WORLDWATCH REPORT 187

Sustainable Energy Roadmaps:

Guiding the Global Shift to Domestic Renewables

ALEXANDER OCHS AND SHAKUNTALA MAKHIJANI
WITH XING FU-BERTAUX, MATT LUCKY, AND SAM SHRANK

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On the cover: Wind turbines in the Dominican Republic.
Photograph by Mark Konold.

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Summary

Although progress has been slow on a global agreement to address human-caused climate change, much is happening within individual nations and communities that offers promise for moving toward an energy system that is environmentally, socially, and economically sustainable. Most developing countries are relatively minor players in the global greenhouse gas emissions total, yet many of these countries are forging ahead with strategies that could accelerate the transition to clean energy. In some cases, the scale and commitment of these efforts far exceeds, relative to population size and affluence, those of large industrialized countries such as the United States.

The combustion of fossil fuels was essential to the development of today's modern societies. But as cleaner alternatives become increasingly viable, our fossil-dependent energy system is being kept alive at a tremendous price to the environment and society as whole. An important first step in reducing energy consumption is embracing energy efficiency, which can result in significant cost savings even in the near term. In addition, most renewable power technologies—including hydro, wind, solar, geothermal, and biomass—result in fewer overall emissions and provide more jobs than conventional fossil fuel power plants. Developing local renewable energy resources, alongside job training and education programs, could provide quality long-term employment and help countries build strong green economies in the decades to come.

The transition to sustainable energy is particularly important in the world's least-developed areas, where an estimated 1.3 billion people lack access to electricity. With 2012 being the United Nations-designated International Year of Sustainable Energy for All, efforts to broaden the availability of energy worldwide are especially timely. As our global population of 7 billion—and growing—heads further into climatic changes, access to sustainable energy for all must involve a shift to energy sources that are as renewable, greenhouse gas-free, and benign to local environments as possible.

The Worldwatch Institute has started to work with countries around the world on a concept we call Sustainable Energy Roadmaps. "Sustainable energy" refers to energy efficiency, renewable energy, and electricity grid technologies that have minimal environmental impact, provide local economic opportunities, and improve livelihoods through expanded energy access. The roadmap process involves technical mapping of domestic sustainable energy resources as well as field-based conversations, reports, and inventories of policy and financing capacities. Collectively, this process can help governments, energy specialists, and the public map paths away from costly imports of carbon-based fuel sources as well as wasteful distribution and consumption. Using the roadmaps, countries (or other political entities) are better able to shift toward local energy resources that can provide long-lasting jobs and boost economic development, while reducing pollution and pointing humanity away from catastrophic climate change.

The roadmap methodology applies an integrated approach to determining the physical, technical, socioeconomic, political, and market potential for renewable energy development. The roadmaps start with an assessment of the current energy system. They then determine opportunities for energy efficiency improvements, including in industries, buildings, and appliances. In a next step, high-resolution data on renewable energy resources—including wind, solar, biomass, and small hydropower—are collected and presented. Consultations with policymakers, experts, and other stakeholders are held to determine the energy technologies and zones of focus for more detailed resource analysis, based on factors including the overall strength of the resource, land availability, population density, grid access, and potential integration with other energy sources and storage options. These zonal assessments include detailed analysis of renewable resource variability and offer data with much higher resolution than are usually available.

The roadmaps also assess the technical potential and limitations for renewable energy development through an analysis of the current electricity grid as well as recommended upgrades and extensions. They examine opportunities for energy storage as well as micro-grid and off-grid solutions. Of particular interest are methods to reduce the variability of renewable power generation through integration with other intermittent but complementary renewable resources as well as baseload energy sources, including biogas, natural gas, biomass, geothermal, hydroelectric, and storage-enhanced solar thermal. The roadmaps also discuss the socioeconomic impacts of developing domestic renewable resources, including through job-creation analyses and electricity price scenarios.

Finally, the roadmaps examine the existing legal, administrative, and financial framework for renewable energy development and investment and provide detailed policy and finance recommendations for strengthening the current institutional structure to encourage substantial renewable investment. This assessment includes recommendations ranging from the need for a robust long-term vision and targets for sustainable energy, to the concrete policy, governance, and finance mechanisms required to successfully implement this vision. Tools such as building codes, feed-in tariffs, streamlined administrative procedures, and new loan packages from the banking sector are among the many options explored in the particular context of each country. The roadmaps also explore potential domestic and international sources of financial support to support sustainable energy polices and investment.

Worldwatch is currently developing pilot Sustainable Energy Roadmaps for three countries—the Dominican Republic, Jamaica, and Haiti—as well as one region (spanning the seven member states of the Central American Integration System, or SICA). Each geographic and political area is different, yet the roadmap process can be applied almost anywhere, in industrialized as well as developing countries and at every level of political organization, from the municipal to the provincial, federal, and regional level. In the Dominican Republic, where Worldwatch has already completed a preliminary wind and solar energy roadmap, our experience provides confidence that Sustainable Energy Roadmaps can contribute significantly to economic development, social equality, energy access for all, and the shift to low-emission energy. The Institute is now working on plans to expand the roadmaps to Africa, China, India, and beyond.

The success of Sustainable Energy Roadmaps depends in large part on the will of communities and governments around the world to commit to a clean energy future. Governments must recognize that sustainable energy systems are in the interest of all people, providing a cleaner environment, local jobs, and a stronger economy. These benefits, and the goal of sustainable energy access for all, will only be realized with public participation, transparency, simplicity, and accountability in the decision making and implementation process.

The roadmap assessments and recommendations aim to build momentum for a binding global climate agreement to reduce greenhouse gases to acceptable net levels. The roadmaps can also support actions for climate change mitigation in advance of such an agreement, and serve as a basis for national commitments once an inclusive, comprehensive framework to address the global climate challenge is established.

The Unsustainability of the Current Energy System

Worldwide, more than 1.3 billion people lack access to electricity, making it harder for them to overcome poverty and to benefit from basic communications, healthcare, and educational services.[1*] Many proponents of coal, oil, and other fossil fuels claim that expanding production of these fuels is necessary to promote economic growth and improve livelihoods, but the real story is much different. Our continued reliance on fossil energy is a leading driver of many of the world's most serious environmental and socioeconomic problems, including climate change, air pollution and its associated health impacts, and heavy dependence on energy imports in most countries.[2]

The combustion of fossil fuels was essential to the development of today's modern societies, and fossil fuels continue to have an important advantage over some renewable energy sources. The three leading fossil energy sources—coal, oil, and natural gas—are concentrated, material forms of energy that can be stored and transported relatively easily until their energy is required. In contrast, leading renewable energy sources such as wind and solar photovoltaic (PV) are subject to variability in generation because the wind does not always blow and the sun does not always shine, and these energy sources cannot be stored directly to be dispatched at times of high demand or low resource availability. Nevertheless, these and other "clean" alternatives to fossil fuels are becoming increasingly viable through cost reductions, efficiency gains, and improved options for energy storage.[3]

In 2009, fossil fuels accounted for 81 percent of global final energy consumption, compared with 16 percent for renewable sources.[4] (See Figure 1.) The bulk of renewable energy usage comes from the burning of traditional biomass, such as fuel wood and agricultural residues, and from large-scale hydropower generation. On a global scale, modern renewable energy sources such as wind and solar power still account for a relatively small share of overall energy consumption, despite rapid growth in recent years.

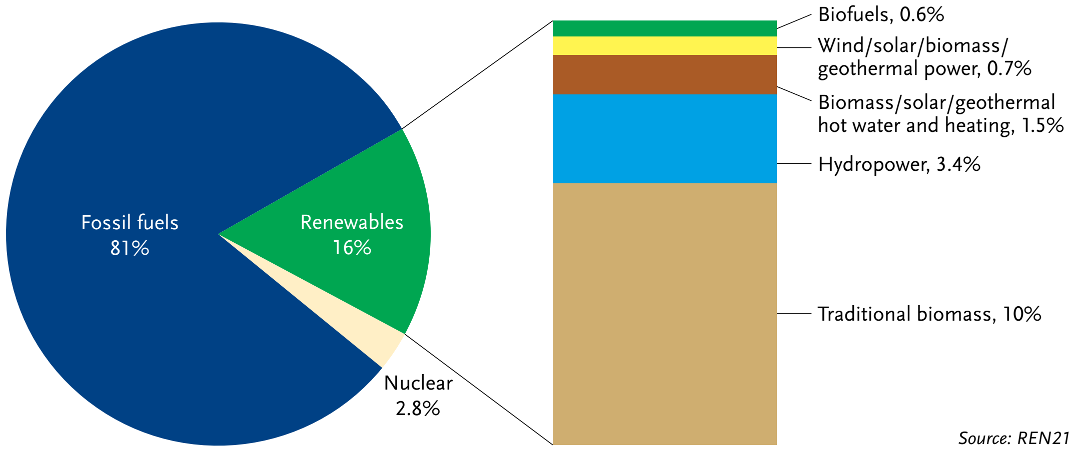
The most serious consequence of our ongoing reliance on fossil fuels is global climate change. As Earth's average temperatures continue to rise, hundreds of millions of people face climate-related threats such as increased droughts, floods, and water stress. By the end of the century, annual damages from flooding could reach $300 billion in the United States and Europe alone.[5†] Other expected impacts include decreased agricultural productivity and increased health burdens from malnutrition as well as diarrheal, cardio-respiratory, and infectious diseases.[6] Under a "business-as-usual" scenario, more than 40 percent of plant and animal species are threatened with extinction.[7] Many of the effects of climate change are already being felt, including shifting agricultural patterns, forest fires, ecosystem disturbances, and human mortality due to heat waves, more-intense storms, and other weather extremes.[8]

At the 2010 United Nations climate change conference in Cancún, Mexico, the international community committed to a maximum average increase in global temperatures of 2 degrees

* Endnotes are grouped by section and begin on page 42.

† All dollar amounts are expressed in U.S. dollars unless indicated otherwise.

