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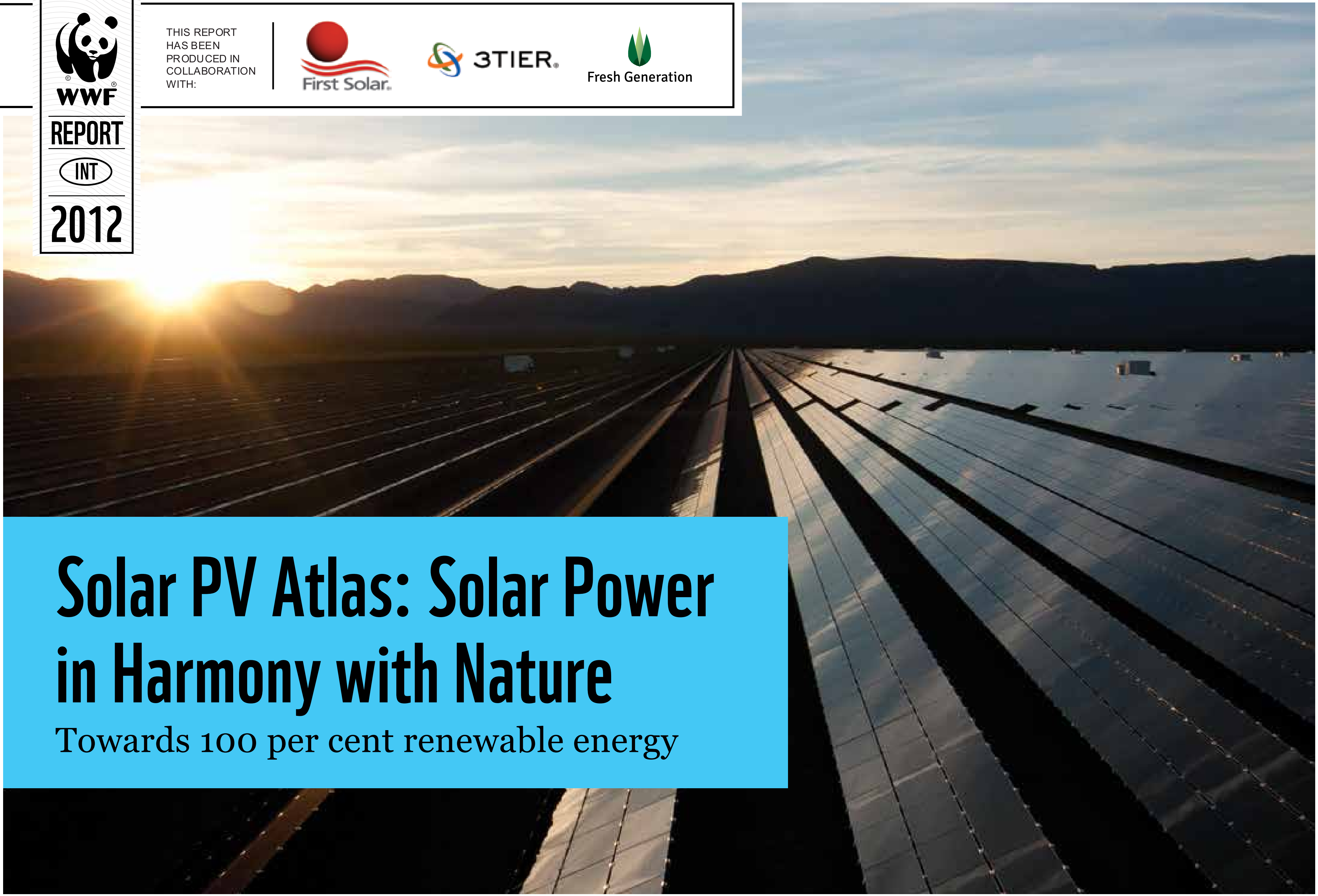

Solar PV Atlas: Solar Power in Harmony with Nature

Towards 100 per cent renewable energy

SOLAR PV ATLAS: PARTNERS

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WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

The Global Climate & Energy Initiative (GCEI) is WWF's global programme addressing climate change and a move to 100% renewable energy through engagement with business, promoting renewable and sustainable energy, scaling green finance and working nationally and internationally on low carbon frameworks.

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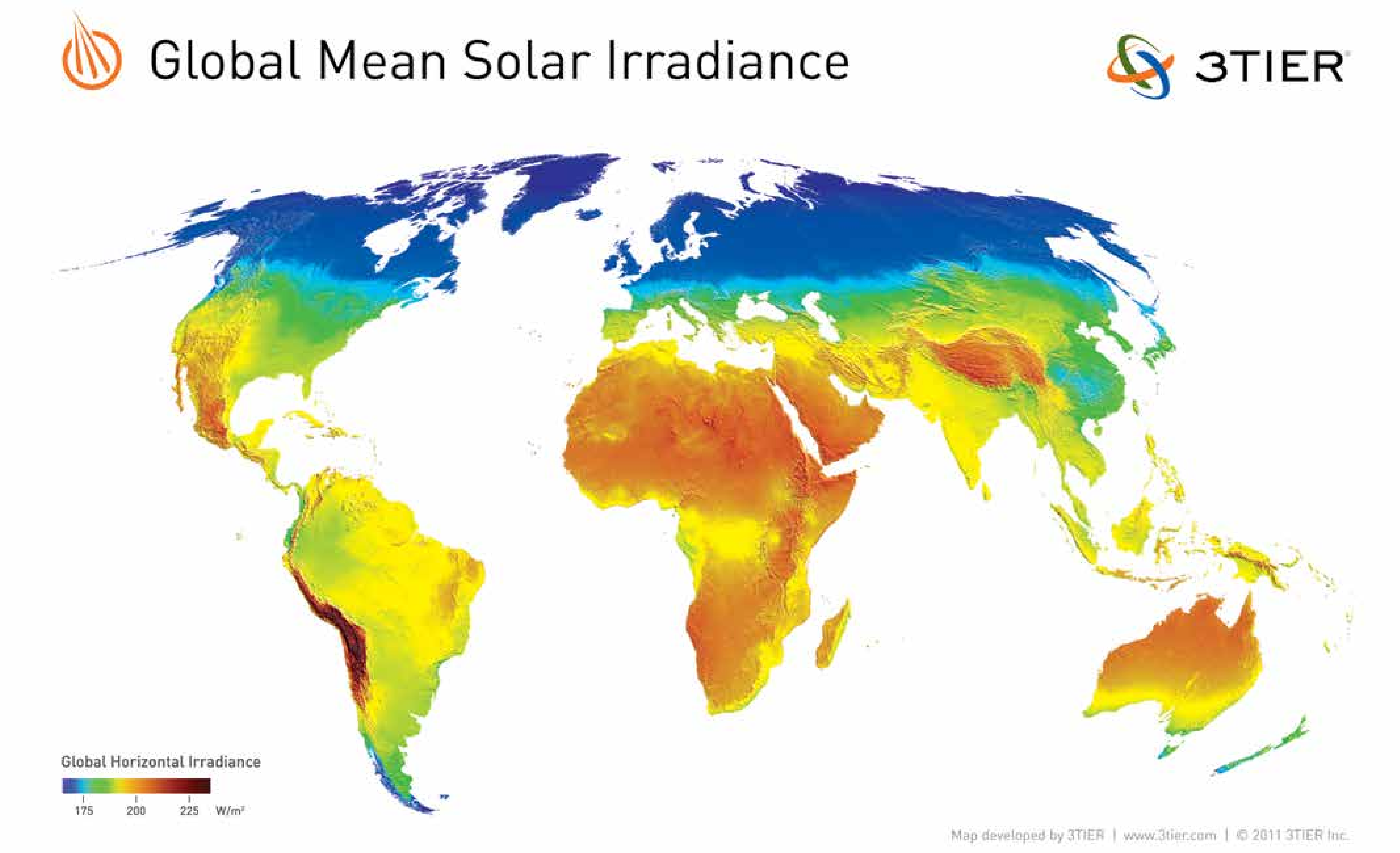
Global Mean Solar Irradiance
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175
200
225
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SOLAR PV ATLAS: CONTENTS

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SOLAR ATLAS: EXECUTIVE SUMMARY

Renewable energy requires land. But just how much?

This atlas illustrates some answers for one sector, solar photovoltaic electricity, in seven different regions.

The Energy Report, published by WWF in 2010, called for renewable energy to meet all global energy needs by 2050. While a balanced portfolio of renewable energy sources will ultimately fill global energy needs, this atlas considers solar photovoltaic electricity. Today, solar photovoltaic electricity, sometimes called just PV, provides 0.1 per cent of total global electricity generation. However, PV has seen an average annual growth rate of more than 40 per cent since 2000. Now a well-established, commercially available and reliable technology, it has significant potential for long-term growth in nearly all world regions now and in the coming decades.

The atlas considers electricity demands in seven diverse regions and calculates the area (land or roof) that would be needed for PV to meet these demands. In each of these cases, less than one per cent of the region's total land cover would be required to host solar PV panels in order to meet one hundred per cent of the region's projected electricity needs in 2050, taking into account solar resources and predicted electricity consumption and demographic changes.

While it is unlikely that all electricity will come from solar PV in 2050, this "100 per cent" scenario serves to illustrate that even using very conservative numbers for calculations, the maximum amount of space solar PV could need, on the ground and on buildings, is relatively low. In a realistic global portfolio of renewable energy generation technologies, PV will very likely require far less land than illustrated here. Several credible scenarios suggest that solar PV could provide about 30 per cent of global total electricity in 2050. Of course, grid integration, storage and balancing are important issues to address for renewable energy to be successful. These topics are beyond the scope of the atlas but are covered in The Energy Report by WWF.

With its selection of diverse areas, the atlas illustrates that PV technology, when well-planned, does not conflict with conservation goals. On a macro level, no country or region must choose between solar PV and space for humans and nature. Quite the opposite. As climate change threatens humans and the environment, it is more important than ever to work for the efficient and wide-scale adoption of well sited, responsibly and effectively operated renewable energy generation facilities. Environmental protection and renewable energy can and must develop in parallel.

At the local level, there has been some concern that PV development could conflict with livelihood and conservation goals. While these concerns are important to consider, research has consistently found that, when developed responsibly, ground-mounted and roof-mounted solar PV power plants provide considerable economic and environmental benefits. PV solar manufacturers, project developers, policy makers, and other relevant parties should convene a multi-stakeholder initiative to establish global, sector-wide guidelines for responsible community engagement and land management.

Each region selected for this atlas holds great solar resource. Resource availability alone, however, does not define markets. Policy also shapes a nation's energy supply, and, despite considerable obstacles to overcome, there is room for optimism in each of the selected regions. From bold targets to tiny first steps, the policies noted in this atlas show potential for large and sustainable solar market development if expanded and enacted well.

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100 PER CENT RENEWABLE ENERGY BY 2050: OUR FUTURE IS RENEWABLE

WWF HAS A VISION OF A WORLD THAT IS POWERED BY 100 PER CENT RENEWABLE ENERGY SOURCES BY THE MIDDLE OF THIS CENTURY.

WWF, The Energy Report : 100 per cent Renewable by 2050

The way we produce and use energy today is not sustainable. Our main fossil fuel sources – oil, coal and gas – are finite natural resources. Furthermore they are the main contributors to climate change, and the race to the last "cheap" fossil resources evokes disasters for the natural environment. Nuclear energy poses its own threats to humanity and the environment and remains cost-prohibitive when full costs are considered. In the developing world, regional and local desertification is caused by the depletion of fuelwood that is often used very inefficiently causing substantive indoor pollution and millions of deaths annually. A fully sustainable renewable power supply is the only way we can secure energy for all and avoid environmental catastrophe. WWF has a vision of a world that is powered by 100 per cent renewable energy sources by the middle of this century.

Already the world is moving quickly in this direction. Figures recently released estimate that renewable energy sources supplied 16.7 per cent of global final energy consumption in 2010, and modern clean sources of electricity – like wind and solar – are growing at impressive rates.[1] Though it currently provides just 0.1 per cent of total global electricity generation,[2] solar PV has been growing the fastest of all renewable energy technologies, with operating capacity increasing by an average of 58 per cent annually between 2006 and 2011.[3]

We stand at an exciting moment of transition when renewable energies are competing head-to-head with long-subsidized fossil and nuclear power. People around the world are grasping the importance of a clean and sustainable energy future while clean technology prices are dropping and policy makers are restructuring markets.

This atlas builds upon the *The Energy Report,* published by WWF in 2010, which calls for renewable energy to meet all global energy needs by 2050. Published jointly with that report, an energy scenario by Ecofys* illustrates one path to attaining that goal and shows how a combination of efficiency measures and renewable generation, using today's technologies, can meet global energy needs to unlock a future of low carbon prosperity.

*The WWF Energy Report and the Ecofys Energy Scenario are available for free download at www.panda.org/energyreport

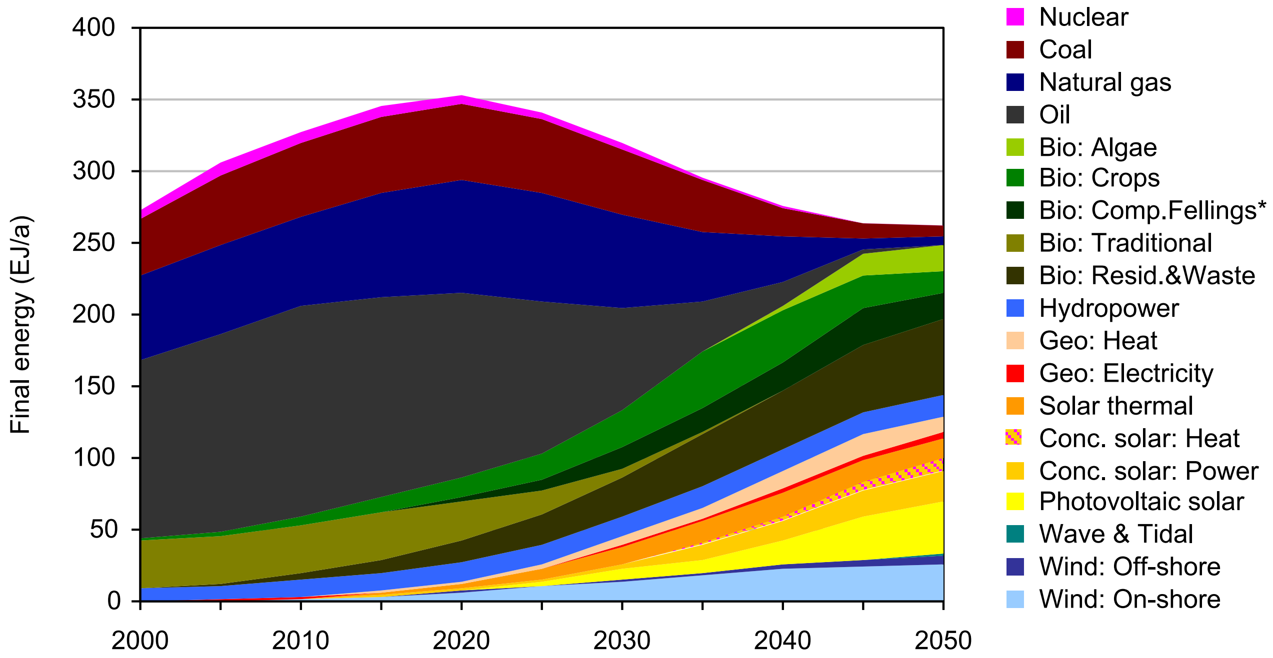


FIGURE 1: GLOBAL ENERGY SUPPLY

Ecofys projects that nearly all global energy needs could come from renewables by 2050. In this scenario, total energy consumption would fall by about 15 per cent by 2050 compared to today with efficiency measures having a stronger trend influence than population growth. *Source: The Energy Report, December 2010.*

Space for humans and nature

WWF strongly believes that renewable energy can develop in harmony with humans and nature. While a balanced portfolio of renewable energy sources will ultimately fill global energy needs, this atlas provides some colourful examples for one major technology, solar photovoltaic electricity.

A series of maps gives a high-level perspective on how renewable energy development, human development and biodiversity conservation can go hand in hand. The nature of this exercise is not to analyse where exactly solar parks should be developed or to discuss which specific areas should be protected but simply to illustrate how much space would be required for the development of solar PV. As reference we also highlight currently identified biodiversity hotspots, protected areas, and areas where high numbers of people now live.

On a macro level, no country or region must choose between solar PV and space for humans and nature. Quite the opposite. As climate change threatens humans and the environment, it is more important than ever to work for the efficient and wide-scale adoption renewable energy generation facilities which are sited and operated responsibly.

Environmental protection and renewable energy can and must develop in parallel.

This atlas looks at Indonesia, Madagascar, Mexico, Morocco, South Africa, Turkey, and the Indian state of Madhya Pradesh. The regions represent diverse geographies, demographics, natural environments, economies and political structures. They receive different average levels of sunshine, and all show vast potential for widespread development of solar PV. By curating this selection of places, we hope to illustrate that PV technology, when well-planned, does not conflict with conservation goals.

Less than one per cent

As the solar irradiance maps illustrate, the sun shines brightly for these selected locations. We illustrate that in each of these cases **less than one per cent of the region's total land cover would be required to host solar PV generation in order to meet one hundred per cent of the region's projected electricity needs in 2050,** taking into account predicted electricity consumption and demographic changes.

