA's World Energy Outlook Demand and Generation projections:

Demand (TWh consumed per year) – from WEO 2014 Table 6.1

Region	2012	2020	2025	2030	2035	2040
Africa	620	852	1035	1258	1540	1868
Latin America	948	1199	1376	1542	1722	1895
Other Asia	1078	1468	1760	2106	2525	3050

Generation (TWh generated per year) – from WEO 2014 Annex A

Region	2012	2020	2025	2030	2035	2040
Africa	741	1023	1241	1504	1835	2217
Latin America	1152	1444	1654	1850	2061	2263
Other Asia	1213	1655	1985	2373	2843	3433

Gross generation is higher than demand, primarily due to parasitic loads in conventional fossil and nuclear power plants, and losses inherent in electrical transmission and distribution networks.

The target gross electricity demand for this analysis accounts for only 50% of the extra generation over demand from WEO2014, as wind, solar PV and hydro do not have as significant parasitic loads as thermal fossil fuel power generation. Some transmission losses would remain.

$$Demand_{FoE} = Demand_{WEO2014} + 50\% \ x \ (Generation_{WEO2014} - Demand_{WEO2014})$$

New electricity demand (DemandFoE) for each region, TWh/year

Region	2012	2020	2025	2030	2035	2040
Africa	680	938	1138	1381	1687	2042
Latin America	1050	1321	1515	1696	1891	2079
Other Asia	1145	1561	1872	2239	2684	3242

W.2 Target Renewable Generation

To calculate required renewable energy generation, the Demand 100%RE figure is multiplied by 1.3, due to the 30% overgeneration target as discussed in the Methodology section of the main report.

Africa – TWh generated per year

Type	2012	2030 – IEA	2030 – 100%RE
Total generation	**741**	**1504**	**1795**
Coal	259	361	0
Oil	89	81	0
Gas	262	573	0
Nuclear	13	25	0
Hydro	112	300	112
Bioenergy	2	31	31
Wind	2	35	322
Geothermal	2	27	72
Solar PV	0	4	677
CSP	0	29	580

Latin America – TWh generated per year

Type	2012	2030 – IEA	2030 – 100%RE
Total generation	**1152**	**1850**	**2205**
Coal	26	55	0
Oil	150	93	0
Gas	195	344	0
Nuclear	22	53	0
Hydro	702	1098	702
Bioenergy	45	92	92
Wind	7	82	679
Geothermal	4	10	44
Solar PV	0	17	598
CSP	0	6	89

Other Asia – TWh generated per year

Type	2012	2030 – IEA	2030 – 100%RE
Total generation	**1213**	**2373**	**2911**
Coal	373	950	0
Oil	119	55	0
Gas	468	672	0
Nuclear	45	99	0
Hydro	175	386	175
Bioenergy	10	84	84
Wind	2	48	444
Geothermal	20	47	582
Solar PV	1	32	1593
CSP	0	1	33

W.3 Capacity Factors

Capacity factors for each technology are given in the WEO 2014 Power Generation Assumptions spreadsheet, for years 2020 and 2035. Figures for 2025 and 2030 have been linearly interpolated. Capacity Factors refer to the annual generation achievable by power plants built in each year, as a percentage of the total theoretical generation that would be achieved if the power plant ran at full capacity every hour of the year. Capacity factors are projected to increase slightly over time with successive generations of power plants due to efficiency and performance improvements in each technology.

Africa - Capacity factors achievable by new power plants - percentages

Capacity Factors	2020	2025	2030	2035
Hydro - Large scale	50	50	50	50
Biomass power plant	70	70	70	70
Wind - onshore	26	26	27	27
Wind - offshore	41	43	44	46
Geothermal	70	72	73	75
Solar PV - Large scale	21	21	22	22
Solar PV - Buildings	18	18	19	19
CSP	44	46	48	50

Latin America - Capacity factors achievable by new power plants - percentages

Capacity Factors	2020	2025	2030	2035
Hydro - Large scale	54	54	54	54
Biomass power plant	70	70	70	70
Wind - onshore	42	42	43	43
Wind - offshore	45	47	48	50
Geothermal	70	72	73	75
Solar PV - Large scale	18	18	19	19
Solar PV - Buildings	16	16	17	17
CSP	46	47	49	50