Figure 1. Renewables' Share of Global Final Energy Consumption, 2009



Source: REN21

Celsius above pre-industrial levels.[9]* According to mainstream science, this amount of warming would give us a 50-50 chance to "prevent dangerous anthropogenic [human] intervention with the climate system."[10] The final Cancún documents note that this threshold may need to be lowered even further—to a maximum increase of 1.5 degrees Celsius—to reduce the risk of catastrophic climate change.[11]

Compared to pre-industrial levels, Earth's average temperatures have increased by an estimated 0.74 degrees Celsius in the past century, and additional greenhouse gases that have been emitted in recent decades are expected to push temperatures up further.[12] According to the Intergovernmental Panel on Climate Change, global emissions will need to peak sometime between 2000 and 2015 to limit probable warming to between 2.0 and 2.4 degrees Celsius.[13] Yet emissions continue to soar, and national pledges for emission reductions fall far short of the global cuts necessary to achieve this warming limit (assuming that these promises will even be met in the absence of binding international commitments).[14] One scientific assessment found that the best estimate for average temperature increase based on pledges under the Cancún agreement is 3.2 degrees Celsius, far above the targeted limits.[15]

Stabilizing the climate will require enormous changes in many sectors of the economy, including agriculture, forestry, and industry. But the burning of fossil fuels is the largest contributor to the problem of climate change, making it essential to reduce the dominance of coal, oil, and other fossil sources in the global energy system. The scale of the necessary shift to a low-carbon economy might be comparable to only two other great transformations in the history of humankind: the transition from hunter-gatherer to agricultural societies and the Industrial Revolution.[16]

Even leaving aside the urgency of addressing climate change, transitioning the energy system away from fossil fuels is an ecological and socioeconomic imperative. Air pollution from fossil fuel combustion is a key contributor to smog and acid rain and can trigger or exacerbate health conditions including chronic respiratory and heart disease, lung cancer, and asthma.[17] A 2011 report from the New York Academy of Sciences estimated that the unaccounted costs to public health and the environment from air and water pollution associated with U.S. coal usage totaled $345 billion in 2008, or 17.8 cents per kilowatt-hour of electricity produced.[18]

In developing countries, where environmental regulations are often weak or ineffectual, these relative costs could be even higher. China estimates that addressing its pollution and related health problems—many of which result from the coal-dominated energy system—requires 10 per-

* Units of measure throughout this report are metric unless common usage dictates otherwise.

cent of its gross domestic product (GDP) annually.[19] Meanwhile, a reliance on offshore drilling to reach increasingly scarce oil resources can have significant consequences for all countries, as exemplified by the 2010 explosion of the BP Deep Horizon rig, which killed 11 workers and released more than 4.9 million barrels of oil into the Gulf of Mexico, causing widespread economic and environmental damage.[20]


Ruhrfisch

A natural gas drilling rig on the Marcellus Shale Formation in central Pennsylvania.

Natural gas can serve as a substitute for coal and oil for baseload power* and as a bridge technology to a future powered entirely by renewable energy sources.[21] Because power from gas-fired plants can be ramped up and down quickly, natural gas can serve as an ally to intermittent renewable energy sources such as wind and solar while new grid and storage solutions are being developed to manage variability in generation. Yet serious concerns about the public health and environmental impacts of natural gas need to be addressed, especially with regard to shale gas production. These include water and land contamination with methane, a powerful greenhouse gas; leakage or spillage of hydraulic fracturing fluids and high-saline water; air pollution; well blowouts; and community impacts such as noise and light pollution.[22]

* The level of continuous generation needed to meet minimum consumer energy demand.

The current energy system has major economic drawbacks as well. The world's least-developed countries and many small-island states depend heavily on fossil fuel imports and are especially vulnerable to price fluctuations on the global market. In some Pacific island nations, an increase in world crude oil prices of just $10 can translate into a 1.5 percent decrease in GDP.[23] The Dominican Republic, a Caribbean island nation, spent 7 percent of its GDP on fossil fuel imports in 2010 (and even more before the world economic crisis brought fossil fuel prices down), a dead loss to the economy that could be invested in developing domestic energy resources and employing local residents in a clean energy economy.[24]

Other countries and regions, such as China, Europe, India, Japan, and South Korea, have rapidly dwindling fossil fuel resources and are likewise increasingly dependent on imports. Even in fossil fuel-exporting countries, such as Iran, Nigeria, and Saudi Arabia, often only a small fraction of the population benefits from the profits, establishing a system of economic inequality and, in many cases, political repression.[25]

Two decades after climate change emerged as a major potential threat, fossil fuels still receive significant subsidies. In 2009 alone, coal, oil, and natural gas production received $550 billion worth of production subsidies, 12 times the amount that went to renewables.[26] An additional estimated $100 billion went to fossil fuel consumption subsidies, and more to other supports like the financing of related infrastructure and public coverage of the many environmental and social externalities associated with fossil fuels.[27]

The continued support for fossil fuel projects, despite their environmental and economic burden, is often justified based on development and employment benefits; however, job creation studies have found that most renewable power technologies provide more jobs than conventional fossil fuel plants.[28] Off-grid renewable energy can provide additional economic benefit, not only for remote households that do not have access to the electricity grid, but also for the tourism industry which is often reliant on costly and polluting diesel generators.

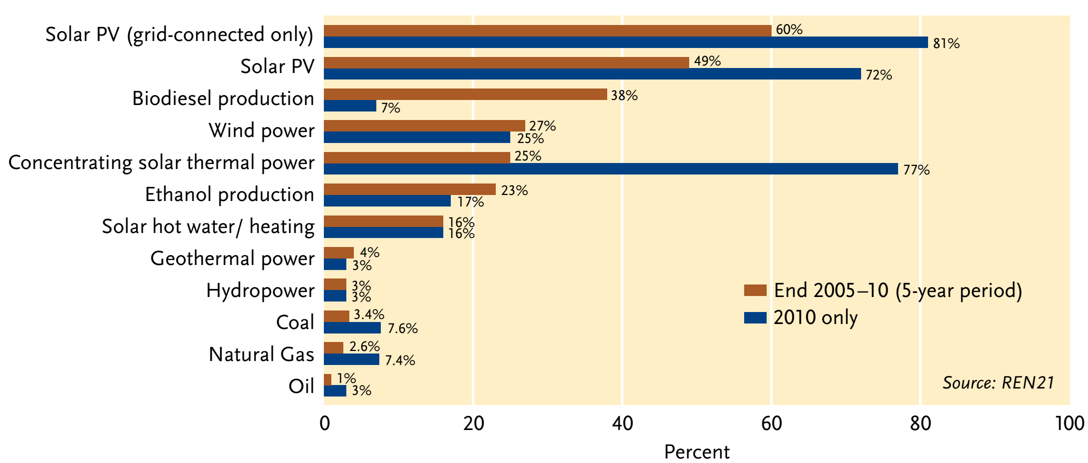
Sustainable Energy for All

As more countries recognize the benefits of renewable energy, a global clean energy transition is gaining momentum. In 2010, renewable energy sources—including wind, solar, geothermal, biomass, and hydropower—accounted for roughly a quarter of installed global electricity capacity and a fifth of total electricity generation.[1] Renewable energy sources made up roughly half of the 194 gigawatts (GW) of new electricity capacity added worldwide that year.[2]

Renewable energy production is accelerating across all mainstream renewable technologies. Between 2005 and 2010, average annual growth in the installed capacity of solar photovoltaic, concentrating solar thermal power (CSP), and wind power ranged from 25 to nearly 50 percent, compared to just 1 to 4 percent for various fossil fuels.[3] (See Figure 2.) In 2010 alone, solar PV grew at 72 percent to reach 40 GW of global installed capacity.[4] Wind power grew 25 percent to reach 198 GW at the end of 2010, and biomass generation increased to a total of 62 GW at the end of 2010.[5] With vast untapped renewable resources available around the world, this growth can be expected to only accelerate, provided that favorable policy and investment environments exist to promote these technologies.

Some renewable energy solutions are already cost competitive with their fossil counterparts and can result in cost savings.[6] A 2011 study by Bloomberg New Energy Finance found that the best onshore wind turbine technologies now produce electricity as cheaply as conventional coal, gas, and nuclear power plants.[7] The study projects that the overall cost of wind power will drop another 12 percent to make the average wind farm fully cost-competitive by 2016, even without accounting for the externalities associated with fossil fuel and nuclear energy (which, until recently, many considered a viable low-carbon energy source; see Sidebar 1.)[8]

Figure 2. Average Annual Growth Rates of Renewable versus Fossil Energy Capacity, 2005–10



As costs come down and as renewables provide a growing share of the world's electricity, many of the challenges related to the variability of these energy sources are being addressed. Biomass energy, generated from the burning or gasification of agricultural or wood wastes or other organic materials, can provide renewable baseload power. Variable renewable sources such as wind and solar can be integrated with natural gas and biogas, lower-carbon alternatives to coal and oil that can be powered on or off quickly to respond to changes in both demand and renewable generation on the grid. Even integrating solar and wind resources in complementary patterns can be used to reduce overall grid variability. Advances in energy storage solutions, such as pumped hydro* and battery technologies, will be essential to ensure that renewable sources can supplant fossil fuel and nuclear energy as a baseload source of power.

To ensure that the transition to a sustainable global energy system accelerates to keep pace with the challenges of climate change, environmental degradation, and economic insecurity, policies are necessary to promote concrete renewable energy development at the local, national, and international levels. Many argue that these policies should be "Loud, Long, and Legal" to create an ambitious, stable, and concrete framework of regulations and market incentives as a basis for renewable development. A strong legal and regulatory framework is important for increasing investor confidence in renewable energy. Successful implementation and positive environmental and socioeconomic outcomes depend on public participation, transparency, and active civil society involvement in the decision-making process.

The experiences of several countries that have displayed a commitment to energy transformation suggest that a shift to low-carbon energy does not have to mean a choice between economic prosperity and environmental protection. In Germany, where the government provides robust policy support for renewable energy, the industry has already created some 340,000 green jobs.[9] South

Sidebar 1. What Role for Nuclear Energy?

In the aftermath of the March 2011 disaster in Fukushima, Japan, countries around the world are reevaluating their use of nuclear power. Yet the nuclear industry was already in decline before the Fukushima events, representing the only major energy source whose capacity actually declined. The year 2009 marked the fourth year in a row that nuclear power generation registered an annual decline. The total number of operating nuclear reactors has shrunk from 444 in 2002 to 434 today. In addition, aging reactors are becoming less and less productive. Factors behind the ongoing nuclear decline include the shutdown of aging plants and a slowing of new additions. Renewable energy capacity additions have been outpacing new nuclear plants for 15 years, and in 2010 global renewables capacity (even excluding hydropower) surpassed installed nuclear capacity.

Safety and security concerns have contributed to nuclear's decline as well. Chernobyl, Fukushima, and many other more minor incidents in the last 25 years have demonstrated that disastrous nuclear accidents, whether from human or technical failure, natural catastrophes, or terrorist attacks, simply cannot be ruled out. In addition, nuclear reactors can be, and have been, used to produce weapons-grade plutonium, the application of which could have devastating planetary consequences. Another major unresolved issue is the secure long-term storage of nuclear waste. And despite the nuclear industry's claims of being low-carbon and having low environmental impact, nuclear power is not a renewable power source. It requires large amounts of material inputs—particularly uranium, a costly and increasingly scarce resource that can cause long-term contamination and public health problems through mining and milling processes.

Most importantly, nuclear energy is arguably too costly for widespread development. A recent study of generation costs for new nuclear power plants in the United States estimates 25 to 30 cents per kilowatt-hour (most of which comes from high upfront capital costs), making new nuclear far too expensive to compete with most other energy sources without significant subsidies. In addition to high upfront installation and capital costs, delays in licensing and implementation as well as cost overruns have plagued the industry. Without major support from governments, utilities worldwide are unwilling to take the economic risks involved in nuclear power projects. Atomic energy is not a power source for the people; it is another technology that puts societies at risk while benefiting the few. The rapid advance in renewable energy technologies and their declining cost is making a nuclear revival not only unlikely, but arguably unnecessary.