While it is unlikely that all electricity will come from solar PV in 2050, this "100 per cent" scenario serves to illustrate that the maximum amount of space solar PV could need, on the ground and on buildings, is relatively low. In a realistic global portfolio of different renewable energy generation technologies, PV will very likely require far less land than illustrated here. For instance, the Ecofys scenario suggests that solar PV will provide about 30 per cent of global total electricity in 2050.

Of course, grid integration, storage and balancing are important issues to address for renewable energy to be successful. These topics are beyond the scope of the atlas but are covered in *The Energy Report*.

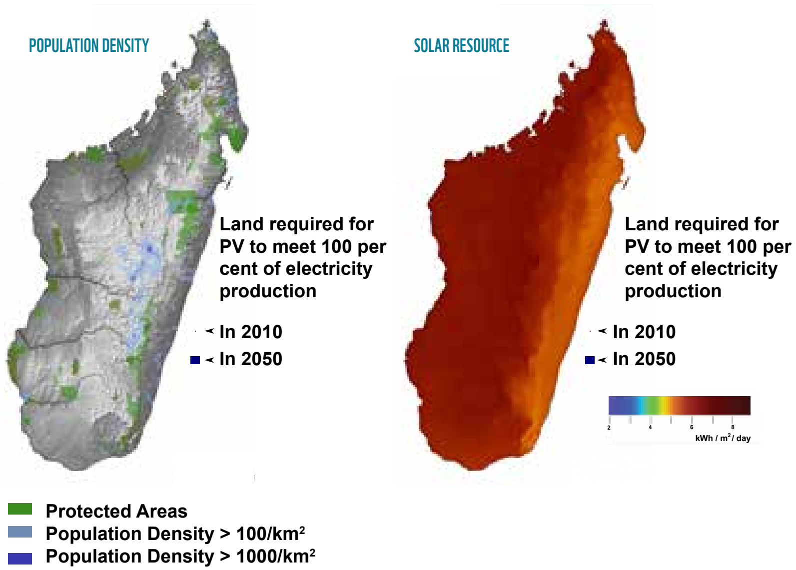


FIGURE 2: EXAMPLE ATLAS MAPS

For Madagascar, one of the atlas focus regions, the almost invisibly small red square on the maps above illustrates the total surface area needed for PV production to equal all of the country's current electricity production. The larger blue square represents the surface area required to meet 100 per cent of projected electricity consumption in 2050. These squares are shown next to currently identified protected zones and densely-populated areas (left) and next to the country's solar resource (right). The solar resource shows values for global horizontal irradiance (GHI).[4]

LESS THAN ONE PER CENT OF EACH REGION'S LAND COVER WOULD BE REQUIRED TO HOST SOLAR PV GENERATION IN ORDER TO MEET 100 PER CENT OF THAT REGION'S PROJECTED ELECTRICITY NEEDS IN 2050.

As we look at the "solar boxes" drawn on the maps and think about different land uses, we shouldn't forget that other human activity and conventional energy also require land. The built environment–buildings and roads–has already claimed much land that now has roofs, awnings, and other potential for shade structures that could host PV. No additional land is required for such co-location of PV with these existing structures. New ground-mounted PV systems often offer remarkable economy of land for the value of electricity they produce. As comparison, ground-mounted PV systems in areas of high insolation require less land than the coal-fuel cycle coupled with surface mining to produce the same amount of electricity.[5]

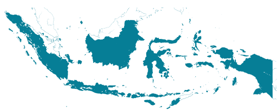
"GROUND-MOUNT PV SYSTEMS IN AREAS OF HIGH INSOLATION REQUIRE LESS LAND THAN THE COAL-FUEL CYCLE COUPLED WITH SURFACE MINING"

In each of the selected regions, ground-mounted solar photovoltaic plants hold huge potential but need to be carefully sited. Given the very limited amount of total land (and/or roof space) required for even 100 per cent of total electricity needs from PV, it is clear that there is enough space for solar PV in each of the selected regions without developing large-scale plants in protected areas or other areas that are not suitable for social, economic, technical or environmental reasons. In those zones, solar PV would be limited to small applications for local needs. Indeed, well-sited solar energy installations of all sizes can go hand in hand with protection of biodiversity.

Each region selected for this atlas holds great solar resource. Resource availability alone, however, does not define markets. Policy also shapes a nation's energy supply, and despite considerable obstacles to overcome, here too we found reason for optimism in the selected regions. From bold targets to tiny first steps, the policies noted in this atlas show potential for large and sustainable solar market development if expanded and enacted well.

SOLAR PV ATLAS: INDONESIA

Less than one third of one per cent (0.27 per cent) of Indonesia's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050.



With a population of almost 250 million, Indonesia is the world's fourth-most populous nation. In 2010 gross domestic product (GDP) per capita was US$4,394, and 12.5 per cent of the population in 2011 was below the national poverty line.[1] As of 2011, 71 per cent of residents had access to electricity.[2] Indonesia is the world's third-largest emitter of greenhouse gasses (GHG), with 3.01 billion metric tons of greenhouse gases emitted in 2007, a combined result of energy production and deforestation.[3]

Indonesia is an archipelago nation located in Southeast Asia, between the Indian and Pacific Oceans. It is second only to Brazil in terms of biodiversity and second to Australia in number of endemic species. Its tropical climate supports approximately 17 per cent of all species in the world with 515 mammal species, 122 species of butterflies, 600 species of reptiles, 1,531 species of birds, 270 species of amphibians and 28,000 flowering plants.[4] The majority of Indonesia is comprised of coastal lowlands, although several of the nation's larger islands have mountainous regions. In the low-lying regions there are numerous coastal ecosystems including sand dunes, estuaries, mangroves, coral reefs and tidal flats. In addition, 60 per cent of Indonesia's landmass is covered by forest. The rapid development and industrialization of Indonesia has led to massive (and often illegal) deforestation and wildfires that threaten many of the indigenous species and ecosystems in addition to contributing to 85 per cent of its annual GHG emissions.[5]

However, in recent years the Indonesian government has shown that it is committed to changing these statistics. As a non-Annex 1 signatory of the Kyoto Protocol, Indonesia is not bound to adhere to the treaty's regulations, but the government affirmed its commitment to reducing emissions at the 2009 G20 Finance Ministers and Central Bank Governors Summit.[6] The government has committed to reduce GHG emissions by 26 per cent below the business-as-usual scenario by 2020 and has indicated a 41 per cent reduction target with international support. Well planned renewable energy will not only improve access to sustainable energy for all but will also reduce emissions and help protect biodiversity.

Electric Sector Profile (2010 and 2011)	
Installed Capacity*	29.27 GW
Total generation	183,421 GWh
Average Residential Electricity Price	US$0.065/kWh
Electricity consumption/ capita	620 kWh
Average electricity consumption/capita in IEA countries (2009)	9,200 kWh
Electricity Generation Mix (2011)	
Coal	42 per cent
Oil	32 per cent
Natural gas	24 per cent
Hydro	8 per cent
Geothermal	3 per cent

*** Only reflects 2011 PLN owned and rented capacity.**

Electricity sector

Eighty-five per cent of electricity supply comes from coal, oil and natural gas powered plants. Off-grid capacity in 2010 was 6.4 GW, split evenly between renewable and non-renewable (diesel) sources.[7]

In 2011 Indonesia's total installed capacity of electricity reached 37 GW, with approximately 78 per cent of production coming from PLN, the state-owned utility.[8] The unbundling of PLN's assets began in 1995, and in 2009, the Electricity Law 30/2009 allowed for electricity supply and distribution to be licensed to privately owned Independent Power Producers (IPPs). However, PLN still has the "right of first priority" for any new production projects and still owns the current power grid.

Indonesia is facing an electricity supply crisis with rolling blackouts during peak demand periods. Energy demand is expected to grow by 9 per cent annually over the next decade, and by 2020 the government plans to have 90 per cent of households connected to the grid.[9] At the current rate, annual energy demand in 2050 is projected to reach 2.6 billion GWh. PLN is not expected to have the financial means to meet the increases in demand (PLN received US$4.9 bln in subsidies from the government in 2009), so increased production will fall mainly on IPPs.[10] Indonesia's most recent energy policy was formalized in Energy Law 30/2007, but many of its provisions have yet to be concretely defined. The law calls for the formation of goals regarding utilization and use of energy resources, security of supply, energy conservation and protection of the environment with regard to energy use, pricing and international cooperation. Additionally the law mandates the creation of a National Energy Council whose tasks include: drafting a national energy policy, declaring measures to resolve the current energy crisis and providing guidance and management on implementation of policies regarding energy R&D and the increasing role of IPPs, which currently provide less than 5 per cent of Indonesia's electricity.[11]

Currently about 15 per cent of on-grid capacity comes from renewable energy (RE) sources, mainly in the form of large-scale hydroelectric and geothermal facilities developed by PLN. Over the past five years, RE electricity generation in Indonesia has increased by more than 5 per cent annually. Recently private developers have entered the Indonesian market after a down period following the Asian financial crisis.[12]

The total technical potential for renewable capacity from hydropower, biomass, geothermal and mini/micro hydro is estimated at 155 GW, which, assuming the current overall capacity factor of 66 per cent, could add around 900 TWh. By comparison, the electricity demand is expected to be around 600 TWh in 2025 (assuming 9 per cent annual growth).

Due to its location on the Pacific "Ring of Fire" Indonesia could install natural hydrothermal systems of about 27-31 GW. Enhanced Geothermal Systems (EGS) could increase greatly this potential. WWF's Ring of Fire programme seeks large-scale expansion of geothermal (i.e., 9.5 GW by 2025) in Indonesia through the creation of enabling policy frameworks and building local capacity. Solar resources are abundant, and solar energy could contribute significantly to the generation mix if fully utilised.[13]

As is expected, achieving the potential generation capacity faces several major obstacles. For example, of Indonesia's nearly 76 GW of hydroelectric potential, 46 per cent is concentrated in the province of Papua, far from areas of demand and in the midst of vast mountain ranges, rain-forests and ecologically protected areas.[14] These factors would make development of generation facilities and transmission infrastructure particularly challenging.

Entering the Indonesian RE market is not a simple endeavour, but the opportunity is worth consideration. There is clear political willingness to promote this market. In its proposal to parliament, the National Energy Council set a target of having 39.5 per cent of Indonesia's electricity supply come from RE sources by 2050.[15] Vision 25/25, an unofficial target in Indonesia's latest draft on new energy policy, calls for 25 per cent of total energy produced in 2025 to come from renewable sources. Notably, PLN has called for at least 57 per cent of total green energy production capacity to be IPP provided by 2019.[16]

Due to its climate—both environmental and governmental—Indonesia appears to be a prime area for investment in RE production systems.

RE Source	Installed capacity (2010)
Hydroelectric	2.3 GW
Geothermal	600 MW
Biomass	500 MW
Wind	30 MW
Solar	17 MW

The government's commitment to improving electricity quality and access for its people, particularly by inviting IPPs into the market, will provide significant opportunities for RE growth. There are several major issues to overcome, including the highly inefficient and unreliable grid currently in place and the viability of delivering RE generated in remote areas to consumers, but they can largely be mitigated by the implementation of solar, not only throughout rural Indonesia, but also in high-population areas.

Solar PV

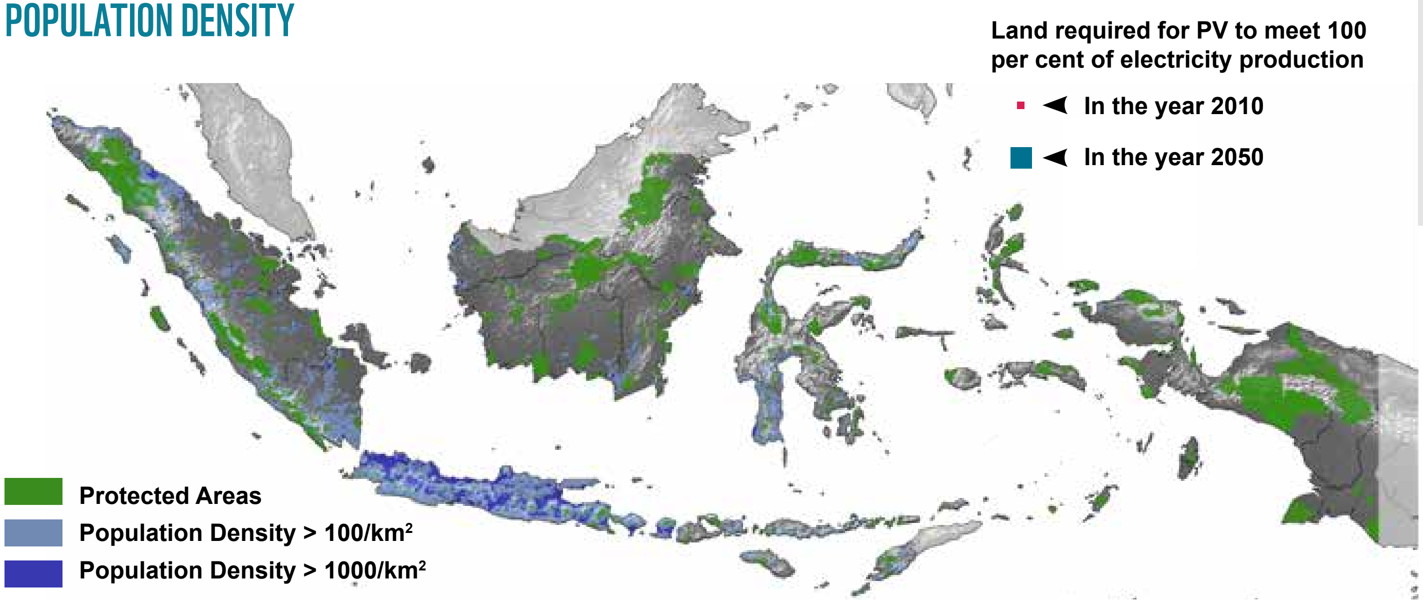
Solar energy has a significant and unique potential in Indonesia. It is well suited to both large- and small-scale production, which is favoured by the Indonesian government and PLN as it can easily be installed in remote villages. The effect of this is two-fold. Many of these remote villages currently rely on diesel generators for electricity so replacing them with solar systems would significantly reduce GHG emissions and could save the logistical difficulty of adding such remote areas to the power grid. It is often the most economical option as well.

In Indonesia's densely populated cities, where rolling blackouts generally last several hours each day, a similar approach could reduce the strain on the current grid and eliminate blackouts. With an efficient deployment process and upgrades to the grid, solar power could significantly contribute to electricity production in Indonesia. The Indonesian government appears to realize this; in 2009, Indonesia distributed 77,433 PV solar home systems of 50 W peak modules to individual households, and nine PV array systems of 150 kW peak each to communities in rural and remote areas throughout Indonesia. Similar numbers were distributed in 2008.[17] Sustainability of these programs is questionable, as on-going service is often neglected.

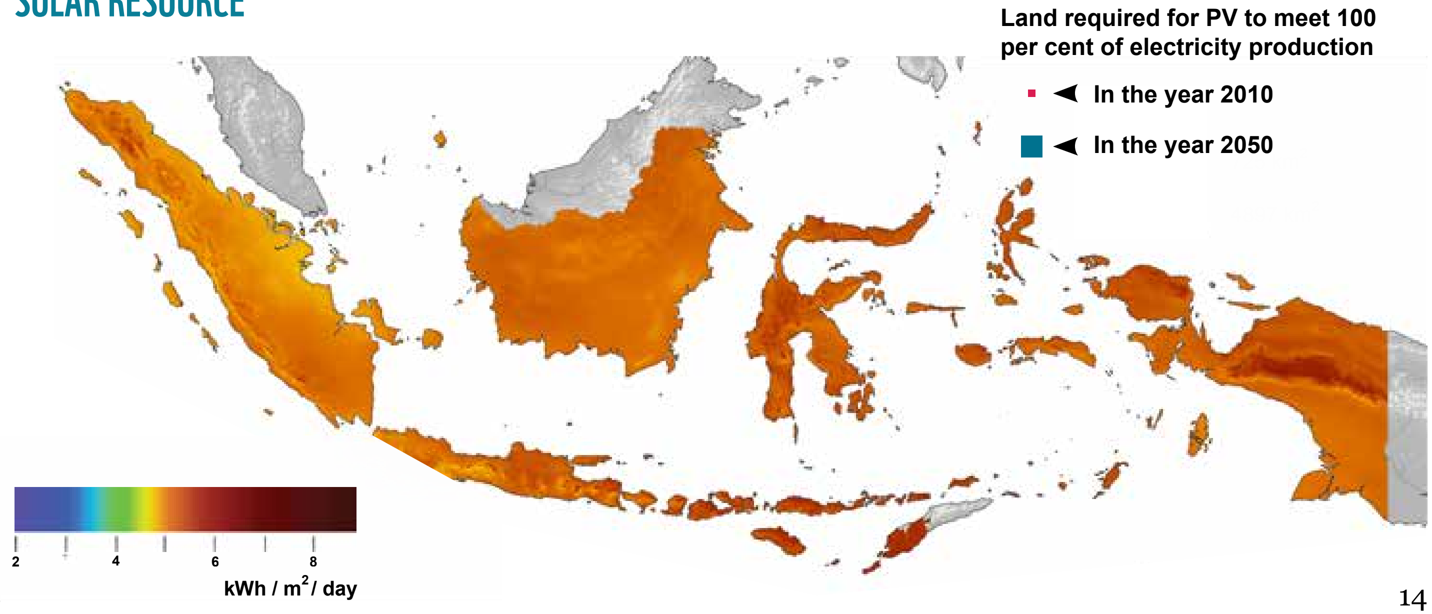
The conditions for solar PV are excellent across the Indonesian islands with mountainous regions receiving some of the best sun in the country. The country's annual average insolation is 5.2 kWh/m2/day.