Other Asia - Capacity factors achievable by new power plants - percentages

Capacity Factors	2020	2025	2030	2035
Hydro - Large scale	37	37	37	37
Biomass power plant	70	70	70	70
Wind - onshore	24	25	26	27
Wind - offshore	41	43	45	47
Geothermal	72	73	75	77
Solar PV - Large scale	18	18	19	19
Solar PV - Buildings	15	15	16	16
CSP	39	39	39	39

W.4 Unit investment costs per kilowatt ($/kW), 2012 US dollars

Unit investment costs for each technology are given in the WEO 2014 Power Generation Assumptions spreadsheet, in 2012 US dollars for years 2020 and 2035. An exponential interpolation was used between the given IEA points of 2020 and 2035.

Africa - Unit investment costs per kilowatt ($/kW), 2012 US dollars

$/kW	2020	2025	2030	2035
Hydro - Large scale	1970	2000	2028	2050
Biomass power plant	2100	2048	1999	1960
Wind - onshore	1430	1411	1394	1380
Wind - offshore	3620	3303	3008	2770
Geothermal	2540	2447	2360	2290
Solar PV - Large scale	1790	1603	1430	1290
Solar PV - Buildings	2440	2182	1943	1750
CSP	3830	3352	2908	2550

Latin America - Unit investment costs per kilowatt ($/kW), 2012 US dollars

$/kW	2020	2025	2030	2035
Hydro - Large scale	2130	2291	2440	2560
Biomass power plant	2150	2113	2078	2050
Wind - onshore	1530	1504	1480	1460
Wind - offshore	3750	3403	3080	2820
Geothermal	2550	2490	2435	2390
Solar PV - Large scale	1780	1593	1420	1280
Solar PV - Buildings	2320	2077	1852	1670
CSP	5490	4859	4273	3800

Other Asia - Unit investment costs per kilowatt ($/kW), 2012 US dollars

$/kW	2020	2025	2030	2035
Hydro - Large scale	1960	2121	2270	2390
Biomass power plant	1830	1800	1772	1750
Wind - onshore	1340	1323	1308	1295
Wind - offshore	3520	3195	2894	2650
Geothermal	2000	1953	1910	1875
Solar PV - Large scale	1360	1222	1094	990
Solar PV - Buildings	1590	1454	1327	1225
CSP	4065	3570	3111	2740

Storage costs - all regions

$/kWh	2020	2025	2030	2035
Storage	250	231	214	200

W.5 Additional renewable generation capacity building timeline, TWh/yr

For calculating the investment over time, a simple linear progression of building has been assumed. We calculate the extra generation capacity over and above what is already assumed in the WEO2014 New Policies Scenario. As we assume no new hydro from 2012 levels, we subtract the hydro capacity that would otherwise be built under the New Policies Scenario.

Africa - additional TWh/yr generation capacity relative to WEO2014 NPS, by technology

	2020	2025	2030	Total
Hydro	-30	-66	-92	-187
Bioenergy	0	0	0	0
Wind	46	101	140	287
Geothermal	7	16	22	45
Solar PV	102	223	311	636
CSP	89	193	269	551

Latin America - additional TWh/yr generation capacity relative to WEO2014 NPS, by technology

	2020	2025	2030	Total
Hydro	-11	-176	-209	-396
Bioenergy	0	0	0	0
Wind	16	266	315	596
Geothermal	1	15	18	34
Solar PV	16	259	306	581
CSP	2	37	44	84

Other Asia - additional TWh/yr generation capacity relative to WEO2014 NPS, by technology

	2020	2025	2030	Total
Hydro	-35	-75	-102	-211
Bioenergy	0	0	0	0
Wind	65	140	191	396
Geothermal	88	189	258	536
Solar PV	258	552	752	1561
CSP	5	11	16	33

W.6 Additional renewable generation capacity building timeline, Gigawatts (GW)

Gigawatts of new capacity are calculated based on the capacity factors from section W.3.

$$Capacity(GW) = \frac{Annual\ Generation\ \left(\frac{TWh}{year}\right)}{Capacity\ Factor\ (\%)\ x\ 8760\ \left(\frac{h}{year}\right)}\ x\ 1000\ \left(\frac{GW}{TW}\right)$$

Storage is calculated in TWh, based on the hours of average demand as specified per region in the main report. CSP storage (6 hours of total CSP GW capacity) is counted separately, such that the Storage TWh figure refers to additional storage required from non-CSP sources – batteries, pumped hydro or others.