Source: See Endnote 8 for this section.

* Pumped hydro is an energy storage technique that uses excess generation capacity during periods of low electricity demand to pump water from a low-elevation reservoir to a high-elevation reservoir. During high demand periods, water is released from the high reservoir through a hydroelectric turbine to generate electricity to meet consumer needs.

Korea, which has made strong efforts to promote renewables as part of its national "green growth" initiative, projects that its clean energy exports will reach $36 billion in 2015.[10] And over the past 20 years, Denmark has cut its total energy use and more than doubled the share of renewables in its energy mix while simultaneously growing its economy by more than a third.[11]

The commitment to a clean energy transition is not limited to developed countries. Costa Rica, which for decades has been a leader in environmental stewardship, has pledged to become "carbon neutral" by 2021 (meaning that the country's territory effectively would emit no more carbon dioxide than it can absorb through reforestation and other land-use changes).[12] China is the world leader in renewable energy investment, directing $50 billion to this industry in 2010.[13] These countries, and others, have realized that transitioning (in some cases leapfrogging) to low-carbon technologies will reduce energy costs in the long term. Whereas the prices of fossil fuels will continue to rise, renewable technology costs will continue to come down as technologies improve further and as economies of scale and the benefits of experience are realized.

The shift to renewables will be easier to accomplish if it goes hand in hand with increases in efficiency. Energy efficiency is often hailed as the "low-hanging fruit" in the energy transition, as efficiency measures not only reduce energy usage but also bring down energy costs. China, for example, cut the energy intensity of its economy by more than 15 percent between 2005 and 2010, despite average annual GDP growth of more than 11 percent over the same period.[14] In the United States, efficiency gains have met 75 percent of the demand for new energy services since 1970, with new energy supplies required to provide only the remaining 25 percent.[15] By implementing effective efficiency programs, governments can avoid many of the costs, vulnerabilities, and ecological consequences associated with energy production and use.

In addition to the widespread economic benefits, harnessing domestic renewable energy resources can help ease global competition over dwindling fossil fuel resources, contributing to a less conflict-ridden world.[16] Countries that currently face high energy insecurity because of reliance on foreign fossil imports, or that engage in civil conflict or even war in an attempt to secure these resources, can divert the freed-up funding and effort from avoided conflict to invest in a smarter, cleaner, and more secure energy economy.

Worldwide, the environmental, health, economic, and social burdens of the fossil-based energy regime are being felt most acutely by the poorest and most vulnerable populations. Grassroots anti-coal protests from Colombia to Bangladesh, some of which have been violently repressed, as well as recent protests against tar sands development in the United States and Canada, demonstrate that significant numbers of people are mobilizing against the environmental and livelihood impacts associated with fossil fuel development.[17] Even the International Energy Agency has admitted that "fossil-energy subsidies go mostly to the rich," noting that only 8 percent of the $409 billion spent on direct fossil fuel subsidies in 2010 went to the poorest 20 percent of the population.[18]

In contrast, renewable energy, and particularly power generated through off-grid and distributed sources, can provide significant benefits to the world's neglected energy poor. At current rates of electrification, it appears highly improbable that most of the 1.3 billion people who lack access to modern energy services, many of whom live in remote and underserviced areas, will be connected to centralized electricity grids in the next 50 years.[19] Renewable energy may be the best chance for these communities to obtain electricity access and to benefit from the quality-of-life improvements that accompany it.

With 2012 being the United Nations-designated Year of Sustainable Energy for All, now is the ideal opportunity to bring attention to these issues and solutions.[20] Governments must recognize that sustainable energy systems are in the interest of *all* people, providing a cleaner environment, social benefits, greater security, and a stronger economy. Decision makers at all levels of political organization should be held accountable for whether their actions advance the transition of our current energy systems toward universal sustainable energy access.

Sustainable Energy Roadmaps

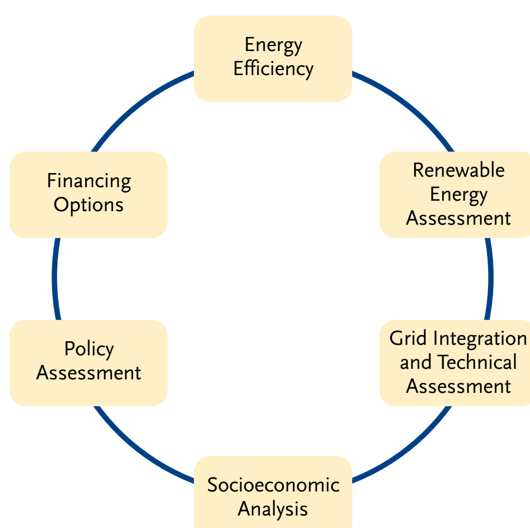
Despite the rapid growth in renewable energy, the existing large share of coal, oil, and natural gas in the world's energy mix means that fossil fuels will continue to dominate global energy production for many decades *unless* effective measures are taken quickly to accelerate the transition to alternatives. Although a sustainable energy revolution is under way, strong policies must be enacted to hasten its positive impact.[1]

To facilitate this shift, the Worldwatch Institute has developed an integrated approach for helping municipalities, provinces, countries, and regions transition from the present inefficient and fossil-fuel centered system to a future that will harness domestic renewable resources, efficiency gains, and smart solutions for energy distribution and storage. Our "Sustainable Energy Roadmaps" are designed to provide policymakers and stakeholders with a complete picture of the potential to develop domestic sustainable energy, with the goal of providing broader socioeconomic benefits and supporting a cleaner environment. Our stages of assessment include analysis not only of renewable resource potentials but also of energy efficiency opportunities, grid and storage needs, socioeconomic impacts, policy frameworks, and financial circumstances. (See Sidebar 2.)

Worldwatch's roadmap methodology can be applied in a wide variety of locations and at multiple levels of political organization, from municipal and state governments to the national and regional levels. The value of this approach lies in the individualized outcomes of each roadmap, which employs a holistic, proven methodology tailored to the particular circumstances of the study area. The findings and recommendations

Sidebar 2. Worldwatch's Sustainable Energy Roadmaps

The Worldwatch Institute's Sustainable Energy Roadmaps are integrated assessments of the physical, technical, socioeconomic, and political potential for sustainable energy development at the local, country, or regional level. The roadmaps provide data and analysis of: (1) opportunities for energy efficiency, (2) renewable energy resources, (3) grid and storage solutions, (4) socioeconomic impacts and benefits of sustainable energy development, (5) best-practice policy recommendations, and (6) domestic and international financing options. Capacity building is a central aspect of all stages of roadmap development to ensure that decision makers and stakeholders have the tools necessary to use the information in the roadmaps and implement their recommendations.



of the roadmaps emphasize diverse technologies, grid solutions, policies, and financial mechanisms, based on our analysis of the resources and governance structures already in place. The result is a comprehensive toolkit that provides policymakers and stakeholders with practical approaches to sustainable energy development.

In 2011, Worldwatch completed a wind and solar roadmap for the Dominican Republic and began work on comprehensive Sustainable Energy Roadmaps for the Dominican Republic, Haiti, and Jamaica.[2] We have also started developing our first regional energy roadmap for Central America and are planning further regional projects for North and West Africa, as well as state-level roadmaps for China and India.

In recent years, many countries have begun developing national strategies that attempt to integrate plans for sustainable development, economic growth, and climate change mitigation. These "low-carbon development strategies"* are designed to help countries set national development and climate priorities and identify ways to achieve an optimal pathway for reducing emissions that is compatible with their development aspirations. Although these strategies are frequently mentioned in international climate, environment, and energy discussions, there is no internationally agreed approach for how to design them, and no consensus on what they should entail.[3]

At the December 2009 UN climate talks in Copenhagen, Denmark, signatories of the so-called Copenhagen Accord agreed that "a low-emission development strategy is indispensable to sustainable development."[4] Yet so far, there is no common universally (or at least widely) accepted set of elements that are required in such plans, nor is there much evaluation of past experiences in developing them. Likewise, the 2010 Cancún Agreements recognize the "need to provide incentives in support of low-emission development strategies" and to create a registry to match "nationally appropriate mitigation actions" that seek international support with available funding.[5] But currently only limited capital is available for action toward emissions reductions in developing countries through decentralized, bilateral channels or international instruments like the Kyoto Protocol's Clean Development Mechanism (CDM).

Worldwatch designed its Sustainable Energy Roadmaps to help fill this void by providing the basis for low-carbon development strategies in the energy sector, a leading source of greenhouse gas emissions and a critical component of a country's economy. Designing sustainable energy strategies is central to a broader countrywide low-carbon development strategy, and a detailed energy roadmap can provide countries with an overview of potential national mitigation actions as well as a game plan for how to implement them.

Given that the financing and design aspects for national low-emission strategies have yet to be decided within the international framework, Worldwatch's Sustainable Energy Roadmaps enable countries to proceed with planning sustainable energy initiatives that will provide development benefits in their own right, while also positioning these countries favorably to receive international financing and support under existing and future international mechanisms. Much like the UN's low-carbon development strategies, Sustainable Energy Roadmaps can be supported by international finance but are owned by the country itself and integrated into national energy and development planning.

Many of the energy efficiency, renewable energy, and grid technologies necessary for a renewable energy transition are already at hand.[6] Worldwatch's Sustainable Energy Roadmaps assess the specific needs and circumstances of each country or region to help policymakers and stakeholders identify the viable energy sources, policies, and financial options that can accelerate the shift to a clean energy future.

* Other common terms used in international negotiations include "low-emissions development strategies" (LEDS), "low-carbon" plans and "low-emissions growth" plans.

Analyzing Energy Efficiency Potentials

Every country, region, province, or municipality has a unique set of challenges and opportunities for undertaking a sustainable energy transformation. In any specific location, the energy structure and level of energy efficiency are determined by a broad range of factors, including past energy prices and policies, the types of economic activity, overall electricity demand, and local knowledge and attitudes about energy conservation. In developing a Sustainable Energy Roadmap for a given area, an important initial step is identifying opportunities for efficiency improvements in the most energy-intensive sectors.