A total of just 725 square kilometres of solar panels would generate enough electricity to meet Indonesia's total current electricity generation. Because population and per capita electricity consumption are expected to rise in the coming years, 4,900 square kilometres of land dedicated to solar production would be required to meet 100 per cent of the country's total electricity needs in 2050. Concentrated into one location, this land would represent a square of about 70 kilometres on each side. The solar map shows the area of land needed for 2010 generation (red square) as well as land use needed to meet electricity demand in 2050 (blue square). In other words, even based on very conservative estimates, less than one third of one per cent (0.27 per cent) of Indonesia's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050. This projection assumes that those living in Indonesia are consuming the projected global average amount of electricity for 2050, which is more than 6.5 times current per capita consumption.

POPULATION DENSITY



SOLAR RESOURCE



Sunset in Madagascar © Martin Harvey / WWF-Canon

SOLAR PV ATLAS: MADAGASCAR

Less than one-fifth of one per cent (0.13 per cent) of Madagascar's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050.

The Republic of Madagascar is home to approximately 22.6 million people (2012).[1] In 2009, the country's per capita GDP was US$438.[2] Most of the population has no access to electricity and cooks with biomass fuels.

Madagascar's electricity sector is relatively limited. Eighty per cent of Madagascans lack access to electricity,[3] and rural dwellers are particularly worse off with 93 per cent lacking access to electricity. Without access to electricity, Madagascans use kerosene and battery-based devices for lighting and electricity. Though effective stop-gaps, these solutions have significant health and environmental costs associated with indoor combustion and the disposal of the batteries. Traditional biomass for cooking is putting a heavy burden on people and the environment. Eighty per cent of wood consumption is for firewood and charcoal, representing 18 million cubic metres annually, a large share of which is harvested at unsustainable levels.[4]

The country is highly dependent on expensive oil imports for transport and for a large share of its electricity. In 2010 imports of petroleum products grew to US$472 million.[5] In response to rising global oil prices, the government and the Norwegian Petroleum Directorate (NPD) agreed to develop the country's energy production sector. Though NPD suspended its work in 2009 due to political instability, plans for oil and unconventional oil exploration continue.

The dependency on polluting energy sources is socially and economically problematic, and it threatens one of Madagascar's major assets: biodiversity. Split from the African continent more than 160 million years ago, the island developed its own distinct ecosystems and extraordinary wildlife. Approximately 92 per cent of Madagascar's reptiles, 68 per cent of its plant life and 98 per cent of its land mammals, including lemurs, exist naturally nowhere else on Earth. The world's fourth-largest island, covering more than 144 million acres, Madagascar is comprised of lush lowland rainforests and mountains along the eastern coast, dry forests in the west, volcanic mountains in the north and the Spiny Forest in the south. The climate is tropical along the coast, temperate inland, and arid in the south, supporting a great range of biodiversity.

Sustainable renewable energy and energy efficiency can contribute, as part of a broad set of measures, to both promote Malagasy socioeconomic development and reduce the energy sector's environmental footprint. RE can reduce Madagascar's costly dependence on imported oil, kerosene, disposable batteries, and traditional biomass while developing remote off-grid or mini-grid electricity access.

Recent government pledges for *Sustainable Energy for All* have yet to play out but fit a clear need.

Electricity sector

There are currently 115 small and mid-sized power plants operating in Madagascar with a total capacity of 406 MW[6] and annual output of 1.2 million MWh. Twenty-one of these plants are part of the only two interconnected grids (IG): Antananarivo IG and Fianarantsoa IG. Power plants are heavily dependent on two sources of energy: hydropower (60 per cent) and thermal power running on imported diesel and heavy fuel oil (40 per cent). Despite large structural subsidies, the average price of electricity to the consumer is US$0.20/kWh. At these rates, RE, whether grid-connected or not, can become a strong and cost-effective alternative to the status quo.

Between 2004 and 2009 demand grew at an annual average rate of 7 per cent. The Madagascar Action Plan (2006), prior to its suspension, planned the construction of three new large thermal plants using oil and the development of a new hydropower plant. Beyond hydropower, the Action Plan aimed to increase the use of other renewable sources of energy (solar, wind, biofuel) from 0 per cent in 2006 to 3 per cent in 2012.[7]

Renewable electricity is currently mainly produced from hydropower.[8] There are a few isolated and relatively small wind and solar projects on the island. However, there is significant additional renewable energy potential. Presently, Madagascar is using only 1.3 per cent of its estimated 7.8 GW potential.[9] Particulary in the north and south, several locations show very good wind conditions with average speeds over 6 m/s. There is huge potential for solar energy as well.

There is currently some support to exploit this vast renewable energy potential, such as the rural electrification fund from the rural Electrification Agency (ADER). These projects, however, face significant barriers such as relatively more expensive initial investments than those required by comparable thermal plants, non-systematic financial support for renewable energy projects, unfair competition with subsidized fossil fuel based electricity, high dependency on foreign aid, and hurdles to developing scaled investments.

Electric Sector Profile	
Installed Capacity (2009)	410 MW
Total net generation (2009)	1,350 GWh
Average residential Electricity Price (2011)	US$0.20/kWh
Electricity consumption/capita (2008)	45 kWh
Average electricity consumption/capita in IEA countries (2009)	9,200 kWh
Electricity Sources (2010)	
Hydropower production	60 per cent
Thermal power production produced using:	40 per cent
Gas oil	*(16.5 per cent)*
Fuel oil	*(23.5 per cent)*

RE Source	Installed Capacity (2008)
Hydro	124 MW
Wind	nominal
Solar	nominal

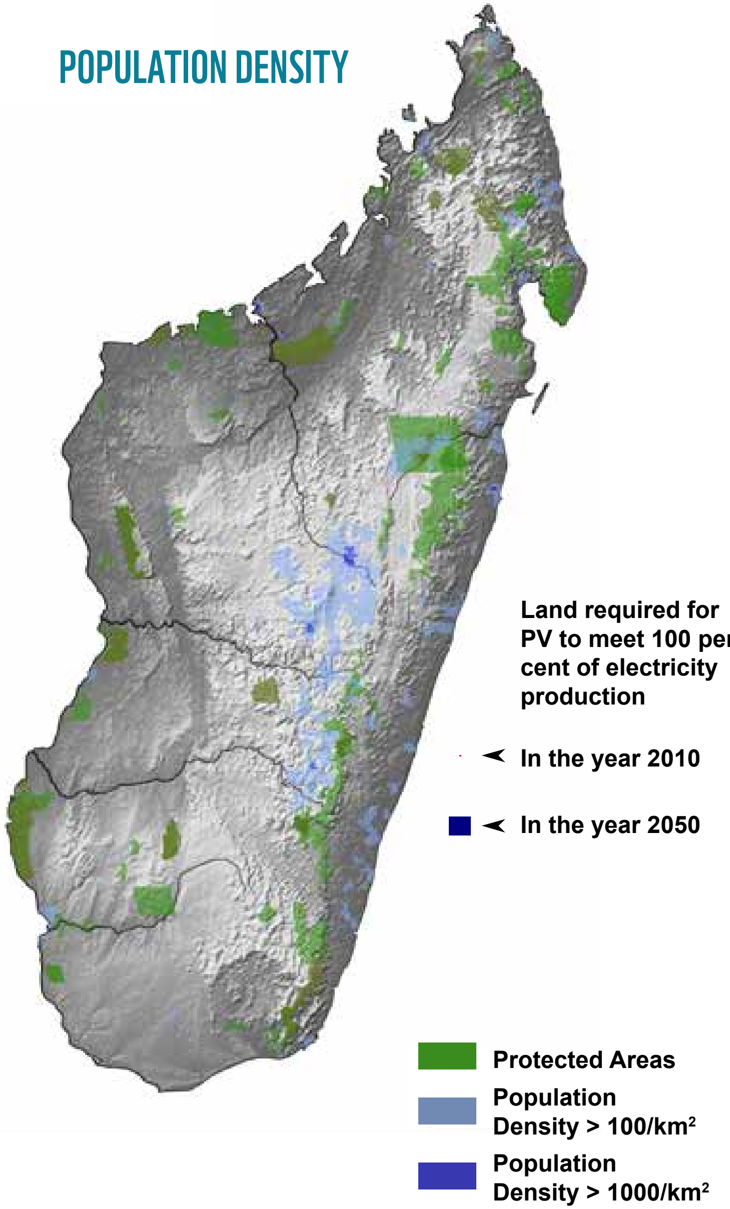
MADAGASCAR

Solar PV

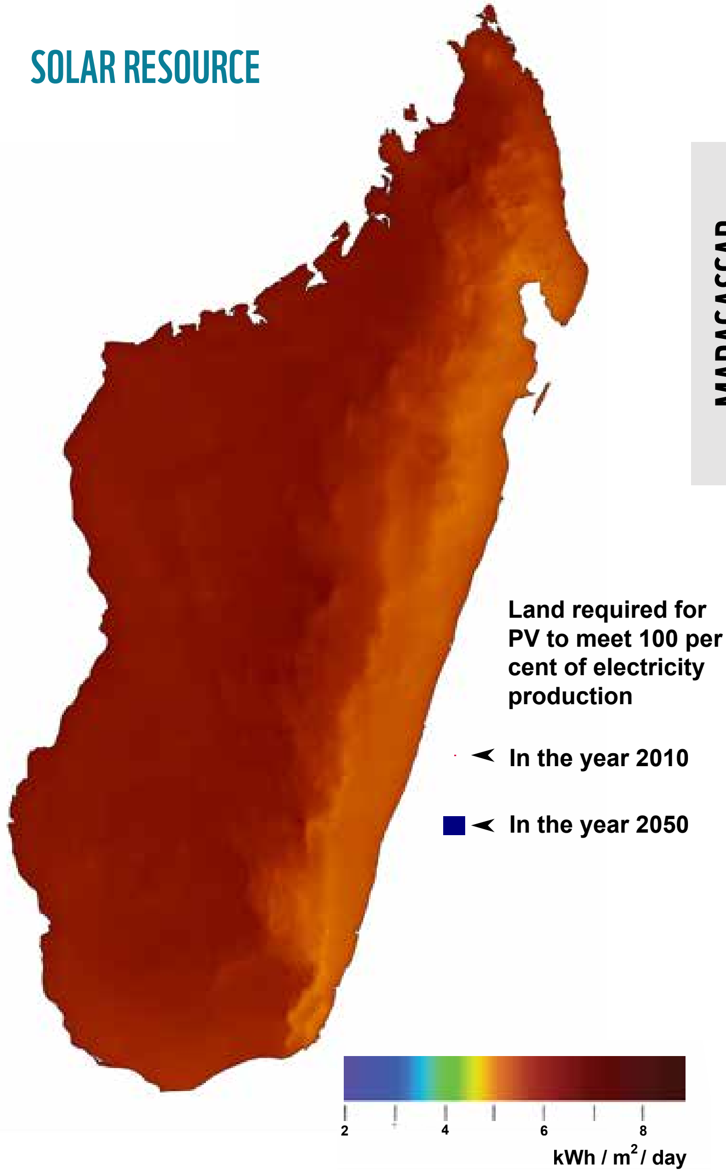
As can be seen on the solar map, the conditions for solar PV are excellent across the island. The prevailing trade winds that come from the east result in a small reduction in solar irradiance on the windward side of Madagascar. Overall however, the solar resource in Madagascar is very strong, with over two-thirds of the island having an annual average insolation greater than 6 kWh/m²/day. Even on the rainy side of Madagascar annual insolation is greater than 5 kWh/m²/day.

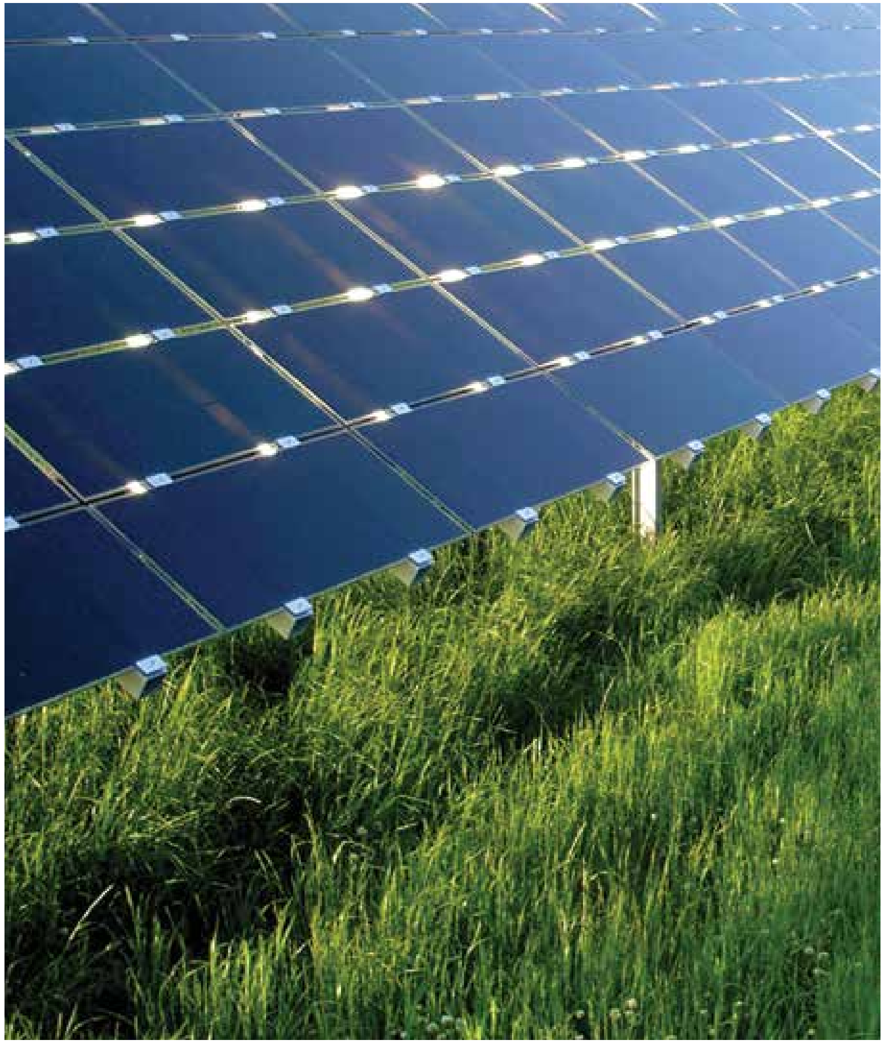
Four and a half square kilometres of solar panels would generate enough electricity to meet Madagascar's total current electricity generation. Because population and per capita electricity consumption are expected to rise in the coming decades, 780 square kilometres of land dedicated to solar production would be required to meet to meet 100 per cent of Madagascar's total electricity needs in 2050. Concentrated into one location, this land would repre-

POPULATION DENSITY



SOLAR RESOURCE





© First Solar. Ground mounted PV can provide distributed off- or on-grid electricity.

sent a square of about 28 kilometres on each side. The solar map shows land needed for 2010 generation (red square) as well as land use needed to meet electricity demand in 2050 (blue square). In other words, even based on very conservative estimates, less than one-fifth of one per cent (0.13 per cent) of Madagascar's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050. This projection assumes that those living in Madagascar are consuming the projected global average amount of electricity for 2050, which is more than 60 times current per capita consumption.

Madagascar's population is predominantly rural, with only 30 per cent of the population estimated to live in "urban" areas according to the UN Environment Programme. This is very encouraging for the development of more distributed community scale solar projects. As can be seen on the basemap, the densest populations are around the capital, Antananarivo and southward; the port cities of Mahajanga on the northwest coast and Toamasina on the east coast also have appreciable population densities, which make them good targets for larger-scale PV installations.

SOLAR PV ATLAS: MADHYA PRADESH, INDIA

Less than one per cent (0.75 per cent) of MP's land would need to host solar PV generation in order to meet 100 per cent of the state's projected electricity needs in 2050.

Situated in the middle of India, Madhya Pradesh is the second-largest Indian state by size. The state is home to more than 72.5 million people, over three-quarters of whom live in rural areas.[1] In 2011 Madhya Pradesh was responsible for 3.29 per cent of India's GDP, or US$52.3 billion. Inhabitants earned an average annual income of 27,250 rupees or about US$528.[2] Though 96.4 per cent of villages in Madhya Pradesh were considered electrified in 2009, the definition of an electrified village allows for up to 90 per cent of the households to lack access to electricity.[3]

Spanning what is considered a "genetic highway" between the western coast's Ghat Mountains and the northeast, Madhya Pradesh features two mountain ranges of its own and some of India's richest biodiversity. The state has approximately 5,000 plant species of which 625 are medicinal flora. Tigers and other endangered megafauna coexist with more than 500 bird species and 180 fish species. With four major forest types, nine national parks and 25 wildlife sanctuaries, the Tiger State is a pioneer state in the national movement for conservation. The national parks and sanctuaries constitute 11.4 per cent of the total forest area and 3.52 per cent of the geographical area of the state.[4]

State and national governments, as well as aid agencies, are investing in grid extension and increased generation, much of which is planned as coal. Solar PV generation offers a more sustainable and ultimately more affordable option for these power expansion plans.