Africa - Gigawatts (GW) of new renewable power plant capacity, TWh storage capacity

	2020	2025	2030	Total
Hydro - Large scale	-7	-15	-21	**-43**
Biomass power plant	0	0	0	**0**
Wind - onshore	17	37	51	**105**
Wind - offshore	2	4	5	**11**
Geothermal	1	3	3	**7**
Solar PV - Large scale	19	40	55	**113**
Solar PV - Buildings	43	92	127	**262**
CSP	23	48	64	**135**
Storage (TwH)	0.22	0.22	0.33	**0.8**

Latin America- Gigawatts (GW) of new renewable power plant capacity, TWh storage capacity

	2020	2025	2030	Total
Hydro - Large scale	-2	-37	-44	**-84**
Biomass power plant	0	0	0	**0**
Wind - onshore	4	61	72	**136**
Wind - offshore	1	10	11	**22**
Geothermal	0	2	3	**5**
Solar PV - Large scale	3	54	62	**120**
Solar PV - Buildings	8	121	140	**268**
CSP	1	9	10	**20**
Storage (TwH)	0.45	0.27	0.32	**1.0**

Other Asia - Gigawatts (GW) of new renewable power plant capacity, TWh storage capacity

	2020	2025	2030	Total
Hydro - Large scale	-11	-23	-32	**-66**
Biomass power plant	0	0	0	**0**
Wind - onshore	26	54	71	**152**
Wind - offshore	3	6	7	**16**
Geothermal	14	30	39	**83**
Solar PV - Large scale	33	69	92	**193**
Solar PV - Buildings	157	329	438	**924**
CSP	2	3	5	**10**
Storage (TwH)	0.58	0.81	1.10	**2.5**

W.7 Investment required in additional renewable power plant capacity

Total investment costs for additional renewable power plants are calculated from the total GW capacity for each period in section W.6, and the corresponding unit costs from section W.4.

Africa - investment in new power plant/storage capacity, 2012 billion US dollars

	2020	2025	2030	Total
Hydro - Large scale	-14	-30	-42	**-86**
Biomass power plant	-	-	-	**-**
Wind - onshore	25	52	71	**148**
Wind - offshore	7	13	16	**37**
Geothermal	3	6	8	**17**
Solar PV - Large scale	33	64	78	**175**
Solar PV - Buildings	106	202	246	**553**
CSP	88	161	186	**435**
Storage (TwH)	55	51	70	**176**
Total	**303**	**519**	**633**	1455

Latin America - investment in new power plant/storage capacity, 2012 billion US dollars

	2020	2025	2030	Total
Hydro - Large scale	-5	-85	-108	**-198**
Biomass power plant	-	-	-	**-**
Wind - onshore	6	92	106	**203**
Wind - offshore	2	33	34	**70**
Geothermal	0	6	7	**13**
Solar PV - Large scale	6	86	89	**180**
Solar PV - Buildings	18	250	259	**527**
CSP	3	44	44	**91**
Storage (TwH)	112	63	69	**244**
Total	**143**	**488**	**500**	1130

Other Asia - investment in new power plant/storage capacity, 2012 billion US dollars

	2020	2025	2030	Total
Hydro - Large scale	-21	-49	-72	**-143**
Biomass power plant	-	-	-	**-**
Wind - onshore	35	72	93	**200**
Wind - offshore	10	18	21	**49**
Geothermal	28	58	75	**161**
Solar PV - Large scale	44	84	101	**229**
Solar PV - Buildings	249	478	582	**1309**
CSP	6	12	14	**33**
Storage (TwH)	146	188	236	**570**
Total	**498**	**859**	**1050**	2408