Improvements in energy efficiency are often the cheapest and fastest way to lessen the environmental and economic costs associated with an energy system. Energy efficiency is an important first step because of its compounding effects: when a user demands one less unit of energy because of efficiency measures, the system typically saves much more than one unit of energy because of avoided losses during transmission and distribution. As a result, efficiency improvements can amplify the benefits of developing utility-scale renewable energy by increasing the impact of added renewable power capacity. Similarly, distributed (as opposed to centralized) renewable generation achieves efficiency gains by producing energy at the point of use, which also improves efficiency by avoiding transmission and distribution losses.[1]

Many renewable energy sources, such as wind, solar, hydropower, wave, and tidal energy, have the additional efficiency advantage of converting natural flows of mechanical energy or the sun's light directly to electricity, unlike fossil fuel combustion and nuclear power which require inherently inefficient thermal energy conversion processes. According to one global estimate, making the transition to 100 percent renewable power plants and all-electric vehicles would result in a 31 percent decrease in primary energy demand in 2030 relative to business as usual.[2]

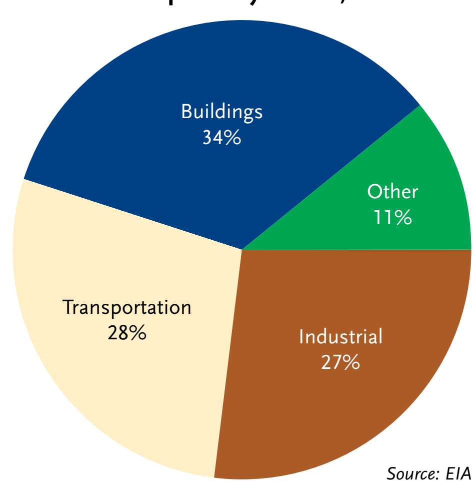
Worldwatch's Sustainable Energy Roadmaps assess the potential for efficiency measures in four distinct areas: industry, the residential sector, appliances, and the electricity grid.

Industry

Industry is a particularly important sector for assessing energy efficiency potential because it often consumes a large share of a country's energy production. Globally, the industrial sector accounts for more than one-quarter of worldwide energy consumption.[3] (See Figure 3.)

In our assessments, we first determine which industries in a given area use the most energy

Figure 3. Share of Global Energy Consumption by Sector, 2008



and have abnormally high "energy intensities," wasting a comparatively high amount of energy per unit of GDP they generate. We then evaluate these industries against international best practices and technologies to identify areas for improvement. We also conduct on-site energy audits as necessary to determine which industries generate high levels of waste heat, with the aim of identifying best practices for capturing and utilizing this heat for applications such as on-site electricity generation, heating, and cooling.

We are particularly interested in identifying and evaluating industries that have high potential for "cogeneration"—the process of capturing waste heat from electricity production and using it for heating and cooling applications in the surrounding area. Cogeneration from producing power and heat together can achieve efficiencies of up to 90 percent, compared to just 15–40 percent when producing them separately.[4] This approach has many practical applications, including in industrial processes such as paper production and minerals processing, commercial and public sector buildings, and district heating for cities. Cogeneration technologies can be implemented across a wide range of scales, from 5-kilowatt residential installations to 500-megawatt district heating systems and industrial cogeneration.[5]

Residential Sector

In the residential sector, promoting energy efficiency is one of the most effective ways to educate people about energy issues and the environmental impacts of their behavior, thereby encouraging wider behavioral changes and energy savings. A first step in assessing residential efficiency is to survey residents about their energy habits and to identify where the most energy is consumed in households. This can help determine the overall effectiveness and enforcement of building codes and regulations. In the Caribbean, for example, a relatively high share of energy is used to cool residential spaces, which suggests that developing building codes that promote cool roofs and passive cooling technologies has a high potential for energy savings.

Residential surveys can also highlight important socioeconomic trends, helping to determine which efficiency policies will be most effective. In many developing countries, for example, low-income households spend a large share of their energy budget on lighting, whereas higher-income households spend more of their budget on heating and cooling. Energy audits of large living spaces such as apartment complexes can provide further insight into the best approaches for improving efficiency. Measuring insulation levels, the location of windows, and other variables can help uncover which efficiency technologies are most appropriate for specific buildings.

Matti Mattila

The Hanasaari B cogeneration coal plant in Helsinki, Finland.

Evaluating a country's diverse climatic zones is also helpful in determining energy efficiency and savings potentials. The climatic conditions surrounding a building can signal a choice between "cool" roofs, which reflect sunlight and minimize the heat emitted into a living space, and "hot" roofs, which absorb sunlight and maximize heat transfer. Dividing a country into climatic zones and matching those zones with ideal roof material and color specifications can help building developers realize the greatest energy savings.

Appliances

Appliances are a third potential source of major energy savings. By evaluating existing appliance efficiency standards, it is possible to identify which appliances have suitable standards but lack

Analyzing Energy Efficiency Potentials

effective implementation, as well as which appliances lack efficiency standards altogether. We can then compare the efficiency levels of common energy-intensive appliances with international benchmarks to identify which standards should be implemented or strengthened.

Depending on the region and sector analyzed, different appliances can be targeted for efficiency gains. In general, refrigeration and lighting are two residential energy services that have significant potential for efficiency gains. Targeting communities that still use incandescent light bulbs and replacing these with more-efficient compact fluorescent lamps (CFLs) or light-emitting diodes (LEDs) can provide significant efficiency gains. For the commercial sector, cooling is a major electricity consumer, and focusing on more efficient heating, ventilation, and air conditioning (HVAC) systems can lead to substantial efficiency gains.

Grid efficiency

As a final variable in the efficiency assessments, Worldwatch looks at the electricity grid and evaluates transmission and distribution losses. A first step is to measure voltage across long-distance power lines: the higher the voltage, the lower the losses being experienced. By comparing local voltage levels with voltage levels across some of the world's most efficient grids, we can highlight areas for improvement. In the case of measuring losses from transformers, we focus our analysis on large transformers with high load capacities, as these have the greatest potential for efficiency savings. Evaluating the design and material composition of transformers and comparing these to best-practice transformers is an effective way to explore efficiency potential.

Assessing Renewable Energy Resource Potentials

A second major stage of Worldwatch's Sustainable Energy Roadmaps is to assess the physical renewable energy resources in the given geographic area, including (if applicable) solar, wind, hydropower, biomass, and ocean wave/tidal potential. Resource assessment data and maps compiled at the regional or country level serve as a valuable educational tool. They can provide a broad overview of technology options and can help justify interest in developing renewable energy resources in the study area. Higher-resolution data that cover narrower geographic zones, however, are necessary when making specific planning decisions about energy generation and transmission installations.

To conduct this highly technical research, Worldwatch partners with specialized organizations such as 3TIER, a resource-mapping company, to produce both broad-scale and zone-specific maps and datasets. In consultation with decision makers and stakeholders in the study region, we designate zones of particular focus for high-resolution assessments, based on the assumed strength of the energy resource, its proximity to major power "load centers," access to the grid, and potential intrusion on protected areas, resorts, and other areas important to natural habitats, tourism, and other socioeconomic needs.

Our assessments of renewable resource potentials are indispensable tools for planning the most suitable energy mix and central transmission structure for a particular area. They provide a window into both the overall potential for renewable energy use in the study area and the effects of geographic dispersion on fluctuations in generation. Our main focus is on five renewable resource areas: solar, wind, small hydropower, biomass (including biofuels and municipal solid waste), and wave/tidal energy.

Solar

Today, a suite of relatively mature technologies is available to convert the sun's energy into electricity. These generally fit into one of two categories: photovoltaic (PV) modules that convert light directly into electricity, and concentrating solar power (CSP) systems that convert sunlight into heat energy that is later used to drive an engine. Solar power can operate at any scale, but whereas CSP systems are considered viable generally only as utility-scale power plants, PV technology is modular and can be scaled for use on a household rooftop, in medium-size settings such as resorts and industrial facilities, or as part of a large network of utility-scale PV farms.

Traditionally, solar power has not been cost competitive with conventional electricity generation, due in part to the high level of direct and indirect subsidies benefiting fossil fuels.[1] Government support, whether in the form of feed-in tariffs, renewable portfolio standards, tax credits, or other mechanisms, has been necessary to help level the playing field and accelerate the adoption of solar technologies. But costs for solar systems are falling rapidly, and an oversupply of modules may further speed this decline. In certain situations, solar is already cost competitive: PV installations in the Persian Gulf region, for example, are offsetting electricity generated from oil, bringing positive returns.[2] The 72-percent increase in new PV installations worldwide in 2010 alone is a result of both strong support policies and rapidly declining technology costs.[3]

To assess an area's solar energy potential, we rely on satellite data as well as data generated from proprietary models of solar irradiance. 3TIER, for example, bases its datasets on 12-plus years of hourly, high-resolution (at least 3 kilometer) satellite imagery. 3TIER processes the imagery to create hourly values for irradiance, wind speed, and temperature, allowing the company to generate annual and monthly means and to track variations in daily patterns throughout the year.

3TIER's datasets provide three key measurements of solar energy that together provide the information necessary for developing solar photovoltaic and solar thermal projects: global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DIF). (See Table 1.) Using these data on monthly and daily variations, it is then possible to determine energy generation potentials. The analysis compares monthly variation in solar generation potential to overall electricity demand throughout the year, and the daily variation for each month against the hours of peak demand in the study area. The solar assessment also measures hourly temperatures and wind speeds, as these factors affect generation from PV systems, most of which experience significant power degradation when the unit's temperature rises.[4]

In addition to providing electricity, solar energy is commonly used for heating water and spaces, replacing electric or gas systems. Solar water heating can be active or passive, meaning that the systems either use pumps and controllers to move and regulate the water, or rely only on convection. Active systems are more efficient but are also more expensive and require significantly more maintenance. Passive systems have no moving parts and are valued for their simplicity. Solar hot water systems are broadly cost-competitive globally, with payback periods under two years in many cases. In 2009, global solar water and space heating capacity reached 180 gigawatts-thermal—enough energy to power more than 15,000 average American homes for one year.[5] Eighty percent of this is in China, and the vast majority is used for water heating.[6]

In small-island states, the attractiveness of solar water heating is clear. Cyprus is the world's leader in installations per capita, and Barbados's experience is considered a Caribbean renewable energy success story.[7] Duty-free equipment imports and tax incentives in the country have created a thriving market, with 40,000 solar hot water systems installed on homes, businesses, and hotels, as well as a market penetration of 33 percent for residential buildings.[8] The success of this

Table 1. Key Measurements of Irradiation and Their Application to Solar Resource Analysis

Measurement	Description	Application
GHI	Total solar radiation per unit area that is intercepted by a flat, horizontal surface	Of particular interest to PV installations, as it includes both direct beam radiation (radiation directly from the sun) and diffuse radiation (radiation scattered from all directions).
DNI	Total direct beam solar radiation per unit area that is intercepted by a flat surface that is at all times pointed in the direction of the sun	Of particular interest to concentrating solar power installations and installations that track the position of the sun.
DIF	Diffuse solar radiation per unit area that is intercepted by a flat, horizontal surface that is not subject to any shade or shadow and does not arrive on a direct path from the sun	Of particular interest to some PV installations which are best suited to diffuse radiation.

project was cited explicitly by the Inter-American Development Bank in announcing a multimillion dollar loan to Barbados for continued renewable energy development.[9]

Wind

Outside of hydropower, wind has been by far the most successful renewable electricity source, with nearly 200 GW installed globally by the end of 2010.[10] In some markets, the costs of wind power are estimated at 4–7 cents per kWh in attractive locations, making it fully competitive with fossil fuel technologies.[11] Although turbines come in many sizes, wind power is used mostly at a larger, utility scale because the low wind speeds at the elevation of most smaller turbines make the units less efficient. This means that wind power is most often used as a centralized source of electricity generation, in contrast to solar photovoltaic systems which can be effective at a small, distributed scale.