Electric Sector Profile[5]	
Installed Capacity (2011)	8.38 GW
Total Generation (Apr. 2011-Mar. 2012)	49412.5 GWh
Avg. Consumer Price of Electricity (2009)[6]	US$0.087/kWh*
Electricity Consumption/ capita (2009-10)[7]	602.07 kWh
Average electricity consumption/ capita in IEA countries (2009)	9,200 kWh
Electricity Generation by Source	
Coal (2011-12)	84 per cent
Hydro-electric (2011-12)	10 per cent
Other	6 per cent

*US$1=56.235 INR, May 30, 2012

Electricity Sector

RE Source	Installed capacity (2010)
Biomass	32 MW
Wind	210 MW
Solar	2 MW

In 2011, Madhya Pradesh had a total installed capacity of 8.4 GW. The state government manages and operates 4.5 GW, the central government 3.6 GW, while only 240 MW is owned by private producers, most of which is in the renewable sector. In the future, the fuel-mix ratio is most likely to change and become even more coal heavy as many new coal-based thermal plants have been planned and there is an unlikely commensurate increase in hydro capacity.[8] The government of Madhya Pradesh has launched preliminary legal documents for projects totaling about 55 GW of new capacity. Of this, work has begun on 3 GW. About 35 per cent of the total potential hydropower (large and medium) assessed at 2.8 GW is yet to be tapped while most of the small and micro-power is still in exploratory stages.

There is scant data on actual households with access to electricity, but rates remain low. Intensive ongoing efforts continue to improve access to the grid under the national Rajiv Gandhi Gramin Vidyutikaran Yojna (RGGVY) rural electrification plan. The RGGVY does not work on three-phase power, however, so large agricultural pumping is not supported. Also, due to location and/or density, 401 villages in Madhya Pradesh are not covered by the RGGVY.

The government of Madhya Pradesh has been promoting the development of RE plants, including wind, through various policy initiatives and incentives for developers. It has also issued an Incentive Policy for encouraging generation of power in Madhya Pradesh through Non-conventional Energy Sources (2006). In 2010, Madhya Pradesh had an installed capacity of about 210 MW of wind power, about 32 MW of biomass based power and about 2 MW of solar power. As the assessed potential is significantly higher (wind – about 800 MW, solar – about 1.0 GW and biomass – about 250 MW), there are plans to expand the renewable power generation capacity in the state.[9] This is being done through the Madhya Pradesh Urja Vikas Nigam (MPUVN), a government agency created to promote renewable energy in the state. MPUVN has also initiated work on promoting energy-efficiency in the state and has estimated an energy-saving potential of 500 MW. There are various demand-side initiatives under way and also initiatives in industry clusters.[10]

To promote renewable energy, the Madhya Pradesh state Electricity Regulatory Commission (MPERC) has set a target of Renewable Purchase Obligations for distribution licensees at 6 per cent for wind, 2 per cent for biomass and 2 per cent for cogeneration and other sources. Together this will ensure that 10 per cent of the electricity production in Madhya Pradesh comes from renewable resources between 2011 and 2013.[11]

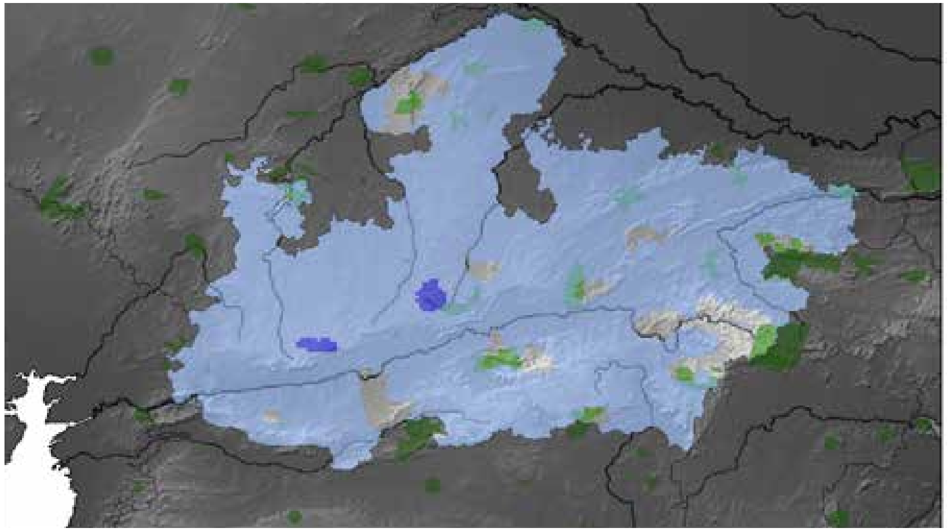
Wind power has made progress in the region, bolstered by the 2006 Incentive Policy. A total of 20 wind power projects have been installed so far. Biogas too has been the focus of much recent activity. Under the National Biogas and Manure Management Programme, about 20,000 biogas plants have been installed. The annual target for 2010 was 2,000 plants, 550 of which were installed by August.

Solar PV

In 2010, Madhya Pradesh launched a Solar Energy Policy through which the state intends to increase solar energy production, enhance energy security, promote efficient and cost-effective solar installations through fiscal and non-fiscal incentives, promote local manufacturing and develop local capabilities. The policy targets up to 500 MW of new solar installations. Apart from this, under the central government plan - Jawaharlal Nehru National Solar Mission (JNNSM) - three 100 MW projects have been registered in Madhya Pradesh and 17 more are planned, with 270 MW of new capacity.

Most areas in Madhya Pradesh receive sunlight for about 300 days in a year, and as can be seen on the solar map, the conditions for solar PV are excellent across the state. Though the climate and weather patterns are strongly influenced by the monsoon cycles, the very good solar irradiance overall makes PV an attractive generation option. Overall, average annual insolation for the state is just below 5 kWh/m²/day.

POPULATION DENSITY



Protected Areas

Population Density > 100/km²

Population Density > 1000/km²

Land required for PV to meet 100 per cent of electricity production

In the year 2010

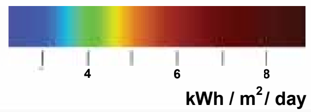
In the year 2050

SOLAR RESOURCE

Land required for PV to meet 100 per cent of electricity production

In the year 2010

In the year 2050



MADHYA PRADESH

© R.Isotti, A.Cambone - Homo Ambiens / WWF-Canon

Two hundred ten (210) square kilometres of solar panels would generate enough electricity to meet Madhya Pradesh's total current electricity generation. Because both population and per capita electricity consumption are expected to rise in the coming decades, 2,320 square kilometres of land dedicated to solar production would be required to meet 100 per cent of Madhya Pradesh's total electricity needs in 2050. Concentrated into one location, this land would represent a square of about 48 kilometres on each side. The solar map shows land needed for 2010 generation (red square) as well as land use needed to meet electricity demand in 2050 (blue square). In other words, even based on very conservative estimates, less than one per cent (0.75 per cent) of Madhya Pradesh's land would need to host solar PV generation in order to meet 100 per cent of the state's projected electricity needs in 2050. This projection assumes that those living in Madhya Pradesh are consuming the global average amount of electricity, which is more than five times current per capita consumption.

Madhya Pradesh's population is predominantly rural, with only 25 per cent of the population estimated to live in "urban" areas. This is generally very encouraging for the development of distributed household-level solar installations. However, as can be seen on the basemap, almost the entire state has a population density greater than 100 people/km² which points to the complimentary value of community microgrids and larger-scale PV installations. The microgrids can aggregate demand where densities of households make this economic, and the larger-scale PV installations can serve these aggregated loads along with irrigation and commercial needs.

© Jean-Philippe Denruyter / Women assemble solar components at the Barefoot College in India. Local employment across the value chain is a benefit of solar PV development.

SOLAR PV ATLAS: MEXICO

Just over one-tenth of one per cent (0.11 per cent) of Mexico's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050.

The federal republic of Mexico has a population of approximately 113.7 million people,[1] 47 per cent of whom live in poverty.[2] In 2010, the GDP per capita was US$13,900.[3] Ninety-nine per cent of the inhabitants have access to electricity.

In energy, natural gas and fuel oil dominate the country's electricity generation mix. Mexico is one of the world's largest crude oil exporters, but it is a net importer of refined petroleum products.

Since 2005, Mexico's energy demand has grown faster than GDP, yet there has been a steep decline in domestic fuel production. Mexican oil consumption is still highly subsidized, with subsidies for gasoline and diesel — for transporation and electricity — totaling more than US$22 billion per year.[4] The Mexican government recognizes the toll this is taking on its environment, fiscal health and national security, and has developed a number of policy frameworks aimed at improving energy security, strengthening energy production, and contributing to greenhouse gas emissions mitigation.[5]

All of these policies have some elements to encourage renewable energy and energy efficiency and to protect Mexico's natural environment.[6]

Dividing the Pacific Ocean from the Gulf of Mexico and serving as a land bridge between North and South America, Mexico is in the top five countries in the world in terms of animal diversity, with 200,000 different species — ten to twelve per cent of all species worldwide. With subtropical, alpine, and desert climates, Mexico is a hotspot for ecological richness and fragility with a very high concentration of endemic species.

Electricity sector

Since the 1990s the Mexican government has allowed the privatization of power plants, but the electricity market is still limited for private power producers. The state-run electric utility (CFE) creates barriers to entry for private producers in order to control most of the country's electricity generation and transmission. Just over 12 GW of installed capacity belongs to 22 private companies, the rest to CFE.[7] Electricity is a growing market in Mexico, with the Ministry of Energy predicting demand growth of 3.3 per cent per year for the next 10 years.

Mexico's electricity mix relies heavily on fossil fuels. Natural gas is the dominant source of electricity generation, and heavy fuel oil and coal also have a large share. Hydropower and a small amount of nuclear power complete the mix. Though hydropower and geothermal development seem stagnant, other RE generation is undergoing modest growth. There is huge growth potential for RE, and Mexican policies are seeking to tap at least part of this potential. In 2008 a special programme for renewable energies was established by the Mexican government and the Mexican Congress approved a set of energy-related laws and reforms. The programme sets three main goals for renewable energy to be achieved by 2012: (1) more than double the installed capacity of renewable energy sources, from 3.3 per cent to 7.6 per cent of total installed capacity; (2) increase renewable energy generation from 3.9 per cent to 6.6 per cent; and (3) use renewable energy to electrify 2,500 off-grid communities. Yet, this programme seemed to be less than a firm commitment for renewable energy expansion, since no comprehensive implementation and financial schemes have been put in place.

The National Energy Strategy (ENE) was created in 2010 as a legal framework for achieving the energy sector's main objectives — security, efficiency and sustainability — over a 15-year time horizon. Subsequent ENEs have been created but not ratified, so the 2010 strategy remains in effect. That ENE called for 35 per cent of electricity generation capacity to be from nuclear energy and RE including large hydro by 2024. It also set the interim goal of 7.6 per cent of installed capacity for RE excluding large hydropower plants.

Currently, wind energy is the only RE technology growing rapidly in Mexico. An energy transition to diversified RE and less dependence on fossil fuels is not yet happening. Because of ambiguities in federal law, the state-run electric utility (CFE) – which controls the majority of the electricity sector in Mexico and is one of the most important players for the development of renewable energies – is constrained. The law states that power production by CFE must be selected at the lowest cost, taking into consideration environmental externalities for each technology, and it must offer optimum stability, quality and safety of the public service. Although the law takes into account the valuation of externalities, there is no approved methodology to quantify these externalities. As a result, externalities are generally not considered, and traditional fossil fuel projects continue to move foreward.

Electric Sector Profile	
Installed Capacity (2011)[8]	51.177 GW
Total net generation (2010)	238,308 GWh
Average Residential Electricity Price (2010)	US$0.10/kWh
Electricity consumption per capita (2009)	1,943 kWh
Average electricity consumption/capita in IEA countries (2009)	9,200 kWh
Electricity Generation Mix (2011)	
Gas	42.6 per cent
Heavy Fuel Oil	21.6 per cent
Hydro (all sizes)	13.5 per cent
Coal	14 per cent
Nuclear	4.8 per cent
Geothermal/Wind	3 per cent
Diesel	0.5 per cent

RE Source	Installed capacity (2011)
Mini Hydro	376.5 MW
Geothermal	964.5 MW
Biomass	475 MW
Wind	873 MW
Solar	28 MW

Nevertheless, in 2012, Mexico passed landmark legislation capping green house gas emissions. With a programme established in 2008 to promote renewable energy development and the new climate law, Mexico's renewable energy marketplace is poised for expansion.

© Stéfane Mauris / WWF-Canon

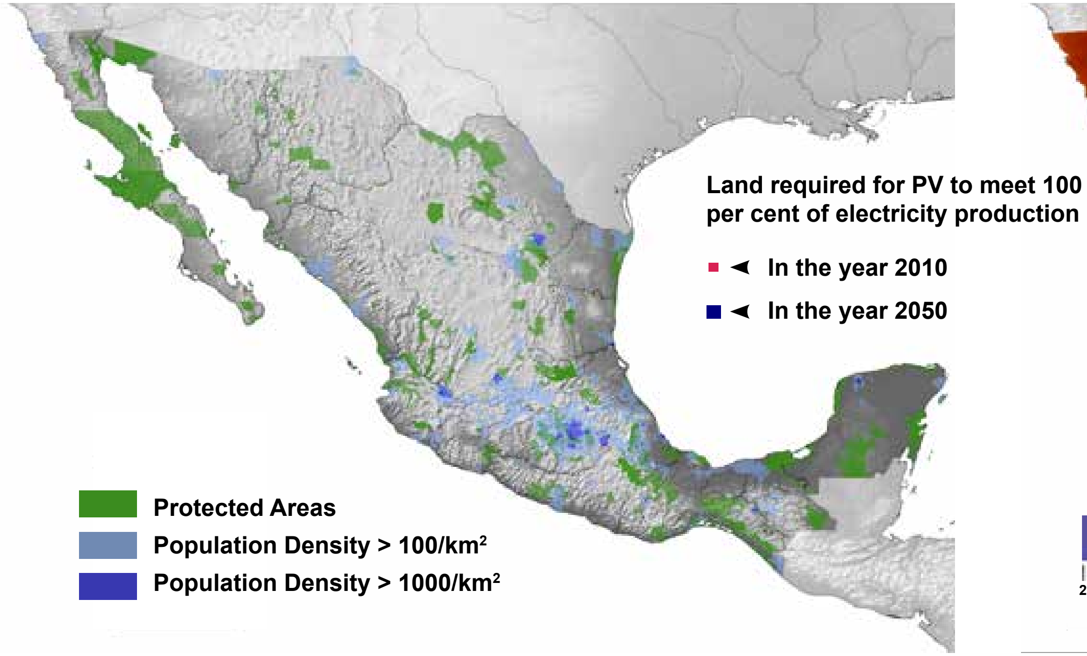
Solar PV

Most of Mexico consists of highlands, with the mountain ranges to the east and west dropping steeply to small coastal plains. The most dominant topographical feature of the country is the inner highlands which cover half of the total area of the country. While the entire country enjoys high levels of insolation, the Sierra Madre Oriental range and the areas to its west hold particularly strong potential for solar development.

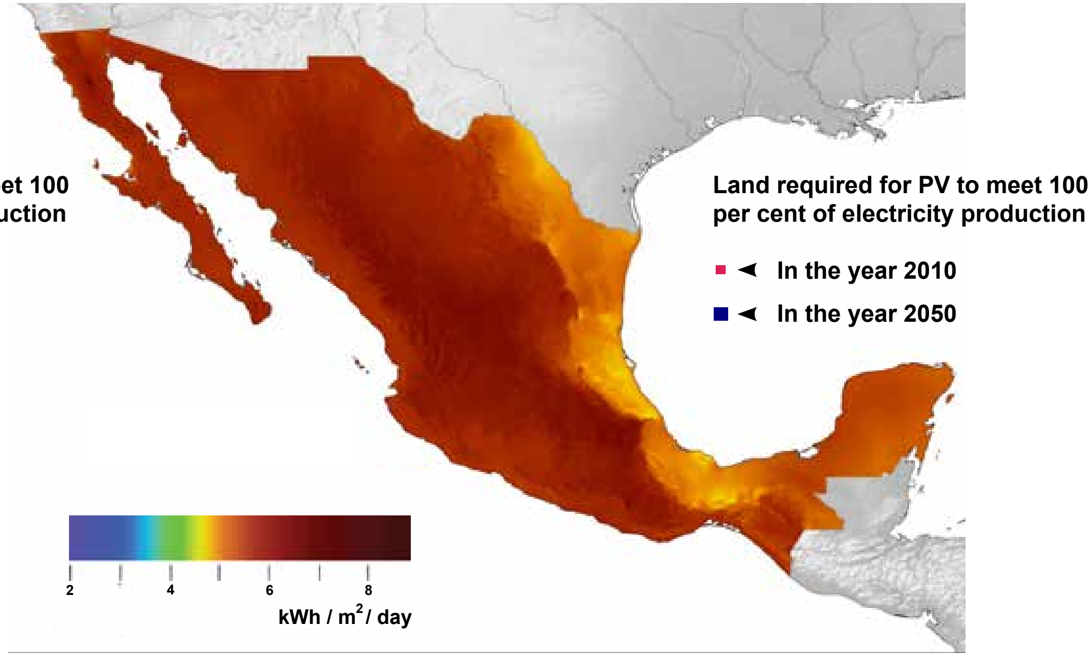
As of 2010, Mexico's total installed PV capacity was 26 MW. In addition to the distributed solar around the country, notable sites are the CFE-operated 1 MW site in Santa Rosalía, B.C. and the 5 MW project it is building in Cerro Prieto, BC. ABB is building a 1.2 MW project in San Luis Potosí. Though PV installations thus far have been small, plans for a 450MW concentrated photovoltaic plant in Baja California were announced in March 2012, with 50 MW planned to come online in 2013.