W.8 Final investment costs, 2014 US dollars

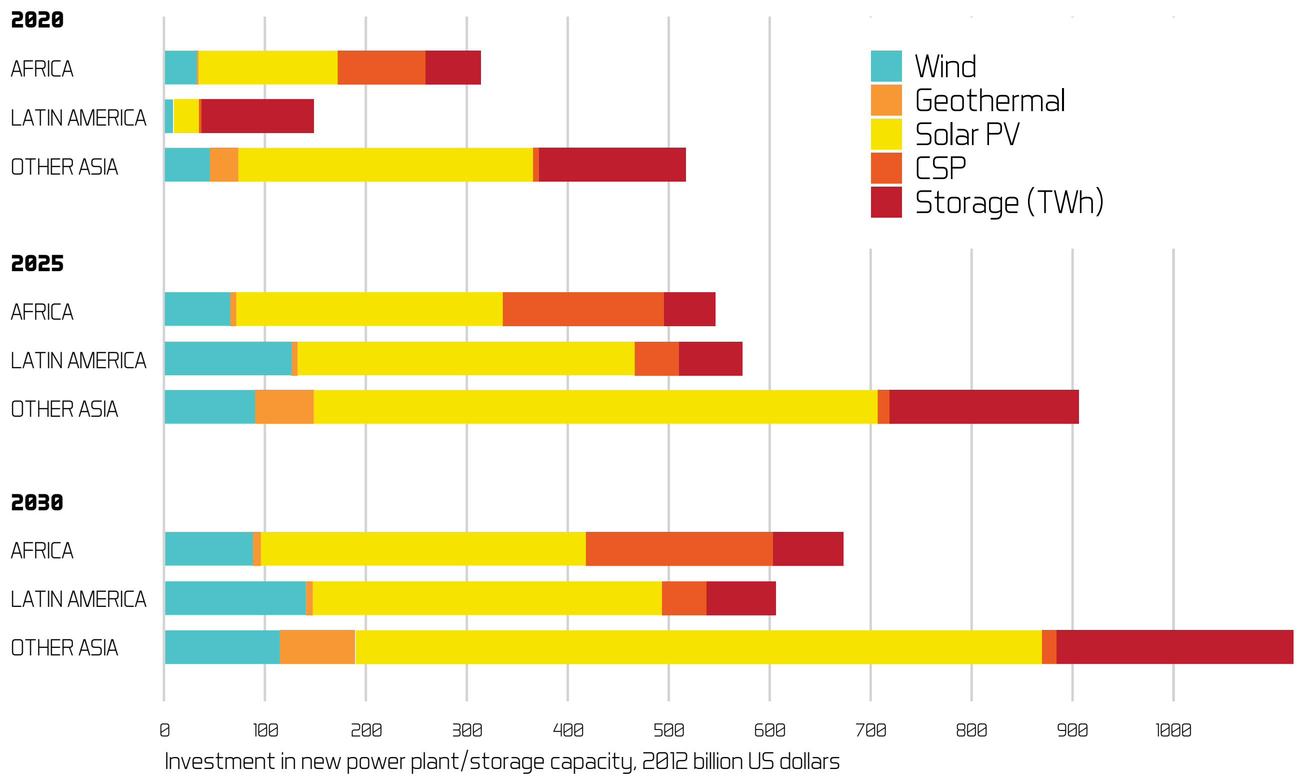
Costs are converted to 2014 US dollars using a US inflation multiplier of 1.031, from the US Bureau of Labor Statistics.

Final investment cost results, billion dollars

Region	2012 US dollars	2014 US dollars
Africa	1455	1501
Latin America	1130	1165
Other Asia	2408	2482
Total	**4993**	**5148**

From the 2014 Forbes Billionaires list, the wealthiest 782 individuals or families had a combined wealth of $5,149 billion. Based on a 2014 population of 7.24 billion, these richest wealth owners represents approximately 0.00001% of humanity. Based on populations from World Energy Outlook 2014, the regional groupings of Africa, Latin America and Other Asia represent approximately 55% of humanity.

Investment required in additional renewable power plant capacity



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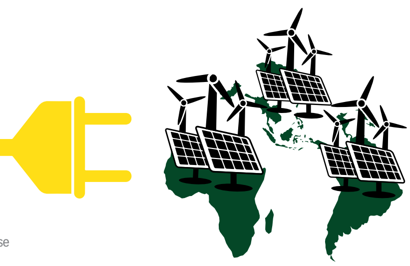

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