Wind turbines can provide on-site electricity generation for large electricity consumers such as a factory or a farm. Unlike traditional on-site thermal generators, however, wind is intermittent and cannot be started up at will. Connecting these turbines to the grid can significantly increase the value of the electricity as landowners are able to sell excess power.

As with solar, Worldwatch relies on data generated from proprietary models to develop our wind resource assessments. The mapping company 3TIER, for example, generates data from a mesoscale numerical weather prediction model, the Weather Research and Forecasting (WRF) model. The company simulates the meteorology over the study area using at least 10 years of hourly wind and power data at resolutions ranging from 90 meters to 4.5 kilometers.

Under ideal conditions, each 4.5 by 4.5 kilometer grid point in the 3TIER analysis could hold 40 wind turbines in four rows of 10. Practical considerations such as difficult terrain, aesthetic design considerations, and wake losses (due to interrupted wind flow for wind turbines downstream of other turbines on the same wind farm), however, often make such turbine density unrealistic. It is therefore common to use a Project Layout Discount Factor (PLDF) to account for limitations. Experience shows that the typical spacing for a wind farm might allow for approximately 20 turbines in a 4.5 by 4.5 kilometer area (equaling a PLDF of 50 percent).

3TIER's calculations of wind power potential assume the use of a 3 MW Vestas V90 turbine (a common model) that is operated at the highest efficiency point, using an "effective wind speed" derived from wind speed, temperature, and pressure data modeled at 10-minute intervals. The result is a capacity factor estimate for each grid point, which measures the amount of power potentially generated compared with the installed capacity of the generation plant. For example, if a 3 MW turbine generated 1 MW of electricity on average, the capacity factor would be one-third, or 33 percent.

For high-resolution wind resource assessments that are site-specific, 3TIER identifies grid points in each zone that have capacity factors of more than 20, 25, and 30 percent, to determine the areas with the greatest potential. A grid point with a PLDF of 50 percent would produce 105 gigawatt-hours per year (GWh/yr) at a 20 percent capacity factor, 131 GWh/yr at 25 percent, and 158 GWh/yr at 30 percent, using the 3 MW V90 turbines.

One of the biggest challenges with wind power is its intermittency. The wind does not blow continuously but varies significantly throughout the year and the day. How pronounced this variation is, and how well wind resources with different variability patterns across the country can be integrated to reduce overall intermittency, go a long way to determining the viability of adding wind power to the electricity grid. Our wind assessments therefore include analyses of both seasonal and daily variation. Seasonal variation is useful for power system planning and scheduling of long-term maintenance, whereas daily variation is especially important for examining if and when peak wind generation coincides with daily peak electricity demand.

The frequency with which potential wind energy sites experience significant changes in generation over short periods of time, known as "ramp events," also plays a role in determining their attractiveness. Our assessments examine wind variation over 10-minute and hourly intervals from representative sites. In both cases, geographical diversification reduces both the number and size of ramp events—either positive or negative changes in output that are greater than 5 percent of installed capacity—but the effect is much greater over 10-minute intervals, as there is less time for multiple sites to be affected by the same weather pattern. One way to significantly reduce the variability of wind generation is to place wind farms in multiple geographic locations with a diversity of seasonal and daily variation, in order to level out daily and yearly generation.

Mike Gonzalez

The Palinpinon Geothermal Power Plant in Negros Oriental, Philippines.

Geothermal

Geothermal energy, or thermal energy stored in the Earth, can be used to generate electricity or to provide heating and cooling services. Currently, geothermal plays a limited role in the electricity sector, however, with only 11 GW installed worldwide in 24 countries.[12] The main limitation is the need for reservoirs with very high temperatures near the Earth's surface. The Geysers in California, the largest geothermal power plant in the world, takes advantage of 300-degree Celsius steam less than two kilometers below the surface.[13] Such resources are rare, however, and most deep geothermal reservoirs are technologically or economically unfeasible to exploit.

Nevertheless, good geothermal resources can contribute significantly to a region's electricity portfolio. For example, geothermal accounts for 27 percent of electricity generation in the Philippines and 4.5 percent in California.[14] A major advantage of geothermal power compared to many other renewable sources is that it can be used as a baseload source of energy.

The most common use of geothermal energy is for heating and cooling. Because geothermal heating and cooling systems rely on reservoirs with much lower temperatures, they are not as site-specific and can be built around the world; at least 78 countries use geothermal energy directly for heating.[15] In addition to direct heating, geothermal resources can power heat pumps.

An area's geothermal potential can be assessed at various levels of scale and accuracy. Factors such as the geologic setting, evidence of volcanic activity, and the existence of geothermal features like natural hot springs can be used to deduce where strong geothermal potential is likely. Geological, geochemical, and geophysical surveys help infer geothermal potential on a regional level. For high-potential areas, test wells can be dug to directly measure the Earth's temperature and porosity at certain depths and to facilitate thermal energy simulation models and develop the most accurate estimate of geothermal energy potential.

Hydropower

Large hydropower comprises the majority of global renewable power generation and accounts for about 16 percent of the world's electricity production.[16] But despite being a low-carbon, renewable energy source, large hydro often has serious environmental and socioeconomic impacts, including widespread ecosystem disruption and occasional large-scale displacement of populations.[17] China's controversial 20 GW Three Gorges Dam, for example, forced the relocation of 1.3 million local residents and has resulted in significant erosion and landslide dangers.[18] Worldwatch's analysis therefore concentrates on the potential for small-scale hydropower development, which has fewer negative human and ecological impacts.

Small hydropower is used around the world, especially in remote areas. Usually classified as hydropower that generates less than 10 MW of electricity, it can operate as "run-of-the-river" systems that divert water to channels leading to a waterwheel or turbine, or, similar to larger hydropower stations, it can operate as dammed systems that have small-scale storage reservoirs.

Small hydro has several advantages as an energy source, including the ability to provide cheap and clean electricity to communities that may not have access to other resources. But small hydro has relatively high upfront costs compared with conventional energy sources and requires certain site characteristics, including adequate stream flow and ensuring that users are close to the harvested hydro resource. Low consumer demand for the electricity due to the lack of economically productive uses for power in many rural areas often makes attracting funding difficult. Issuing grants or setting up preferential financing schemes, as well as cultivating local small hydro manufacturing economies, have proven crucial for initiating and maintaining small hydro projects.

Assessments of small hydro potential are very expensive and usually are conducted only for specific locations. For larger-scale assessments, such as our country- and regional-level roadmaps, we measure small hydro potential in a select number of representative areas, from which we extrapolate the approximate potential of the full study area.

Biomass, Biofuels, and Municipal Solid Waste

Energy can be generated from a wide variety of biological materials, including agricultural crop residues, forestry wastes (woody biomass), and even municipal solid waste. In most agricultural locations, crop residue follows a regular pattern of production and can be measured proportionally to the amount of land used to grow the crop and the number of times the crop is produced each year. Both crop residue and woody biomass can be used directly for heat or electricity, or they can be gasified to have the same functionality as oil and natural gas, but with lower net carbon emissions.

A key barrier to developing biomass as an energy source is the logistical challenge of collecting the dispersed biomass residue in an economically efficient way. In addition, the diversion of crop residues for energy purposes has the potential to compromise soil quality for future agricultural production by removing a source of soil nutrients. Proper agricultural waste management is thus important to achieving a net positive societal outcome from using biomass.

Scaling up biomass production also can have serious implications for the local environment, affecting key ecosystem services, biodiversity, and the tourism industry. Large-scale production of energy crops can encourage monoculture agricultural practices that cause a host of local environmental problems including soil degradation, loss of biodiversity, overuse of chemical pesticides and fertilizers, and contamination of waterways. Expanded use of biomass energy can also create competition with food crops for limited agricultural land, a trend that in some places has driven up food prices and placed a particular burden on poorer populations.[19]

Given the sizeable role that biomass energy may play in the future energy matrix, however, this resource cannot go overlooked. In the short- to medium-term, biomass generation can serve as a reliable, renewable source of baseload power, particularly as solutions are still being developed to address the variability challenges that arise with other renewable energy sources such as wind and solar.

Like biomass energy, bio-based fuels (biofuels) can be used for power generation as well, although they are most commonly used in the transportation sector. In particular, biodiesel derived from oilseed crops, such as the jatropha tree, can be used as a substitute for diesel to fuel thermal power plants. The use of biofuels for electricity generation, however, is not suitable for communities that are less reliant on petroleum-based fuels. It is also important to consider the wider impacts of biofuel production, which can be similar to those of biomass production—such as the effect on local food prices.

Municipal solid waste can also be used for electricity generation. This waste contains significant organic material, and, when burned, it can drive a turbine similar to any other thermal power plant. In addition, landfill gas (primarily methane) can be captured and used to power a thermal power plant. Municipal sold waste is advantageous because it can be used as a baseload source of power. Because the waste would otherwise be discarded, it is also a cheap fuel source that requires little resource extraction or change in land use. But using municipal solid waste for electricity generation can be challenging in communities that lack organized waste-disposal infrastructure.

One way to assess biomass resources is to model the potentials for cultivating crops in particular locations, looking at environmental variables such as annual rainfall, soil nutrient levels, and average temperatures, as well as variables like land availability and economic costs. Although resource potentials vary depending on the location and crop considered, they are relatively easy to assess assuming that the data are readily available. It is harder, although equally important, to measure the secondary impacts of biomass development, such as the effects on food production. Assessing the potential of municipal solid waste is generally easy in areas that have waste collection and storage programs and that maintain data on waste levels.

Wave and Tidal

Wave energy is a third-hand form of solar energy and a second-hand form of wind energy. Sunlight warms pockets of air, producing temperature gradients that induce atmospheric circulation in the form of wind, which then drives water to produce waves. The peaks and troughs that store the wave's potential energy are proportional to how fast and consistent the wind blows over an open area of water.

Tidal energy, in contrast, is created by imbalances between the gravitational forces of the Earth, Moon, and Sun in orbit and the forces required to keep the orbits in place. The regular cycles of the orbits create a regular cycle of inflows and outflows in certain tidal estuaries and channels. Many tidal power systems use a design similar to wind turbines, except the units are located underwater at the base of tidal estuaries and channels. Because water is roughly 1,000 times denser than air, the systems are capable of producing roughly 1,000 times more energy than wind using water moving with the same flow speed as the air. Tidal energy resource assessments are based on grid-based oceanographic data including maximum current velocities, seabed depth, maximum probable wave height, seabed slope, significant wave height, and distance from land.[20]

Wave and tidal power face similar economic and technical barriers. The costs of building and installing these systems, including both the generation equipment and the underwater cables, are extremely high, and existing global capacity is almost exclusively in the form of pilot and demonstration projects. There also are many factors that need to be considered when it comes to developing marine energy projects, including corrosion of equipment in seawater, coexistence with other human uses of coastal waters such as fishing and recreation, grid connection obstacles, and potentially significant ecosystem disturbances.