A total of 950 square kilometres of solar panels would generate enough electricity to meet Mexico's total current electricity generation. Because population and per capita electricity consumption are expected to rise in the coming years, 2,200 square kilometres of land dedicated to solar production would be required to meet to meet 100 per cent of Mexico's total electricity needs in 2050. Concentrated into one location, this land would represent a square of about 47 kilometres on each side. The solar map shows land needed for 2010 generation (red square) as well as land use needed to meet electricity demand in 2050 (blue square).

POPULATION DENSITY



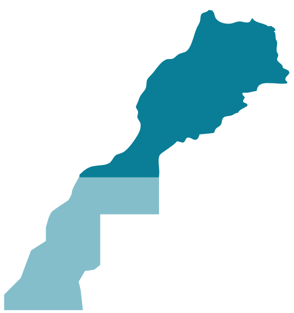
SOLAR RESOURCE



In other words, even based on very conservative estimates, just over one-tenth of one per cent (0.11 per cent) of Mexico's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050.

SOLAR PV ATLAS: MOROCCO

Less than one-fifth of one per cent (0.17 per cent) of Morocco's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050.



Located on the northwest coast of North Africa, the Kingdom of Morocco is a constitutional monarchy with a population of approximately 32 million people. In 2010, the GDP per capita of Morocco reached US$2,798, slightly higher than that of North Africa overall.[1]

Morocco is the largest energy importer in northern Africa, importing 97 per cent of its energy.[2] This heavy energy dependence makes the country particularly vulnerable to price fluctuations and supply disruptions. In 2008, total costs related to energy imports reached US$8 billion. Costs for energy imports have been rising for years and the Moroccan government has subsidized fuel prices with more than US$2 billion in order to keep Moroccan purchasing power from plummeting. Funding these subsidies for fossil fuels posed a significant strain on the national budget, especially with primary energy demand predicted to treble by 2030.

While 97 per cent of Moroccans have access to electricity,[3] it is important to note that fuel for cooking presents enormous challenges in Morocco. The harvesting of firewood for cooking is contributing to tens of thousands of hectares of deforestation.[4] Electrification of cooking and transportation would place additional demands on the current grid, but grid planners should consider the effects of integrating these sectors in the future.

Morocco fronts both the Atlantic Ocean and Mediterranean Sea, bordering their juncture at the Strait of Gibraltar. Its climate is largely Mediterranean, though its interior is drier and more desert like. Large coastal plains and plateaus edge the mountainous northern coast and interior. There are more than 32,000 species of flora and fauna in Morocco – of which 14 per cent are endemic – the second highest concentration of terrestrial species and highest concentration of marine species in the Mediterranean basin.[5]

Electricity Sector

With growth in both population and socio-economics, Morocco is experiencing rapid growth in electricity demand. Electricity demand is trending at a 7 per cent annual growth rate and is predicted to quadruple between 2008 and 2030. It imports both fuel for electricity generation and more than 3,400 GWh of electricity directly through grid interconnections with Spain and Algeria.

Electric Sector Profile	
Installed Capacity (2010)	6.3 GW
Electricity Production (2010)	22,531 GWh
Residential Electricity Price (2010)	US$0.10-0.16/kWh
Electricity consumption/capita (2009)	756 kWh
Average electricity consumption/capita in IEA countries (2009)	9,200 kWh
Electricity Generation Mix (2010)	
Heavy fuel oil	24 per cent
Coal	34 per cent
Natural gas	7 per cent
Hydro	33 per cent
Wind	2 per cent

The state-owned Office National de l'Electricité (ONE) is the primary player in generation, transmission, and distribution of grid electricity. Through reforms the ONE has encouraged partial privatization, primarily in generation. Independent Power Producers can also conclude Power Purchase Agreements with industrial off-takers connected on the ONE High Voltage network. Morocco can benefit from deals with its gas-exporting neighbour, Algeria. For instance, since the mid 1990s, a natural gas pipeline has led from the Algerian Hassi R'Mel gas field through Morocco to Spain. Through royalties earned from this passage, Morocco has been able to tap into the pipeline for some of its own electricity generation.

At the same time it is important for Morocco to reduce its dependency on energy imports. The country seeks to take advantage of its local coal resources, but is also investing in more promising and sustainable energy sources, like solar and wind energy. A high share of electricity is already coming from hydropower, resulting in pumped storage aspects of its grid that could be used to balance renewable generation with variable outputs.

In 2009, the government launched a sweeping energy reform aimed at addressing rising costs of imported energy, to ensure reliable supply, and to expand access to electricity by encouraging renewable energy development. In an effort to support Morocco's growth with secure and sustainable energy, the reform called for a diversification of generation technologies. The country's current renewable energy target is 42 per cent of total electricity generation by 2020. It plans 1.72 GW of wind power and 2 GW of solar power, on top of 2.6 GW of new hydropower.[6]

RE Source	Installed Capacity (2010)[7]
Large Hydro	1.27 GW
Solar PV	10 MW
Solar Thermal Electric	20 MW
Wind	291 MW

Solar PV

As a result of rural electrification programmes, photovoltaic solar energy has a relatively well-established presence in Morroco's countryside. At the end of 2007, 44,719 households were equipped with solar home systems. A different government-run pilot programme, the Chourouk programme, will install 1,400 micro PV power stations of 0.5-1 kW in the regions of d'Errachidia, Benguerir and Ouarzazate. These PV stations will be connected to the low voltage grid. While the rural electrification programmes continue, current discussion of solar often focuses on large-scale solar, both photovoltaic and concentrated solar power that could provide utility-scale inputs to the grid.[8]

In November 2009, the King announced the Moroccan Solar Plan, a 2.0 GW solar target by 2020. In March 2010 the country established the Moroccan Agency for Solar Energy (MASEN) to implement the 2.0 GW mandate.

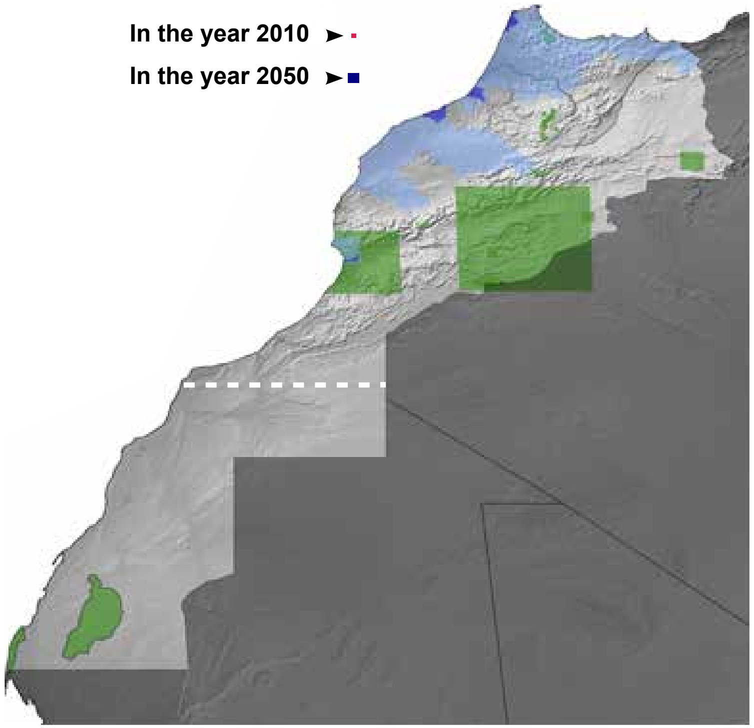
Morocco has recently upgraded the grid connection to Spain, and is actively

POPULATION DENSITY

Land required for PV to meet 100 per cent of electricity production

In the year 2010 ➤

In the year 2050 ➤



Protected Areas

Population Density > 100/km²

Population Density > 1000/km²

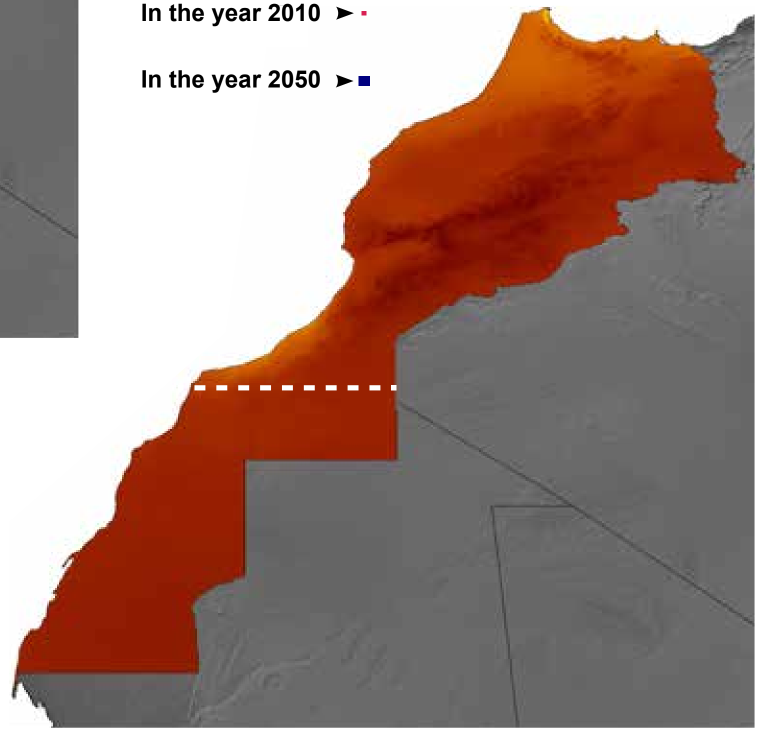
This map includes only the biodiversity data available through global data sets. Additional biodiversity information on protected areas in Morocco is available at *www.eauxetforets.gov.ma/fr/index.aspx (biodiversité)* and *http://ma.chm-cbd.net/manag_cons/esp_prot/stat_int_ma/ramsar_site_ma*

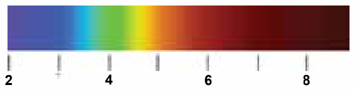
SOLAR RESOURCE

Land required for PV to meet 100 per cent of electricity production

In the year 2010 ➤

In the year 2050 ➤





engaged in discussions aimed at channeling solar power into Europe from North Africa. Over time, renewable electricity trade between North Africa and Europe could help both regions to progress towards WWF's vision of 100 per cent renewable energy and enable the development of a "super smart grid."

With more than 2,500 hours of annual sunshine, Morocco has an exceptionally good solar resource. As can be seen on the solar map, the solar resource over the entire land area of Morocco is excellent with the exception of a few tiny areas on the Mediterranean coast.

A total of 120 square kilometres of solar panels would generate enough electricity to meet Morocco's total current electricity generation. Because population and per capita electricity consumption are expected to rise in the coming years, 760 square kilometres of land dedicated to solar production would be required to meet 100 per cent of Morocco's total electricity needs in 2050. Concentrated into one location, this land would represent a square of about 28 kilometres on each side. The solar map shows land needed for 2010 generation (red square), as well as land use needed to meet electricity demand in 2050 (blue square).

In other words, even based on very conservative estimates, less than one-fifth of one per cent (0.17 per cent) of Morocco's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050.

SOLAR PV ATLAS: SOUTH AFRICA

SOUTH AFRICA

Less than one-tenth of one per cent (0.09 per cent) of South Africa's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050.

The Republic of South Africa is a country of approximately 50.6 million people (2011).[1] In 2010, approximately 62 per cent of the population lived in urban areas,[2] and the country's GDP per capita was US$10,280.[3] About 75 per cent of South Africans have access to electricity.

The South African energy supply is dominated by coal, with 65.7 per cent of the primary energy supply, followed by crude oil with 21.6 per cent, renewable and wastes with 7.6 per cent and gas with 2.8 per cent. South Africa is a large coal producer, with proven coal reserves of 48 gigatonnes, representing 5.7 per cent of total global reserves.[4]

South Africa is the third-most biologically diverse country in the world. With a land surface area equivalent to just 1 per cent of the Earth's total land surface, South Africa has almost 10 per cent of the world's known bird, fish, and plant species and more than 6 per cent of the Earth's mammal and reptile species. South Africa's incredible biodiversity is due to its wide range of climatic conditions and unique topography. Most of the country is situated on a high-lying plateau, between two very different oceans: the Atlantic and the Indian.

Habitat destruction, pollution, invasive species, and climate change are currently threatening South Africa's flora and fauna. More than 2,000 of the nation's plants are threatened. The government is trying to counteract this decline in biodiversity with several programmes but progress has been slow. A rapid development of renewable energy in the country would contribute to the world's fight against climate change and could mitigate some of the local threats to habitat by reducing local pollution and destructive land use practices.

© Michel Terrettaz / WWF-Canon

Electricity sector

According to its national Department of Energy, South Africa supplies two-thirds of Africa's electricity and is one of the four cheapest electricity producers in the world. Yet one quarter of South Africans have no access to the grid and instead rely on candles and kerosene for lighting.[5]

Eskom, the state-owned utility, dominates electricity generation, supplying about 95 per cent of South Africa's electricity. While Eskom does not have exclusive generation rights, practically speaking it has a monopoly on bulk electricity as it owns and operates the national electricity grid. More than 90 per cent of all electricity generated by Eskom comes from South Africa's indigenous coal supplies.

In 2008 South Africa experienced rolling blackouts. Since then it has managed to avoid further blackouts, but there are predictions that demand will exceed supply by 9 TWh by the end of 2012. In order to avoid further disruptions, the government has introduced a series of measures to boost electricity production. According to the government's new Integrated Resource Plan (IRP), local installed capacity must increase to supply 454,000 GWh by 2030 with a Policy-Adjusted 2010 IRP installed capacity for 2030 of 89.5 GW. The IRP also commits to reducing water use and carbon dioxide emissions (275 million tons of carbon dioxide annually after 2024).

Despite the IRP's commitment to renewable energy, unsustainable energy sources such as coal or nuclear would still be the major source of power in South Africa in 2030. Coal would lead with 65 per cent of electricity production. Nuclear power would emerge as the second largest source, increasing its share of electricity production from 5 per cent to 20 per cent. Renewables would come third, producing 9 per cent of electricity.[6]

The need for alternative sources of energy in South Africa is critical, and not only to meet the growing electricity demand. Reliance on coal-fired power has resulted in South Africa's greenhouse gas emissions being double the global per capita average.

Electric Sector Profile	
Installed Capacity (2008)	44.1 GW
Total Net Generation (2009)	246,800 GWh
Average Residential Electricity Price (2010)	US$0.062/ kWh
Electricity consumption/capita	4,600 MWh
Average electricity consumption/capita in IEA countries (2009)	9,200 kWh
Electricity Generation Mix (2010)	
Coal	90 per cent
Nuclear	5 per cent
Hydropower	5 per cent

RE Source	Installed capacity
Hydro	2.1 GW
Wind	22 MW
Solar PV	6 MW

Along with emitting large amounts of carbon dioxide, coal-fired plants use significant amounts of water – net water consumption was 327,252 million litres in 2011, the highest level since 2007.[7] In addition to contributing to South Africa's goal of reducing carbon emissions by 42 per cent by 2025,[8] renewable energy sources can help tackle unemployment, one of South Africa's most serious and persistent socioeconomic issues.[9] A green economy could create jobs by ramping-up the existing manufacturing capacity to meet the region's growing demand for alternative low-carbon energy sources.

Pretoria has adopted several measures that indicate that it is serious about developing renewables. In November 2011, the government released the National Development Plan (NDP) – Vision for 2030. This advisory document dedicated a whole chapter to transitioning to a low-carbon economy. The plan envisions material investments into low-carbon infrastructure by 2030, backed by international financial aid.[10]

In December 2011, South African President Jacob Zuma announced another initiative to promote the development of renewable energy generation and industrial development in South Africa: The South African Renewable Initiative (SARi). SARi will provide low cost loans and other financial instruments combined with time-limited pay-for-performance grants to large-scale renewable developments. Although the South African government initiated SARi, it is funded through a partnership agreement between the United States Department of Energy, the European Investment Bank and the governments of the UK, Germany, Denmark, Switzerland and Norway.[11]

© First Solar. Rooftop PV applications like these could provide significant generation for urban areas in South Africa.