Despite the current barriers, wave and tidal power may soon play an important role in some locations, such as small-island states that have extensive coastal territories. As technologies mature and costs come down, wave and tidal generation could become cost-competitive in the long term in some coastal regions.[21]

Integrating Renewables Into the Grid

In addition to exploring the diverse renewable resource and energy efficiency options in a given study area, Worldwatch examines specific variables associated with the deployment of renewables. Because there is no silver-bullet solution in the transition to a renewable energy future, each municipality, province, country, or region must adopt integrated solutions that are most appropriate for its particular circumstances. With this in mind, a third important element we explore in our Sustainable Energy Roadmaps is the technical challenges associated with integrating renewables into a given region's electricity grid.

A key characteristic of some renewable energy sources, particularly wind and solar PV, is that they are "variable generation" sources, meaning that the fuel cannot be stored directly like oil, coal, or biomass. Without direct storage capabilities, this power cannot be quickly "dispatched," or ordered to generate electricity, in response to changes in energy demand. Therefore, both wind and solar PV generation come with particular technical challenges relating to grid connection and integration. (Concentrating solar power, or CSP, on the other hand, can provide baseload power when paired with molten salt, which can trap and store heat for up to a couple of days to continue steady electricity generation on overcast days and at night.)

The nature of these challenges depends on the scale of the installation. Distributed generation systems, which are smaller in scale and do not necessarily feed their energy into a large power grid, face different issues than centralized, utility-scale projects, which usually do. Hydropower, solar, geothermal, biomass, and wind can be utilized in both applications, although hydro and wind power have been used mainly in centralized, larger-scale installations.

Xing Fu-Bertaux

Solar PV installation in Santo Domingo, the Dominican Republic.

Opportunities and challenges of distributed generation

For remote areas that are far from the electricity grid, distributed, off-grid technologies often provide the most economical (and sometimes the only) route to electrification. Off-grid power generation from sources such as small-scale solar PV and micro-hydro does not need to be transported and distributed through a grid and can therefore play an important part in electrifying rural communities. Since off-grid generation does not enter the transmission and distribution system, it offers efficiency gains as well.

Another solution for remote areas is "micro-grids," or localized grids that distribute power for consumers near the grids' generation systems. Micro-grids rely on one or more small generating systems, often renewable energy systems such as solar, wind, geothermal, biomass, or hydro. One benefit of a micro-grid is that it does not require investment in an expansive transmission and distribution system. For communities that are far from population centers or a major grid system, a micro-grid may provide the only economical source of community electrification. Because the electricity is generated nearer to the consumer and is transported shorter distances, a micro-grid wastes less energy in operation. But micro-grids can also be connected to major grid systems, which allows the micro-grid to tap into the major grid when the micro-grid is unable to meet local needs cheaply, or disconnect during production lows on the major grid to avoid paying high electricity prices.

Distributed generation systems do not inherently pose technical problems, even if installed at grid-connected locations. A basic grid-connected distributed generation system simply generates power behind the user's meter, reducing the amount of electricity that is drawn from the distribution network and appearing to the grid simply as a reduction in electricity demand. Regulations that provide incentives for interconnecting distributed generation systems so that they can actually feed power back into the grid (such as feed-in tariffs) complicate this picture, although they have the potential to significantly improve distributed systems' cost competitiveness.

The creation of a feed-in tariff (price guarantees for renewable generation) or net-metering program (which allows small self-producers to deduct the outflow of energy to the grid from the inflow) requires additional infrastructure. Net metering may necessitate the installation of a two-way meter that can track both the electricity consumed from the grid and the electricity sent back into it. A feed-in tariff, on the other hand, can be more complicated to implement, necessitating the installation of additional wiring and a second meter to separately track the higher-priced electricity generated by the distributed generation system.

There are legitimate concerns about the impact of interconnected distributed generation systems on the grid.[1] Achieving a high penetration of this type of generation requires that both grid operators and regulators have a better understanding of key potential challenges as well as the available solutions.[2] (See Sidebar 3.) Overall, however, the advantages of renewables outnumber the challenges, which can be effectively addressed, and there are many opportunities that make the promotion of distributed generation a worthy priority for decision makers at all levels.

The economics of distributed generation systems are particularly favorable in areas that experience high technical and non-technical losses in their transmission and distribution grids.[3] Because these systems generate electricity at the point of use (rather than having to pass through the grid), a kilowatt-hour that comes from, say, a rooftop solar panel, on-site wind turbine, or biomass-fired generator is more effective than a kilowatt-hour from a centralized fossil fuel plant. In instances where the distributed generation system is integrated with the grid (such as under a net-metering or feed-in tariff regime), some of the system's output would be subject to the grid's transmission losses. In general, distributed systems are more financially attractive in places where area-wide transmission lines do not exist or where grid losses are reflected in high electricity prices, compared with countries where grid power prices are lower.

Most importantly, the use of distributed generation systems reduces the number of overall kilowatt-hours that need to be generated by centralized plants, improving the efficiency of the electricity system. Larger-scale, centralized renewable power generation poses technical challenges (related to connecting to and integrating with the grid) that do not exist for off-grid or micro-grid systems. Utility-scale wind and solar facilities, for example, are more location-dependent than power plants that consume portable feedstocks such as fossil or bio-based fuels (although these are often costly to transport). This is a particular challenge for regions where transmission lines are not well distributed and are concentrated in particular areas. A region may have a very good hydro, solar, or wind resource, but the cost of grid extension may make development prohibitively expensive. Thus, finding a viable wind or solar site requires balancing the resource available at the location with its proximity to existing consumers and transmission infrastructure.

Facilitating the integration of renewables into the grid

A grid system's difficulty in absorbing variable generation can present a barrier to the growth of renewable power, particularly in the absence of continued improvements in infrastructure and market design. There are many steps, however, that can ease the process, from better resource forecasting to improved grid flexibility.

High-quality renewable resource forecasting is an important prerequisite for integrating variable generation into the grid. The more accurately that renewable energy producers and grid operators can predict renewable power production, the less they will have to rely on regulatory markets to account for unexpected changes. Worldwatch's renewable resource assessments are thus useful not only for analyzing the production potential of different technologies, but also as an important input to grid integration and transition studies.

In general, integrating variable generation into a grid requires greater grid flexibility. Larger grids or balancing areas (whether measured by the number of generating facilities or the geographic area covered) tend to be more flexible because there are more (and more diverse) power plants, which can help smooth the variability in supply and demand.

Stronger grids are better able to transport electricity from the point of generation to the point of demand, and are typically more flexible. Grid strength is often limited by old, inefficient, or bottlenecked transmission and distribution networks. To respond to changes in variable generation output, it is important that grid operators explicitly designate other generators that are available to provide quick increases and decreases in power supply to meet demand needs. Both natural gas and biogas capacity can be quickly turned on and off, meaning that use of these resources can serve to offset variability in renewable generation. In the near- to medium-term, these gases are a cleaner alternative to coal or oil-based energy sources and can be an important

Sidebar 3. Key Technical Challenges for Integrating Distributed Renewable Generation into Electrical Grids

A variety of technical challenges may arise when integrating distributed generation from renewable energy sources into the electricity grid. These include:

Power Flow Reversal. In instances where distributed power generation is higher than local electricity demand, the increased voltage in the local network may exceed the voltage that the grid supplies, resulting in a reversal of power flow. Reversed power flow may overload and damage electrical equipment if the grid is already experiencing power flow near its maximum capacity.

Voltage Regulation. Voltage regulation allows grid operators to ensure a high quality of electricity by maintaining voltage in the distribution line within 5 to 10 percent of the designed operating voltage. Distributed generation systems fluctuate in voltage output during operation, or when turned on and off, and can potentially harm sensitive loads (such as manufacturing equipment) to which they supply power.

Harmonic Distortion. When the fundamental frequency of the electric current is distorted by other interfering frequencies, this can cause the total effective current to exceed the capacity of the transmission system, leading to overheating and voltage regulation problems. To prevent this from happening, any distributed generation unit connected to the grid must comply with limits for maximum harmonic distortion.

Protection Scheme Disturbance. Modern grids have several measures in place to protect against bidirectional power flow or an exceeding of the maximum transmission line capacity. When a new distributed generation system begins feeding power back into the grid, problems can arise. For example, a fuse may melt if the power flow exceeds a certain threshold to prevent damage to the grid downstream.

Unintentional Islanding. Unintentional "islanding" is a significant potential problem with distributed generation systems, although it has been largely solved with advances in inverter standards.* In the event of a grid outage, breakers automatically isolate the section of the grid in which a power interruption occurs. A generator that is still providing power within this "island" during a grid interruption can interfere with the breaker isolation procedure, leading to longer-than-necessary outages.

* Inverters convert the direct electric current from distributed systems into an alternating current that can be fed into the grid. Inverter standards can require that inverters include mechanisms to detect when the grid is shut down so that distributed systems cease generating when this occurs.

Source: See Endnote 2 for this section.

ally for the massive scale-up of renewables.

Grid renovation is also important. By analyzing the ability of a transmission and distribution network to accommodate new renewable electricity capacity, it is possible to pinpoint needs for grid improvement and renovation, as well as to identify institutional barriers and opportunities for these renovations.

Operational matters influence a grid's overall flexibility as well, not least because there are many situations where existing flexible generation cannot be accessed because of a grid's institutional framework or scheduling rules. Each grid is governed by codes that define how and whether renewable energy devices respond to certain grid conditions, including voltage sags and over-generation. The rate at which electricity markets operate also affects grid flexibility, with close-to-real time market clearing allowing for better response to unanticipated variability than hourly markets.[4]

In addition to grid-based solutions, energy storage technologies can help reduce the variability of renewable energy on the grid by storing unused energy during times of peak production for use when the sun stops shining or the wind stops blowing. Key energy storage options available today to offset variable generation include batteries, pumped hydro, compressed air, and thermal storage. (See Table 2.)

Table 2. Electricity Storage Options Compatible with Renewable Generation

Option	Description
Batteries	An effective solution for use with off-grid technologies (battery technology is not developed enough to use at a large industrial scale). Most commonly used to store electrical energy from PV systems, including at the household level. Car batteries are often used for this purpose.
Pumped-storage Hydro	Most commonly used for large-scale energy storage, and to complement solar and wind. At times of low power demand, excess electricity is used to pump water uphill into a sealed-off reservoir. During periods of peak demand (or low energy production), the stored water is released through a hydropower plant, pushing a turbine that rotates a generator to produce electricity. Requires hydro resources and mountainous landscapes.
Compressed Air	Functions similarly to pumped-storage hydro and fits well into a micro-grid system. During times of low energy demand, cheap electricity is used to power a motor, which runs a compressor that forces air into tight underground reservoirs. During periods of peak demand, the compressed air is released and heated with natural gas, causing the air to expand and push a turbine that drives a generator to produce electricity.
Thermal Storage	Often used in conjunction with concentrating solar power (CSP) systems. Relies on heat-absorbing materials, such as molten salt, to absorb and store heat. In such systems, several hours, and in some cases up to a couple of days, of thermal energy can be stored in molten salt. This stored heat can later be released to help generate electricity at night or on a cloudy day.

Assessing Socioeconomic Impacts of the Renewable Energy Transition

In addition to technical considerations, the transition to renewable energy involves numerous socioeconomic considerations. In our Sustainable Energy Roadmaps, Worldwatch explores variables such as the effects on expanded electricity access, energy costs to households and businesses (including the effects on both capital and fuel costs), and local improvements in health and economic development. For example, we provide estimates of job creation associated with potential energy projects, including in the energy efficiency, renewable energy, and grid modernization sectors. We also assess socioeconomic impacts in other sectors of the economy, including, where applicable, tourism, agriculture, and manufacturing.

Direct jobs in renewable power are generally divided into two categories: construction, installation, and manufacturing; and operations and maintenance. Construction, installation, and manufacturing jobs are concentrated in the first few years of setting up a renewable energy facility, whereas most operations and maintenance jobs exist for the lifespan of the installation. To estimate long-term job creation, construction, installation, and maintenance jobs can be averaged out over the expected lifetime of new projects, a calculation that is particularly useful for countrywide estimates where it can be assumed that new facility installations will be ongoing for years to come.

A 2010 analysis of clean energy employment found that, over their lifespans, renewable power plants employ more people than conventional fossil fuel plants.[1] (See Table 3.) Solar PV, geothermal, and biomass facilities tend to be the most labor intensive, whereas wind generation generally requires far fewer jobs. In countries that boost their renewable energy capacities, the high labor costs for building new renewables plants can be offset in part by the savings gained from no longer having to pay for costly fossil fuels to feed conventional power plants. In that sense, investments in renewable energy support "goods" (jobs) and avoid investments in "bads" (such as polluting fossil fuels).

Renewable energy facilities create indirect and induced employment as well. Indirect jobs are positions created throughout the supply chain based on the increased demand for materials and components required for renewable energy equipment. Induced jobs are the jobs created as the salaries earned via the direct and indirect jobs are then spent on a range of goods and services in the wider economy. In addition, reliable and affordable access to energy allows for investments in new local businesses, which bring additional revenue, incomes, and jobs.

Sustainable energy development offers promising employment opportunities and an alternative for many regions that are currently transferring wealth out of the region to pay for fossil fuel imports. It is important to note, however, that most of the initial local jobs from renewables will occur in installation, operations, and maintenance, since these positions are located in-region; by contrast, most manufacturing and indirect jobs will be concentrated in the places that manufacture the renewables equipment and materials.

To capture the full domestic employment opportunities from sustainable energy, and to justify the upfront installment costs, it will be important for regions to invest in capacity building, including maintaining or expanding the domestic manufacturing base to allow for production

Table 3. Average Employment Over Lifetime of Power Generation Facilities, by Energy Source

Energy Source	Construction, Installation, and Manufacturing Jobs	Operations & Maintenance and Fuel Processing Jobs	Total Jobs
		jobs per megawatt of capacity	
Solar PV	0.29–1.48	0.12–1.00	0.41–2.48
Geothermal	0.10–0.44	1.67–1.79	1.77–2.23
Biomass	0.11–0.21	1.21–1.53	1.32–1.74
Solar thermal	0.18–0.41	0.22–1.00	0.40–1.41
Small hydropower	0.14	1.14	1.28
Nuclear	0.38	0.70	1.08
Wind	0.10–0.44	0.14–0.40	0.24–0.84
Natural gas	0.03	0.77	0.80
Coal	0.21	0.59	0.80

Source: See Endnote 1 for this section.

of renewable energy equipment and training a skilled labor force to install, operate, and maintain new facilities. Increased education and job training contribute to long-term employment generally by creating a skilled and educated green workforce. Including capacity building as a central aspect of sustainable energy programs will help ensure a "homegrown" effort and workforce in which green jobs are created locally rather than exporting jobs and financial resources abroad to import energy fuels and equipment.

In addition to creating new job opportunities, the shift to energy sectors that focus on energy efficiency and renewable energy will affect energy prices. An important starting point in measuring these impacts is conducting so-called "levelized cost of energy" (LCOE) analyses for various energy development scenarios in the short, medium, and long terms. LCOE analyses typically consider several factors, including the continued rise in oil and other fossil fuel prices (especially in import-dependent countries) and falling renewable technology costs. Worldwatch's energy cost-benefit analyses will go an important step further by weighing the upfront costs of transitioning to sustainable energy technologies against the long-term benefits of lower fuel-import costs, increased energy security, and improved public health due to decreased energy-related pollution.

Through comprehensive cost-benefit analyses, we can evaluate many of the socioeconomic factors that are commonly associated with energy production but are frequently left unquantified. These include the public health effects from local air pollution, the transmission costs of centralized energy, the consequences of carbon emissions, and the impacts on economic development of harnessing domestic energy sources rather than paying for fossil fuel imports. In our scenario analyses, we also assess the potential for various sustainable energy resources and policies to mitigate greenhouse gas emissions. Although the mitigation efforts of small economies will have a relatively minor impact at the global scale, such measurement tools can help policymakers plan for future energy development, including by harnessing the international climate financing needed to implement sustainable energy projects.

Reforming Policy, Governance, and Finance

Worldwide, the promotion of energy efficiency, renewable energy, and intelligent grid solutions has consistently been a policy-driven process. Supportive policies and their effective implementation have been key in countries that have succeeded in developing a favorable investment climate for sustainable energy solutions. Our analysis suggests that these pioneering countries often share three important elements: a long-term vision, concrete support policies and measures, and an effective administrative structure.

In the policy component of our Sustainable Energy Roadmaps, Worldwatch focuses specifically on the role of government and public institutions in encouraging the deployment of sustainable energy technologies. To assess the domestic policy arena, we conduct semi-structured interviews with key representatives from government agencies, the private sector, civil society and academia, and international organizations. We also study official government, donor agency, and academic reports as well as media materials. Our analysis covers four major areas: the political framework/vision, concrete policies and measures, governance and administration, and finance. In our recommendations, we provide suggestions for reforms as well as alternative solutions in all four areas.

Developing a long-term vision

A critical first step toward creating a comprehensive energy policy is developing a long-term vision that can guide political action well into the future, beyond any changes in leadership. A comprehensive vision for the energy sector outlines the overall goals and targets and should be put in writing, to be easily accessible for any interested party. This vision serves as a framework and reference point and is designed to commit all government branches as well as key non-governmental stakeholders to a joint agenda of change, thus providing the impetus for the development and implementation of concrete, consistent policies.

Although policies are critical to building clean energy markets, experience shows that it is difficult to achieve the perfect policy design from the start. Spain, for example, introduced ambitious feed-in tariffs in 2007 that stimulated solar investment, but after some critics viewed the subsidy as being too expensive, there was pressure to remove it. When the government drastically reduced the tariff and set a rigid annual capacity cap to limit the number of eligible projects, solar investment collapsed. As this illustrates, it is important to leave room for policy improvements and fine-tuning details. Exact reference points such as tariffs for individual renewable resources ought to be able to accommodate revisions over time to integrate emerging needs and opportunities as well as lessons learned; still, the overarching vision and goals should remain consistent to serve as a benchmarks for current and future governments.

At the 2004 International Conference on Renewable Energy in Bonn, Germany, renewable energy financiers who were invited to provide policy input to the event concluded that in order to be effective, policy needed to be "Loud, Long, and Legal."[1] In other words, it had to be ambitious enough to make a real difference in the final result (Loud), it had to be perceived as sustained for a duration that reflects the financing period of projects (Long), and it had to be anchored in a legally established regulatory environment

(Legal). These policy characteristics serve to build confidence among all key parties that political regulations and market incentives will be stable and provide the basis for long-term, capital-intensive investments.

Creating policies and measures

A second key step in energy policy assessment is examining the various laws and other policy mechanisms that promote and otherwise influence sustainable energy development in a particular political entity. Compiling an overview of the regulatory framework is particularly helpful for identifying which institutions should be the focus of targeted policies and reforms. In our roadmaps, we provide decision makers with detailed information on possible support mechanisms for sustainable energy development, including international best-practice design and experiences with these policies. They can then draw from this "policy toolbox" to meet their specific needs and context, based on the advantages and disadvantages of each option.

Mechanisms in the policy toolbox range from energy efficiency measures such as establishing building codes and appliance standards, to tax and financial incentives for renewables and efficiency, to improved grid standards and capacity building. (See Table 4.) In addition to these targeted measures, eliminating fossil fuel subsidies can create a strong incentive for a more rapid transition to efficient and renewable technologies.

Improving governance and administration

Sustainable energy development has profound implications across society, the economy, and government, including in the areas of transportation, health, infrastructure, manufacturing, labor, trade, education, agriculture, land use policy, and foreign diplomacy. Designing and implementing a successful energy policy therefore necessitates taking into account a wide range of issues and integrating diverse development goals. Such policy "mainstreaming" requires the participation of all government branches and sectoral departments. Having in place a clear system for sustainable energy coordination across departments, as well as a means for inter-ministerial dialogue, helps to promote understanding of the deep implications of a renewable energy transition.

Policies are more successful when they are well supported by key political constituencies. The private sector, energy experts, and civil society are all critical stakeholders in energy policy outcomes and should be closely involved in policy development.[2] Consultations with key stakeholders not only foster engagement and buy-in, but they help ensure that policies are transparent and visible, politically feasible, follow an appropriate time horizon, recognize costs, complement other political priorities, create space for development needs, and integrate environmental and social aspects for all members of society.

On a technical subject like electricity, policymakers may be reluctant to open the debate to non-experts. A review of environmental decision making in the United States, however, reveals that in a significant number of cases, decisions were substantively improved through public participation.[3] And a study on civil society participation in electricity-sector governance in India, the Philippines, Indonesia, and Thailand concludes that, "improved governance can open the door to more creative solutions..., better systems of implementation, and stronger mechanisms of accountability."[4] Successful social and environmental outcomes are more likely if policies and regulations in the power sector are open to public debate and scrutiny.