Solar PV

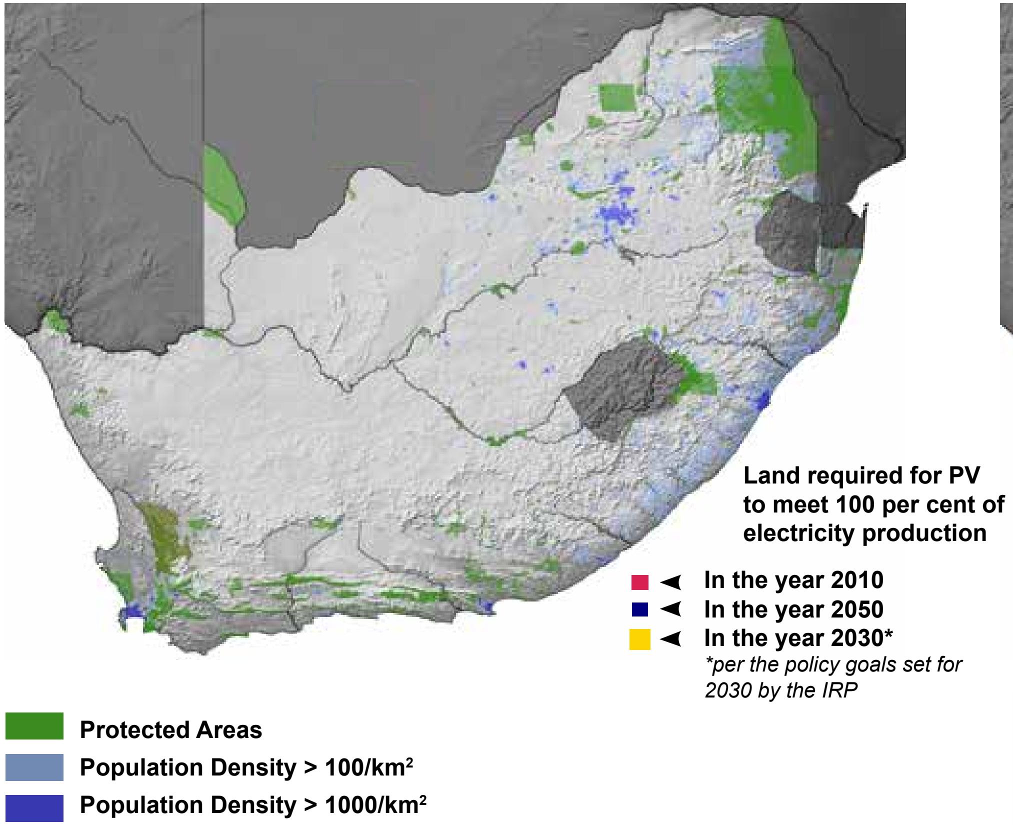
With an average of more than 2,500 hours of sunshine every year, South Africa has one of the highest and most stable solar radiation levels in the world. Yet solar power generation has remained largely untapped. Nevertheless, in December 2011, Taiwan's AUO Optronics announced along with Eskom that they had completed a 1.2 MW PV project, the first system of its kind in the country. President Zuma officially launched the facility, which is expected to supply electricity and jobs to the eThekWini municipality.[12]

As can be seen on the solar map, the conditions for solar PV are excellent across the country. The effects of the coast and the mountains result in a small reduction in solar irradiance along the country's southern and eastern edges. Solar PV can greatly contribute to the country's energy mix through decentralized access to electricity as well as large-scale PV power stations.

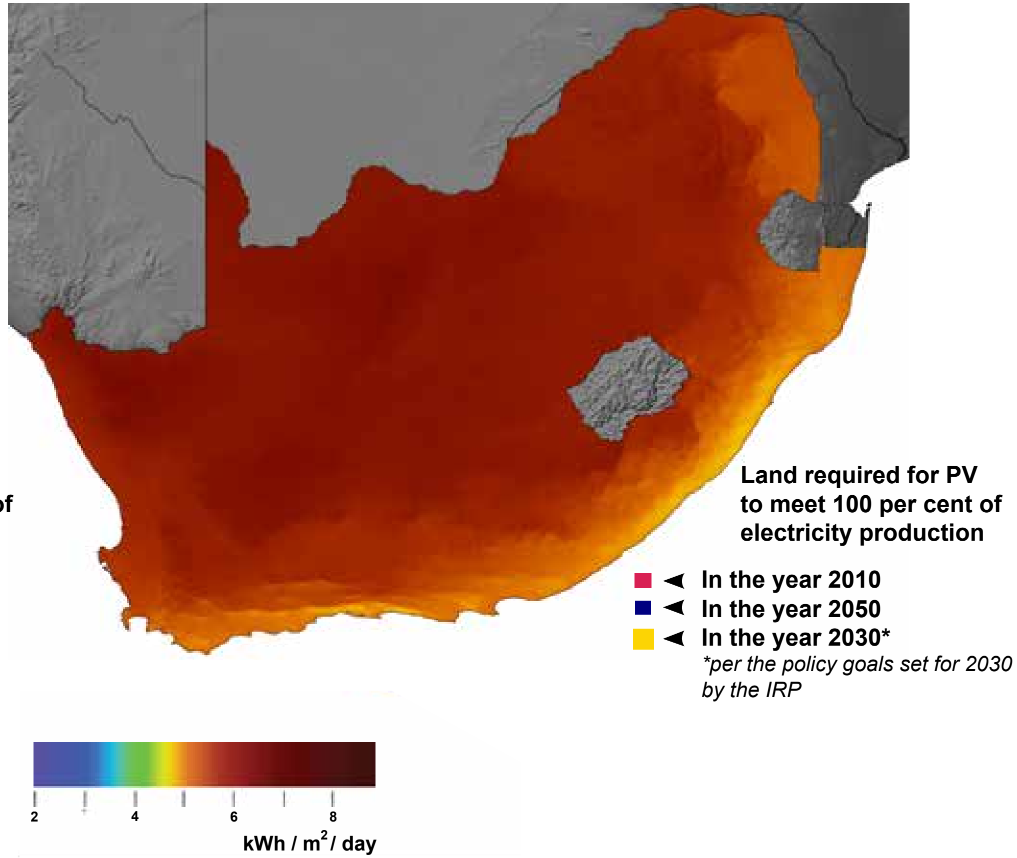
A total of 1,130 square kilometres of solar PV installation would generate enough electricity to meet South Africa's total current electricity generation. Population is projected to rise slightly in the coming years, but if South Africa adopts efficiency measures that would bring it in line with WWF's projected global per capita averages, it could see both universal electrification and a slightly lower per-capita electricity demand by 2050. With those assumptions, the area of land required to meet 100 per cent of South Africa's total electricity needs in 2050, using today's PV technology, stays about the same – 1,110 square kilometres. Concentrated into one location, this land would represent a square of about 33 kilometres on each side. The solar map shows land needed for 2010 generation (red square), as well as land use needed to meet electricity demand in 2050 (blue square). In other words, less than one-tenth of one per cent (0.09 per cent) of South Africa's land would need to host solar PV generation in order to meet 100 per cent of the country's projected electricity needs in 2050. If, conversely, South Africa continued to expand generation capacity as per the 2010 IRP, to double by 2030, the "100% solar square" represented on the map for 2050 would be larger but still remarkably modest.

The energy profile published in South Africa's 1st National Communication under the United Nations Framework Convention on Climate Change[13] notes that although coal is by far the largest non-renewable energy resource with an impressive energy reserve of 1,298,000 PJ, it is almost insignificant in comparison to the country's largest renewable energy resource, namely solar with an energy reserve of 8,500,000 PJ/year. Thus, the total coal reserve is only equal to around 15 per cent of the solar resource that is available to South Africa every year.

POPULATION DENSITY



SOLAR RESOURCE



SOLAR PV ATLAS: TURKEY

Less than one quarter of one per cent (0.21 per cent) of Turkey's land would need to host solar PV generation in order to meet 100 per cent of Turkey's projected electricity needs in 2050.

The Republic of Turkey has a population of 74.7 million people (2011), 77 per cent of which live in urban areas. In 2010, the country's GDP per capita was US$10,067,[1] after growing 9 per cent from 2009. Most people have access to electricity but with a high rate of losses and illegal consumption at 15 per cent.

Turkey has experienced rapid growth in energy demand in recent years that is likely to continue in the medium- to long-term.[2] The government is trying to avoid bottlenecks in supply and sustain the country's fast economic growth by opening its markets to outside investment. It is also committed to expanding energy production capacity while reducing dependence on imported energy sources, which stood at 71 per cent in 2011.

Though Turkey stands as a global leader in solar water heating, with an installed capacity second only to China's, Turkey's electricity sector remains largely fossil fuel dependent. Demand for energy has grown substantially in recent years, particularly in the power sector.

Turkey sits at the junction of Europe, Asia and Africa and is a part of three different bio-geographical regions. Thanks to its diverse ecosystems and topographic, geologic, geomorphologic and soil variety, Turkey is rich in fauna and flora, hosting 132 mammal, 456 bird, 10,000 plant, 125 reptile and amphibian, 364 butterfly and 405 fish species.

Environmental conservation in Turkey has historically followed an inconsistent path. As suggested by the unbridgeable gap between legislation and enforcement and the recent regressive changes proposed for conservation legislation, conservation is not advancing. Unfortunately, current energy policies add additional pressure on the environment, whether through greenhouse gas emissions, coal mining, nuclear plants or poorly planned hydropower projects.

© Gokham Tan

Electricity sector

Between 2000 and 2009, Turkey's electricity demand grew 55.3 per cent, compared to 6.9 per cent in OECD countries and 22 per cent in the world.[3] To meet this demand, government has ramped-up annual electricity generation to 211,000 GWh, a four-fold increase over the past 25 years. In its efforts to meet the rapid demand increase, Turkey has favoured thermoelectric power plants, and as a result natural gas has become the main energy source in electricity generation.[4]

Turkey's growing dependence on fossil fuels has resulted in a dramatic increase in import dependence, as almost all of the natural gas and one-third of the coal used to produce electricity has to be imported.[5] Concerned with the impact of this dependence on its energy security and finances, the government introduced several measures to improve energy efficiency, increase diversification while reducing carbon emissions. In the 2009 "Electricity Energy Market and Supply Security Strategy Paper," the government announced its electricity generation goals for 2023 as reducing natural gas while building more nuclear and renewable capacity.[6] A target of 30 per cent renewable electricity by 2023 was announced.

Following the law's approval, Turkey experienced a boom in wind power. Installed capacity for wind energy, which was almost absent in 2002, reached 1.799 GW in 2011. In the same period, the geothermal installed capacity grew from under 20MW to 94.2 MW.

© Sedat Kalem / WWF-Turkey

Electric Sector Profile (2011)	
Installed Capacity	52.458 MW
Total Net Generation	211,000 GWh
Residential Electricity Price	0.258 TL/kWh $US0.14/kWh
Electricity consumption/ capita	2,791 kWh
Average electricity consumption/capita in IEA countries (2009)	9,200 kWh
Electricity Generation Mix (2009)	
Natural gas	43.8 per cent
Coal	26.6 per cent
Hydropower	24 per cent
Wind, geothermal, + other RE	2.5 per cent
Other	3.1 per cent

RE source	Installed Capacity (2011)
Hydro	17.036 GW
Wind	1.799 GW
Geothermal	94 MW
Solar PV	1 MW

Solar PV

Presently there is a small solar photovoltaic market in Turkey. This market emerged when commercial companies – shopping malls, factories, hospitals – and several homeowners decided to reduce their electricity costs by installing solar panels for their own energy production. As of 2010, official figures rate solar PV at one megawatt of installed capacity.

Despite adoption by a small segment of the population, solar power is still a nominal source of electricity. Recently, the government approved an amendment to the Renewable Energy Law which was in part designed to increase the generating capacity of solar power. Reactions to this amendment have been mixed as the proposed feed-in tariff is capped at 10 years, too short a time to finance projects with traditional capital markets. Additionally, clear regulations are needed to allow solar power to be connected to the grid.

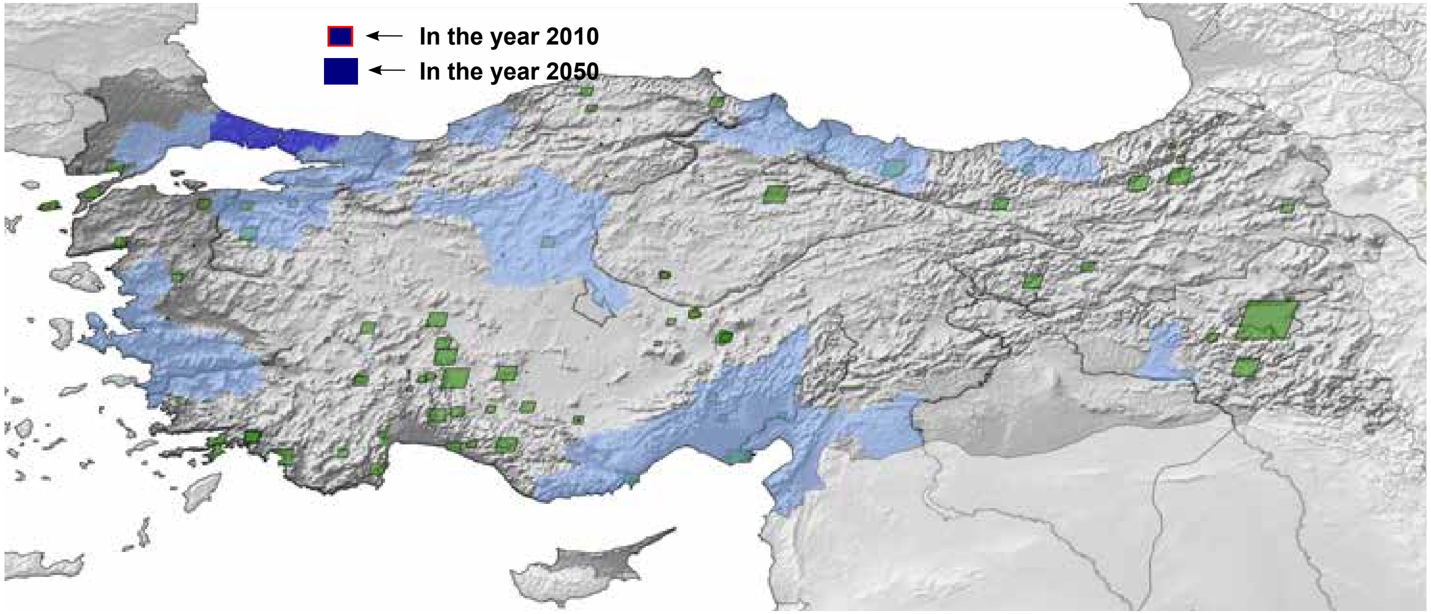
Potential investors in Turkey's solar energy sector are attracted by Turkey's possible participation in the European Electricity Market, following the 2009 synchronization between the Turkish power system and the interconnected power systems of continental Europe. Turkey is also expected to play an important role in cross-border renewable projects "Desertec"[7] and "Mediterranean Solar Plan,"[8] both as a solar energy supplier and a bridge between the Middle East and Europe.

Most of Turkey's southern half has annual insolation values above 5.0 kWh/m^2/day. Istanbul, due to the effects of the Black Sea, is less sunny with about 4.1 kWh/m^2/day. Solar development along the Aegean and Mediterranean coasts appears to present the best opportunity for aligning population centres and large PV plants.

A total of 790 kilometres of solar panels would generate enough electricity to meet Turkey's total current electricity generation. Because population and per capita electricity consumption are expected to rise in the coming decades, 1,600 square kilometres of land dedicated to solar production would be required to meet 100 per cent of Turkey's total electricity needs in 2050. Concentrated into one location, this land would represent a square of about 40 kilometres on each side. The solar map shows land needed for 2010 generation (red square), as well as land use needed to meet electricity demand in 2050 (blue square). In other words, even based on very conservative estimates, less than one quarter of one per cent (0.21 per cent) of Turkey's land would need to host solar PV generation in order to meet 100 per cent of Turkey's projected electricity needs in 2050.

POPULATION DENSITY

Land required for PV to meet 100 per cent of electricity production



Protected Areas

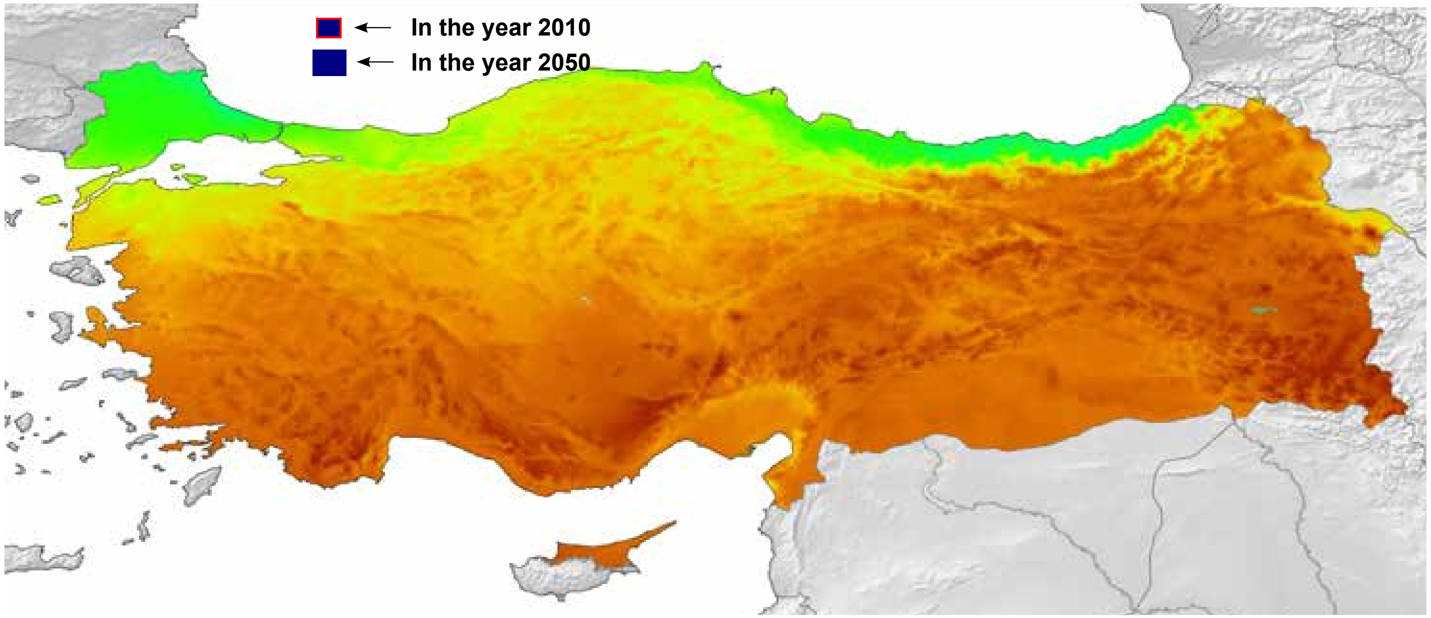
Population Density > 100/km²

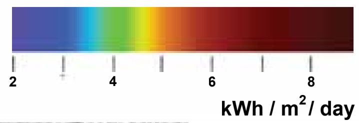
Population Density > 1000/km²

This map includes only the biodiversity data available through global data sets. Additional biodiversity information for Turkey is available through the Ministry of Forestry and Water Affairs at: *http://geodata.ormansu.gov.tr/3d/indexv5.aspx*

SOLAR RESOURCE

Land required for PV to meet 100 per cent of electricity production





TURKEY

ELECTRICITY CONSUMPTION IN 2050 – EFFICIENCY AND ELECTRIFICATION

A fully sustainable renewable energy power supply is the only way we can secure energy for all and avoid environmental catastrophe.

In one city, halogen lights shine brightly in unoccupied offices. In another, people are literally sitting in the dark. Electricity consumption levels of much of the world today are unsustainable: 1.3 billion people completely lack access to electricity, while electricity generation to support consumption levels in much of the world is already straining human health and the environment. A fully sustainable renewable energy supply is the only way we can secure energy for all and avoid environmental catastrophe. As we contemplate this shift to renewable energy and universal access, all plausible scenarios point to energy efficiency as the first and finest “fuel.” To meet global electricity demands in 2050, fewer joules will be providing more energy services. This is why global energy supply decreases by 2050 in the Ecofys scenario, despite the projected population increase and expansion of energy services (see Figure 1, page 9.)

While global energy consumption is projected to fall, electricity consumption is projected to double by 2050, as a result of electrification trends in transportation, heating and other sectors. Use of renewable sources allows the global share of electricity supply to increase drastically by 2050 while fossil and nuclear fuels are phased out.

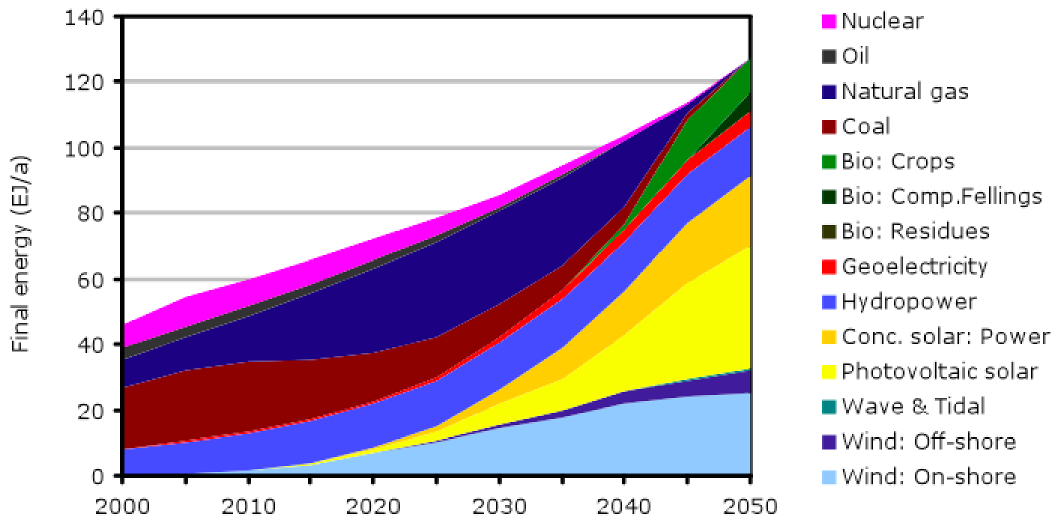


FIGURE 3: GLOBAL ELECTRICITY SUPPLY

Ecofys sees a dramatic increase in renewable electricity, completely displacing the need for fossil and nuclear based electricity by 2050. *Source: The Ecofys Energy Scenario, December 2010.*

Access and Equity

The Ecofys Scenario makes no mention of how the global electricity supply will be distributed among countries. To reach per capita electricity consumption in 2050 for the various regions in this atlas, we make the bold assumption that there will be energy equality across borders. In this UN "Year of Sustainable Energy for All", we assert optimistically that through efficiency, innovation, and responsible deployment of existing technologies, we can and will build sustainable energy systems that both eradicate energy poverty and protect economic and environmental prosperity.

As the graph below illustrates, projected per capita electricity consumption for 2050 falls far below current levels of consumption in the EU and US and also slightly below current levels in South Africa. It exceeds current levels of consumption in the other six selected regions. It is important to note that in many of the selected regions much of the population is living without any electricity. The per capita consumption data are thus low for these regions not because of energy efficient economies but because of energy poverty. Expanding access to electricity is critical, and in expanding access careful decision makers must fully assess the real cost effectiveness of deep efficiency and renewable energy development to meet these needs. Indeed, the areas of least access are often the areas of greatest potential for thoughtful development. Much as mobile telephony saw explosive growth in areas where copper phone wires did not exist, so too can sustainable energy systems leapfrog traditional electricity systems in areas with little incumbent energy technology. These innovations spill across borders, and, as we have seen in sectors from agriculture to telecommunications, "South-to-North" technology transfer can transform established systems.

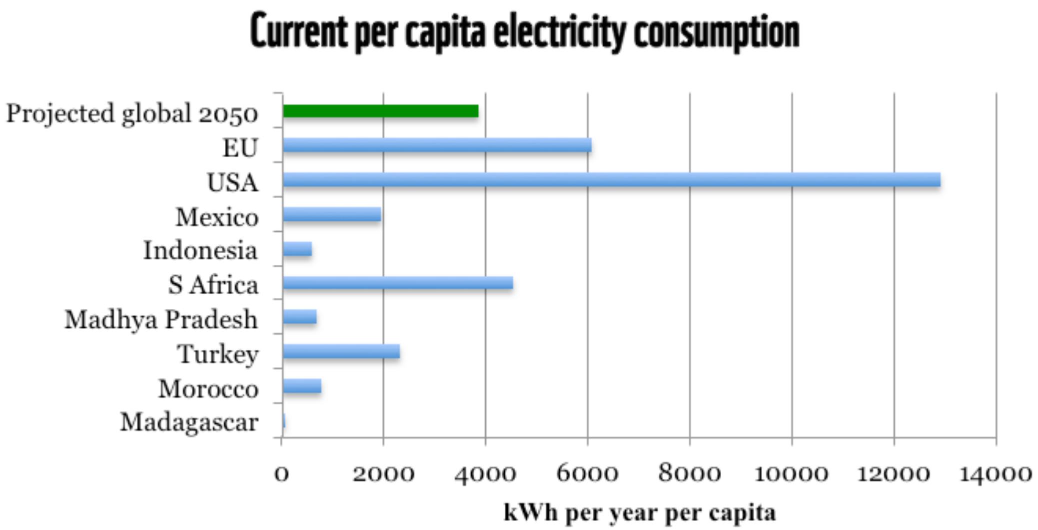


FIGURE 4: 2050 GLOBAL AND CURRENT REGIONAL PER CAPITA ELECTRICITY CONSUMPTION.

This atlas calculates solar needs based on levelized global per capita energy consumption in 2050. Given current trends, this atlas very likely overestimate future per capita electricity consumption in many of the focus regions, while it may slightly underestimate future electricity consumption in heavily industrialized countries such as South Africa. *Sources: 2050 global - Ecofys Scenario 2010, World Bank and Government of India.*

ELECTRICITY IN HARMONY WITH NATURE: PHOTOVOLTAICS

Solar energy is the most abundant energy resource on Earth. The solar energy that hits the Earth's surface in one hour is about the same as the amount of energy consumed by all human activities in a year. PV systems directly convert solar energy into electricity. Other solar technologies harness the sun's energy through concentrating solar power (CSP) and with solar thermal collectors for heating and cooling (SHC).

PV is a versatile technology. Systems can be connected to the utility grid, to mini-grids or operated in stand-alone applications. They can be used in building-integrated systems (BIPV) or be ground-mounted, for example, in large-scale electricity production facilities.

There are four end-use sectors with distinct markets for PV:

- Residential systems (typically up to 20 kW systems on individual buildings/dwellings).
- Commercial systems (typically up to 1 MW systems for commercial office buildings, schools, hospitals, and retail).
- Utility scale systems (starting at 1 MW, typically ground-mounted).
- Off-grid applications (varying sizes).

PV generation installed directly at the site of electricity consumption can alleviate grid congestion and defer or eliminate the expense of upgrading grid infrastructure. Utility-scale systems can leverage economies of scale and optimal siting to achieve low levelized costs of energy (LCOE). Off-grid and mini-grid applications bring reliable electricity to areas previously underserved or served with expensive diesel supply. These different applications have different system costs and compete at different price levels.

Today, PV provides 0.1 per cent of total global electricity generation.[1] However, PV has seen an average annual growth rate of more than 40 per cent since 2000. Now a well-established commercially available and reliable technology, it has significant potential for long-term growth in nearly all world regions now and in the coming decades.

Grid parity is already a reality for solar PV in some applications and markets. Nevertheless, the realities of explicit and structural subsidies for fossil fuels and nuclear energy mean that achieving high levels of PV electricity supply cost-effectively – and the associated, environmental, economic and societal benefits – will require concerted policy support.

PROVIDING POWER, GROWING FOOD AND PROTECTING BIODIVERSITY

Solar PV is socioeconomically one of the most benign energy technologies that exist today. Impacts on the local environment are relatively low or even positive;[2] energy pay-back time is short; greenhouse gas emissions are close to zero when measured over their entire life-time; and socially, solar PV creates jobs in manufacturing, development, construction, installation and operation of roof-top solar and solar parks. PV is also a crucial technology to provide a reliable access to electricity to the many people living in remote areas without access to a grid.

Policy makers and land planners must constantly balance land use and conservation. We need land for buildings and other infrastructure, to grow food and fibres and raise livestock, we need forests for timber and paper, and seas for food and leisure, and we also need to leave space for nature. We need healthy ecosystems to provide clean air and water, regulate our climate, keep our soils and seas productive, prevent flooding, and more. To build sustainable electricity systems over the coming decades we will need to develop an extensive renewable energy infrastructure, and making the right choices on technologies and land use will be crucial.

It is in this context that there is growing public attention on how solar parks affect both climate change and biodiversity. Although the land use for solar parks is minimal compared to other uses, the solar sector must also evaluate and manage any negative impacts of its activities on the environment.

Overall, research has consistently found that when developed responsibly, ground-mounted solar PV power plants provide considerable environmental benefits. Replacing existing grid electricity with PV arrays reduces emissions of greenhouse gases, criteria pollutants, heavy metals, and radioactive species by at least 89 per cent[3] and also significantly reduces water withdrawal and consumption.[4]

A 2009 study of PV solar generation environmental impacts found that, “Solar technology is concluded to be **much preferable** to traditional means of power generation, even **considering wildlife and land use impacts**”. From the 32 environmental impact categories the researchers identified for solar power plants, they found that 22 were beneficial relative to traditional power generation, 4 were neutral, none were detrimental, and 6 needed further research.[5]

Table 1: Impacts Relative to Traditional U.S. Power Generation (Turney and Fthenakis, 2011)

Impact category	Effect relative to traditional power	Beneficial or detrimental	Priority	Comments
Exposure to hazardous chemicals				
Acid rain: SO NOx	Reduces emissions	Beneficial	Moderate	Solar power emits ~25x less
Nitrogen, eutrophication	Reduces emissions	Beneficial	Moderate	Solar emits much less
Mercury	Reduces emissions	Beneficial	Moderate	Solar emits ~30x less
Other: e.g., Cd, Pb, particulates	Reduces emissions	Beneficial	Moderate	Solar emits much less
Oil spills	Reduces risk	Beneficial	High	Note: BP Horizon Spill, Valdez Spill
Physical dangers				
Cooling water intake hazards	Eliminates hazard	Beneficial	Moderate	Thermoelectric cooling is relegated
Birds: flight hazards	Transmission lines	Detrimental	Low	Solar needs additional transmission line
Roadway and railway hazard	Reduces hazard	Beneficial	Low	Road and railway kill is likely reduced
Habitat				
Habitat fragmentation	Neutral	Neutral	Moderate	Needs research and observation
Local habitat quality	Reduces mining	Beneficial	Moderate	Mining vs. solar farms; needs observation
Land transportation	Neutral	Neutral	Moderate	Needs research and observation
Climate change	Reduce change	Beneficial	High	Solar emits ~25x less greenhouse gases

FIGURE 5: SOLAR PV IMPACTS RELATIVE TO TRADITIONAL U.S. POWER GENERATION

Source: Turney and Fthenakis, 2011.

All large-scale energy infrastructure developments must as a minimum ensure legal compliance, pass environmental impact assessments, meet environmental and social criteria and engage local stakeholders. The Gold Standard for best practice in projects delivering carbon credits, including a "do not harm" sustainability assessment and local stakeholder consultation guidelines, provides a good example.[6] In the hydropower sector, the International Hydropower Association developed a sustainability protocol together with key stakeholders including WWF. For biofuels, there is a Roundtable of Sustainable Biofuels–in which WWF has participated since the initiative's launch.

No such industry standard yet exists for solar PV development, but developers, policy makers and environmental groups are active in this field and developing guidelines and best practices. In 2005, German NGO NABU and Solar Association BSW issued the first guidelines for solar PV. A 2010 report by the German Renewable Energies Agency summarizes the results of an assessment of eight solar parks, looking at several years' worth of monitoring data and best practices. The report concludes that using land for PV development, climate protection and environmental protection can happen simultaneously provided that solar plants are responsibly planned, constructed and operated, and sensitive areas are properly protected or avoided. According to the report, several solar parks have even shown an increase of biodiversity, especially in areas that were previously sealed, used for intensive agriculture or former military fields. The report also describes good practices and gives recommendations on planning and management of solar parks:

- Dedicated buffer areas in solar parks can grow into important biotopes for endangered species.
- Environmental impact assessments need to consider specific local conditions and propose relevant compensatory measures.
- It is important to involve (local) experts for ecologically sound project planning.
- Soil sealing needs to be avoided to the extent possible - sealing should usually not exceed 1 per cent of the total surface.
- Species selection for post-construction replanting within the solar park should preserve local genetic diversity.
- Minimizing closed areas and creating passageways for animals reduces negative effects of fencing for animals.
- Continuous monitoring is essential to gather useful information for future improvements.

In 2011, CLER, a French umbrella NGO promoting renewable energies, developed a position paper "Solar Parks, Yes, But Not at All Costs"[7] and later launched a guide for responsible solar parks that is in line with the NABU/BSW guidance and with the AEE report's best practices list.[8]

These reports, guidelines and policies contribute to a balanced debate on the development and acceptance of solar parks and the promotion of renewable and solar energy globally. PV solar players, project developers and other key stakeholders should consider launching a multi-stakeholder initiative in this area and agree on sector-wide guidelines for responsible land management to be applied globally. The International Energy Agency's Very Large-scale PV Systems Task 8 is currently looking at impacts and best practices, and could play a role in this process. A summary table of impact categories that can be considered when planning, developing, constructing and operating a large-scale PV facility is included as Annex 2.

Another often-raised concern, soon mandated in the EU, relates to the take-back and recycling of end-of-life (EOL) PV modules. As a way to improve the green footprint of all PV companies, take back and recycling allows for material recovery and for reduction of cumulative energy demand and associated carbon footprint of PV modules. Volumes of EOL panels are still relatively low (PV panels have a long life time, 20-30 years) but are expected to considerably grow when larger amounts of solar panels are retired and returned. To assess the sustainability of PV modules and installations, all three pillars of sustainability—economic, social and environmental—should be considered while taking the entire lifecycle, from sourcing of raw materials to production, operation, and end-of-life reclamation.

ANNEX 1: ABOUT THIS ATLAS – ASSUMPTIONS, DATA, AND PROCESS

THE FIGURES USED FOR LAND USE CALCULATIONS ARE EXTREMELY CAUTIOUS:

PV contribution to total electricity mix
The Ecofys Scenario in the *The Energy Report* suggests solar PV could contribute 29 per cent of total electricity production in 2050, (page 232) however the squares shown in the preceding maps represent the equivalent of 100 per cent electricity generated by PV. In reality a mix of different renewable energy generation technologies will meet the world's future electricity needs.

PV efficiency
Our calculations assume PV efficiency of 15 per cent, a conservative number based on today's commercial technology. Already manufacturers are showing viable modules at efficiencies of around 20 per cent, and it is reasonable to assume that technology will further improve between now and 2050.

Solar resource
Annual mean Global Horizontal Irradiance solar resource data is drawn from 3TIER's global solar dataset. This high-resolution (approximately 3 km) solar resource dataset has global coverage and is based on more than a decade of high resolution satellite imagery using proven techniques, state-of-the-art satellite processing algorithms, and publicly available observational data. We converted GHI values of watts/metre^2 into kilowatt-hours/metre^2/day, and we then found the average value for each region.

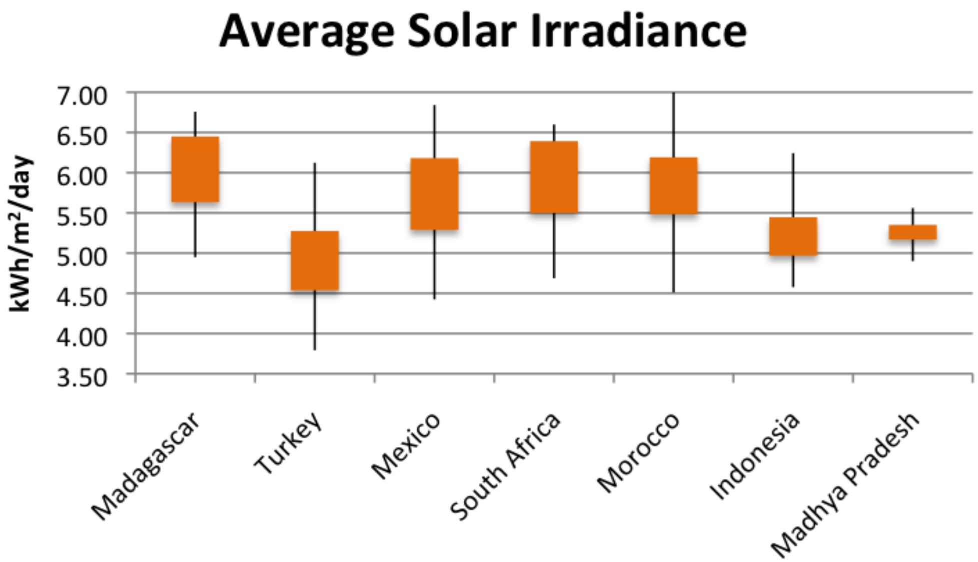


FIGURE 6: EACH OF THE SELECTED REGIONS HAS A "VERY GOOD" TO "EXCELLENT" SOLAR RESOURCE.
The boxplot above shows the relative values and variability of irradiance for the selected areas. The orange boxes represent the mean irradiance value plus and minus one standard deviation for each area. The extremes of the black "whiskers" on the plot illustrate the minimum and maximum values. Thus the regions with long whiskers see a high variability of solar irradiance across their territories. Regions with small whiskers, like Madhya Pradesh, see little variation of solar characteristics across their territory. The average solar irradiance figures for each area of interest were derived from the 3TIER global horizontal irradiance data set.

De-rating factor
Not every bit of the land dedicated to PV electricity production will actually host modules. About 20 per cent will be necessary for roads, shadow reduction, service stations, etc. To satisfy this in our calculations, we 'de-rate' the land required so that our land estimates reflect all land dedicated broadly to PV generation, including these roads and shading areas.[1]

Per capita electricity consumption in 2050
This atlas makes the bold assumption that there will be energy equality across borders. To reach per capita electricity consumption in 2050 for the various regions, it takes the total global electricity supply for 2050 (127.4 EJ/year or 3.5389E+10 MWh/year) reached by Ecofys in the *The Energy Report*[2] and divides by the UN Population Department's projection for 2050 global population (9,191,287,000)[3] to get 3.85 MWh/year/person. A region's projected energy consumption is the the region's projected population in 2050[4] multiplied by 3.85 MWh/year/person.

PROTECTED AREAS DO NOT EQUAL CONSERVATION PRIORITIES

Protected areas
For consistency, this atlas drew from two global data sets to illustrate protected areas and areas of particularly critical biodiversity importance: the International Union for Conservation of Nature's Protected Areas (all categories) and the Alliance for Zero Extinction's list of critical refuge sites. Beyond what is shown, various levels of data exist regarding important conservation areas for each region. Please refer to WWF country and regional offices for more information about local protected areas and conservation priorities.

TECHNICAL CORNER

- Global Horizontal Irradiance data, courtesy of 3TIER (www.3tier.com)
- Population density data from the UNEP and FAO
- Protected areas from the UNEP (www.protectedplanet.net)
- Protected areas from the Alliance for Zero Extinction (www.zeroextinction.org)
- Basemap data from Natural Earth (www.naturalearth.com).
- Country boundary information from the Global Admin dataset (www.gadm.org)

Geospatial processing for this atlas was completed using a combination of GDAL tools (www.gdal.org) and QGIS (www.qgis.org) for rendering.
In general, the processing steps were the following:

1. Clip out region specific information for irradiance and population density.
2. For population density, mask out areas with population density <100 per km^2.
3. For display purposes for solar irradiance, overlay the GHI data on top of the Base map data.
4. For display purposes for population density and protected areas, overlay these layers on top of the greyscale basemap data.

To calculate the spatial extent of PV needed to support a given country's population in 2050, the following steps were taken

1. Calculate average irradiance in the selected region by averaging the 3TIER GHI data for the region, defined by Global Admin dataset country boundaries.
2. Using this value, expand to a full year to derive the expected irradiance kWh available.
3. Using the estimated 2010 populations and 2050 populations, calculate how much energy will be needed, using conservative estimates for per capita kWh/year.
4. Using a derating factor (assumptions explained in Annex 1 main text) convert the total energy needed to support the population with PV to the number of square metres (and then, square kilometres) of PV needed.

The following calculations for Madagascar illustrate the land area calculation process:

From 3TIER data, we calculate the average GHI value for Madagascar to be 6.04 kWh/m²/day. We multiply that figure by 365 and divide by 1000 to arrive at 2.2046 MWh/m²/year.

6.04 kWh/m2/day * 365 days / 1000 = 2.2046 MWh/m2/year

To conservatively estimate a "reasonable PV generation per square metre per year", we multiply the above figure by 0.15 (for performance of PV system) and by 0.8 (a derating value to account for shadows, roads, etc. in a project installation.) We get 0.264552 megawatt-hours per square metre per year.

2.2046MWh/m2/a * 0.15 * 0.8 = 0.264552 MWh/m2/year

To estimate the land area needed to support current electricity generation in Madagascar, we divide the current annual electricity generation (1,200,000 MWh/year) by the 'reasonable PV generation per square metre per year.' For simplicity of expression, we convert square metres to square kilometres and round the number.

1,200,000 MWh/year / 0.264552 MWh/m2/year * 0.000001 ≈ 4.5 km2

To estimate the land area needed to support projected electricity generation in Madagascar in the year 2050, we first estimate 2050 electricity generation by multiplying the 2050 projected population in Madagascar (53,561,000 people) by the projected global per capita electricity generation in 2050 (approximately 3.85 megawatt-hours per person per year.) We arrive at 206,224,680.9 megawatt-hours per year for total projected electricity generation in Madagascar in 2050.

53,561,000 people * 3.850276898 MWh/person/year ≈ 206,224,680.9 MWh/year

From here we follow the same steps to convert to estimated land area.

206,224,680.9 MWh/year / 0.264552 MWh/m2/year * 0.000001 ≈ 780 km2

NOTE: Most of the uncertainty of this calculation is due to uncertainties of the population and per capita energy consumption in Madagascar in 2050. These calculations are purposefully very conservative and likely overestimate the required land areas.

ANNEX 2 : IMPACT CATEGORIES FOR UTILITY-SCALE SOLAR PV

There is currently no international standard for responsible utility-scale PV development, construction, and operation, but the following table highlights important areas for evaluation and proactive mitigation. This overview has been developed as a summary of current and best practices and of guidelines issued by organizations described above under Electricity in Harmony with nature. The list constitutes the kinds of factors that can arise and should be addressed when developing a solar project.

Category	Sub-Category	Low Score	High Score
Community	Dust	Little regard for dust generation, no control efforts	High regard for dust generation, worker education , control methods (palliatives, focused water use)
	Visual	Arrays adjacent to property lines or high traffic roadways; no screening or landscaping; night illumination	Completely out of sight from roads and neighbors
	Noise	Equipment backup alarms, post driving, heavy equipment, close to property lines or receptors; night work	Significant distance buffer; equipment selection; equipment noise shielding; weekday/daylight hours work only
	Stakeholder Engagement	Little to no engagement	Active local engagement through community organizations and governments; local educational or college programs tours; public outreach activities (meetings, tours)
	Labor	Non-local workers; minimum wage; minimum safety requirements	All local workers; prevailing wage; full personal protective equipment and extensive safety training and oversight; maximizing local economic development and job creation; focus on aboriginal and indigenous engagement and employment
Biology	Species, Plants, etc.	Design and construction with no regard to local biodiversity	Detailed surveys conducted; special interests and other stakeholders consulted; design and construction with high regard for biodiversity; appropriate mitigation measures; ongoing monitoring of impacts; maximizing buffer areas around the active site, providing improved habitat potential, visual buffer, etc.
	Environmental Impact Studies	Not performed; no awareness of any environmental issues	Environmental Impact Study /Assessment conducted, mitigation plan developed with stakeholder involvement
	Soil Protection	Little regard for protecting the grassland or site soils	Rigorous fire protection plans; topsoil conserved or replaced; adequate seeding of native grasses; compaction and permeable surfaces support growth

Category	Sub-Category	Low Score	High Score
Water	Usage	Little regard for water use	Usage measured and reported; ambitious water reduction goals set; Construction methods implemented to minimize water use
	Storm Water	Little regard for storm water or run-off onto neighboring properties	Appropriately sized and protected protection and conveyance measures (retention ponds; rip rap; silt fencing; etc.), effective measures to counter stormwater flow and runoff are in place; post event performance and condition assessment
Design and Construction	Site Selection	Prime agricultural, biological, or cultural land used	Use of disturbed or previously used sites; superimposed on existing structures (roofs, landfills, parking lots, etc.); greenfield or prime agricultural land avoided, worn agricultural or contaminated land used to restore biodiversity; consider potential for 'dual use' of sites (e.g., agricultural/grazing) – this will depend on local climate and farm practices
	Grading	Heavy cut and fill; stripped topsoil; invasive seeds introduced; long-term drainage or dust issues	Minimizing grading, installation follows existing topography, minimizing built roads/gravel, minimizing trenching; topsoil retained or restored; no standing water or dust areas
	Footprint/ Layout	Inefficient use of space	Minimize project footprint with careful balance of ground coverage ratio, row spacing, module height, etc.
End of Life (EOL)	Site Restoration	No consideration of land restoration after project life	Ensure that a site can be restored to its original state (or better) at the end of project's useful life
	Recycling	No take-back and recycling at module EOL offered	Take-back and recycling of EOL modules and Balance of System products considered and addressed as part of project development and permitting phase

ANNEX 3 : PV DEVELOPMENT EXAMPLE – DESERT SUNLIGHT

In the 550MW Desert Sunlight project in California, First Solar significantly reduced the project footprint from the original study area of over 19,000 acres to approximately 3,800 acres. These reductions were based on survey results and advice from experts in a range of disciplines with the aim of minimizing the biological, cultural, and visual impacts of the project, including avoiding critical habitat for the threatened desert tortoise. The reductions also minimized impacts to other sensitive resources such as the Pinto Wash and sand dunes, known migration routes for bighorn sheep, areas with high concentration of foxtail cactus, and known cultural resources, including significant prehistoric resources and key elements of General Patton's Desert Training Center. In addition, First Solar worked to improve construction efficiency with innovative disk and roll micro grading site preparation techniques, which led to a reduction in earth movement, resulting in reduced air emissions and water use during construction associated with dust control and soil preparation. The Sunlight project benefited from extensive biological and cultural survey efforts and diverse stakeholder interaction involving the local County and State agencies, the US Fish and Wildlife Service, the US Army Corp of Engineers, Native American Tribes, and numerous environmental NGOs.

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GLOSSARY : SOLAR ATLAS TERMINOLOGY

ANNEX I SIGNATORY OF THE KYOTO PROTOCOL:
One of a list of 41 developed/industrialized nations listed in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC) which have accepted a greater share of responsibility for the reduction of greenhouse gases as signatories of the Kyoto Protocol.

EOL (END-OF-LIFE):
Referring here to the decommissioning of materials at the end of their useful life in a manner responsible to environmental as well as market-based concerns. SEE TAKE BACK.

EPC (ENGINEERING, PROCUREMENT, AND CONSTRUCTION):
"Turnkey" arrangement wherein a contractor delivers a completed project to an owner for a pre-determined price. Financial risks and design control are shifted to the contractor and away from the owner.

DNI - DIRECT NORMAL IRRADIANCE:
Solar radiation that comes in a straight line from the direction of the sun at its current position in the sky. See GHI for further explanation.

DIF - DIFFUSE HORIZONTAL IRRADIANCE:
Solar radiation that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions. See GHI for further expalation.

GHI - GLOBAL HORIZONTAL IRRADIANCE:
The total amount of shortwave radiation received from above by a surface horizontal to the ground. This value is of particular interest to photovoltaic installations and includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DIF). DNI is solar radiation that comes in a straight line from the direction of the sun at its current position in the sky. DIF is solar radiation that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions. On a clear day, most of the solar radiation received by a horizontal surface will be DNI, while on a cloudy day most will be DIF. More information and full definitions are available at www.3tier.com/en/support/glossary/

GHG - GREENHOUSE GASES:
Natural and manmade gases capable of reflecting heat back to the surface of the earth, carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs) are specifically mentioned by the Kyoto Protocol as targets for immediate reduction.

INSOLATION:
Insolation is solar irradiance during a period of time, measured in this atlas as kilowatts per square meter per day (kWh/m2/day). Compare to IRRADIANCE.

IPP - INDEPENDENT POWER PRODUCER:
Also, Non-Utility Generator (NUG), an organisation owning facilities to generate electricity for sale to utilities or to end users. These organisations are often granted price guarantees or protection by a government entity or incumbent utility.

IRRADIANCE:
Solar irradiance refers to the amount of solar energy reaching a surface. Compare to INSOLATION, and see also GHI.

GLOSSARY : SOLAR ATLAS TERMINOLOGY

LCOE - LEVELISED (OR LOCALISED) COST OF ELECTRICITY:

The cost of electricity production in standardised units up to the point of distribution. Measured in Euro/kWh or $/MWh, for example. LCOE is distinct from the prices customers pay for electricity and often does not reflect subsidies or externalities.

O+M - OPERATIONS AND MAINTENANCE:

The performance of duties related to delivering an expected service and conducting preventative and corrective maintenance of facilities or equipment.

PV - PHOTOVOLTAIC:

A property of those materials which generate an electrical current when exposed to light. Sometimes used as a noun to describe a product or technology with this property.

RE - RENEWABLE ENERGY:

Energy (often electricity) drawn from sources in the natural environment which are renewed or replenished on a regular basis without human intervention. Examples include solar photovoltaic, wind, hydroelectric, geothermal or biomass-based energy.

SUSTAINABLE ENERGY FOR ALL:

The UN Initiative calling for increased renewable energy, energy efficiency, and universal access. More information available at sustainableenergyforall.org

TAKE BACK:

A mandatory or voluntary effort by manufacturers or retailers to encourage end-users of a product to transport the product to a collection center for recycling, repurposing, reuse, or reclamation of components.

GLOSSARY : UNITS

KW = KILOWATT:
One thousand (1,000) watts. A measure of power often referring to instantaneous peak power generation or consumption capacity.

MW = MEGAWATT:
One million (1,000,000) watts. A measure of power often referring to instantaneous peak power generation or consumption capacity.

GW = GIGAWATT:
One billion (1,000,000,000) watts. A measure of power often referring to instantaneous peak power generation or consumption capacity.

KWH = KILOWATT-HOUR:
A measure of energy, often used to describe electricity generation or consumption over time. Ten (10) light bulbs rated at 100 watts burning for one hour consume one kilowatt-hour of electricity.

GWH = GIGAWATT-HOUR:
One billion (1,000,000,000) watt-hours, or one million (1,000,000) kilowatt-hours.

TWH = TERAWATT-HOUR:
One trillion (1,000,000,000,000) watt-hours, or one billion (1,000,000,000) kilowatt-hours.

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