But creating a vision, setting domestic targets, and passing energy legislation are not enough to ensure that long-term policy goals will be achieved. It is also important to have metrics in place to measure progress toward achieving these goals. International measurement standards and practices such as the Greenhouse Gas Protocol and ISO standards for measuring carbon emissions can guide policymakers in building in-country accounting methodologies and systems to track domestic policy implementation.[5] Progress needs to be "measurable, reportable, and verifiable." This MRV requirement is also a prerequisite to receive credit (both morally and potentially financially) for climate action as part of the UN climate regime, as envisioned in the 2009 Copenhagen Accord.[6]

Table 4. Selected Policies and Measures to Promote Energy Efficiency and Renewable Energy

Policy/Measure	Description
Energy Efficiency	
Building codes	Establishes codes for energy-efficient technologies in buildings, including insulation, cool roofs, passive lighting and heating, window sealants, and use of renewable energy technologies such as solar water heaters.
Appliance standards	Sets standards for most common appliances in the household, business, and industrial sectors, including air conditioners, refrigerators, televisions, heaters, ovens, clothes dryers, computer hardware, and heavy machinery. Adapting appliance standards from countries with successful efficiency programs can guide new appliance standards.
Weatherization programs	Provides energy efficiency measures to low-income residents free of charge, such as adding weatherstripping to doors and windows, installing insulation, and tuning heating and cooling units.
Energy audits	Provides energy assessments to determine home energy usage and efficiency measures, through techniques including a blower door test, thermographic scan, and air infiltration measurement.
Public education	Provides residents with information about cost-saving efficiency measures. Education programs in schools can also ensure that energy conservation becomes a cultural priority with younger generations.
Grid Reliability and Efficiency	
Grid standards	Includes measures such as mandating distributed power generation, minimum voltage requirements for long-distance power distribution, and transformer technology standards.
Renewable Energy	
Tax exemptions	Includes exemptions on imports of equipment and machinery necessary for renewable energy production, income from renewable energy generation, and equipment costs for self-producers.
Feed-in tariffs	Mandates a price to be paid over a guaranteed period of time for power produced from a renewable source to encourage new renewable generation while technology prices are high and/or the investment environment is still uncertain. Feed-in tariff policies can also guarantee access to the grid and require utilities to buy electricity or renewable energy credits from renewable power producers.
Net metering	Enables small self-producers of renewable energy sources to deduct their energy outflow to the grid from metered energy inflows from the grid.
Renewable Energy and Energy Efficiency	
Emissions trading	Places an overall cap on emissions of carbon dioxide or other pollutants. This maximum amount is divided into emission allowances that are allocated or auctioned to emitters such as energy generators or industry. Emitters with low-cost emission reduction options can sell their excess allowances to emitters that face high mitigation costs, allowing for a cost-effective approach to meeting the overall emission limit.

continued on next page

Table 4. *continued*

Policy/Measure	Description
Ecotaxes	Involves taxing a range of products and activities to reduce carbon emissions or other environmental impacts, including via carbon-based taxation of cars and fuel suppliers, traffic congestion fees, and a direct tax on carbon emissions.
Domestic public financing	Creates a specialized financial institution within the government to leverage the private capital necessary for sustainable energy. Domestic public funds can provide the financial backing necessary for a range of incentives including feed-in tariffs and loan packages for energy development projects.
International funding options	Includes harnessing international funding sources such as the Clean Development Mechanism and Joint Implementation funds under the UN Framework Convention on Climate Change, World Bank loans, and bilateral development assistance.
Capacity building in banking and financial sector	Aims at addressing a lack of available capital to invest in renewable energy sources as well as a lack of available borrowing (soft loans, credit, grants, tied and untied loans) and guarantee instruments for renewables, based on the assumption that in the long term, the private sector, backed by commercial banks, will need to be the main source of renewable energy finance.
Government procurement	Includes requirements for government purchases of efficiency and renewable technology, with the ultimate goal that these demonstrate successes, reduce costs of certain technologies and practices, and help create economies of scale. Governments often are the largest energy consumers in a given area.

Streamlining project development and funding

In many countries, investors seeking to develop renewable energy projects must go through a complex process that involves several governmental institutions, environmental certification, as well as thorough technical and financial assessments. Creating a single administrative window within the government for renewables investors can help streamline applications and mitigate the complexity of bureaucratic procedures for obtaining concessions and financial incentives. To facilitate the process, governments can create documents that map out the administrative steps and compile a handbook for all concession-related questions, to serve as a centralized resource. Setting up a hotline or information service is also useful for applicants.

Inexperienced developers often lack the skills to carry out energy projects, which can bog down the bureaucracy enormously. To strengthen the project development process, governments can require a thorough review of a project's bankability and of the availability of funds committed. In addition to performing a comprehensive analysis of a project's financial viability, the concessionary body can set up a service to match project financial needs with available domestic public financing or international climate finance.

In preparing Sustainable Energy Roadmaps, Worldwatch collaborates with and contributes to capacity building in the banking and financial sector of the study area. Renewable energy is a relatively new industry in most countries, and business developers and financiers still face a variety of challenges, including a lack of available capital to invest in renewable energy sources as well as a lack of available borrowing (soft loans, credit, grants, tied and untied loans) and guarantee instruments for renewables.[7] Banks are often unable to provide attractive loan products for relatively small-scale renewable energy projects, as compared with large-scale fossil power plants.

Lack of awareness and capacity to finance renewable energy remains a barrier in most countries' banking sectors. One particular challenge is the repayment period that banks can accept on loans for energy investments. For renewable technologies, the repayment period is typically 10–20 years, which is often much longer than banks are able to accept.[8] The lack of an appropriate public or private guarantee mechanism (which would allow banks to offload some of the risk to the government or another organization) is a further barrier for the banking sector.

To identify the key barriers specific to a study area, as well as the techniques and policies to overcome them, Worldwatch conducts interviews with representatives from the banking sector. Our work in roadmap development also provides a forum for exchanges between domestic commercial sector stakeholders and international funding sources, creating a linkage to fill knowledge gaps and identify international financing opportunities.

Douglas Cataylo

The Bangui Bay Project in the Philippines is one of the first large-scale sustainable energy projects in Southeast Asia. Carbon Emission Reduction Certificates were awarded to the private developer.

Insights from a Case Study:

Roadmap for the Dominican Republic

In 2011, Worldwatch completed its first Sustainable Energy Roadmap, titled *Roadmap to a Sustainable Energy System: Harnessing the Dominican Republic's Wind and Solar Resources*. The Dominican Republic presents an ideal first case study for the need and applicability of the Sustainable Energy Roadmap approach for a variety of reasons.

Perhaps most significantly, 85 percent of the country's electricity is generated from imported fossil fuels.[1] This dependence comes at a high economic cost: in 2010, the country spent $3.5 billion on fossil fuel imports, or nearly 7 percent of net GDP (down from an even higher share before the world economic crisis).[2] As a result, the island nation is extremely vulnerable to global oil price fluctuations, creating an unfavorable trade balance, and fossil fuel use contributes to local air and water pollution as well as global climate change. Wind and solar power have been developed only minimally in the Dominican Republic, meaning that there is enormous untapped potential for renewable energy growth.

Renewable Energy Assessment

An important first step in developing the roadmap was to assess the Dominican Republic's physical wind and solar resource potential.* At a countrywide scale, such assessments can be useful in planning the central energy generation and transmission mix. More detailed zonal analyses can then be used to gain an understanding of the aggregate potential of studied regions, as well as of opportunities for reducing fluctuations in generation by developing geographically dispersed sites. These resource potential assessments provide the basis for further observational data and modeling in wind and solar calculations to obtain the more accurate understanding of a site's potential that is necessary for development purposes.

In addition to commissioning a national solar assessment, we selected the cities of Santo Domingo and Santiago as areas of particular focus because of the government's interest in distributed generation. These two cities are the centers of electricity consumption in the Dominican Republic, and solar power is uniquely suited to household- and business-scale development for both electricity generation and water heating.

An analysis performed by the mapping company 3TIER found that the Dominican solar resource is quite good, judged globally. In general, the average solar resource across the country is comparable with that of the U.S. Southwest and areas along the coast of the Mediterranean Sea. Within the Dominican Republic, irradiance is generally higher in the western half of the country, with some of the best areas found in the southwest.[3] (See Figure 4.)

Zooming in, we found that both Santo Domingo and Santiago have very strong solar potential. Although other sites in the Dominican Republic boast higher solar resources, the integration efficiencies and economies of scale involved in installing and servicing solar in the two biggest load centers are notable. In addition to detailed solar irradiance maps, 3TIER also developed daily and monthly profiles of solar capacity in both cities.[4] (See Figure 5.) This allows energy developers to anticipate at which times of the day and year solar installations will generate the most electricity, and to what extent these generation levels

* We did not conduct an energy efficiency assessment as part of our Dominican Republic solar and wind analysis, due to time constraints and to the preliminary nature of the project.

align with peaks in energy demand.

Other avenues for solar development deserve closer scrutiny. Outside the cities, particularly in the sunniest areas of the western part of the country, either solar PV or CSP grid-scale solar development may be viable. Opportunities also exist for off-grid solar development, both for the small number of households currently not connected to the national grid and in the tourism industry, where many resorts rely on costly diesel generators. In some circumstances, solar would not only be economical, but it may allow resorts to market themselves as "eco-friendly" in the mold of successful tourist destinations in Costa Rica and around the world.

Our national wind analysis revealed that the Dominican Republic has many locations with strong wind energy potential, particularly in the southwest.[5] (See Figure 6.) For the more detailed zonal analysis wind assessment, the country's National Energy Commission (CNE) consulted with key government stakeholders to ultimately select six zones for in-depth analysis: Montecristi, Puerto Plata, Samaná, La Altagracia, Baní, and Pedernales.

These areas for wind projects must be chosen carefully. Because the Dominican wind resource shows strong variability—both daily and seasonally—building all of the country's wind projects in a single location would likely create challenges for system operation. Certain regions, however, have complementary daily cycles that could be used to limit the system's exposure to strong daily variation. Geographic diversity could also play a positive role in reducing the short-term variability of the country's power output, meaning that the inclusion of wind generation in the national energy mix could help strengthen the overall reliability of the Dominican grid. One way to provide more stable generation throughout the day would be to develop wind sources at Baní and Pedernales, which see the greatest generation in the late morning and early afternoon, and in Montecristi, which has higher generation levels in the evening.[6] (See Figure 7.)

Grid Integration and Socioeconomic Analysis

As the next stage of our roadmap assessment, we analyzed the Dominican Republic's national

Figure 4. Average Solar Potential of the Dominican Republic, 1997–2010

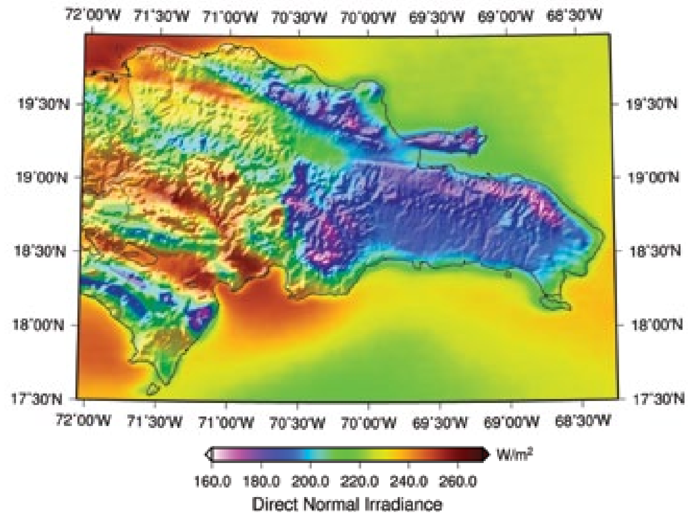


Figure 5. Daily Variation of Solar Radiation in Santiago, the Dominican Republic

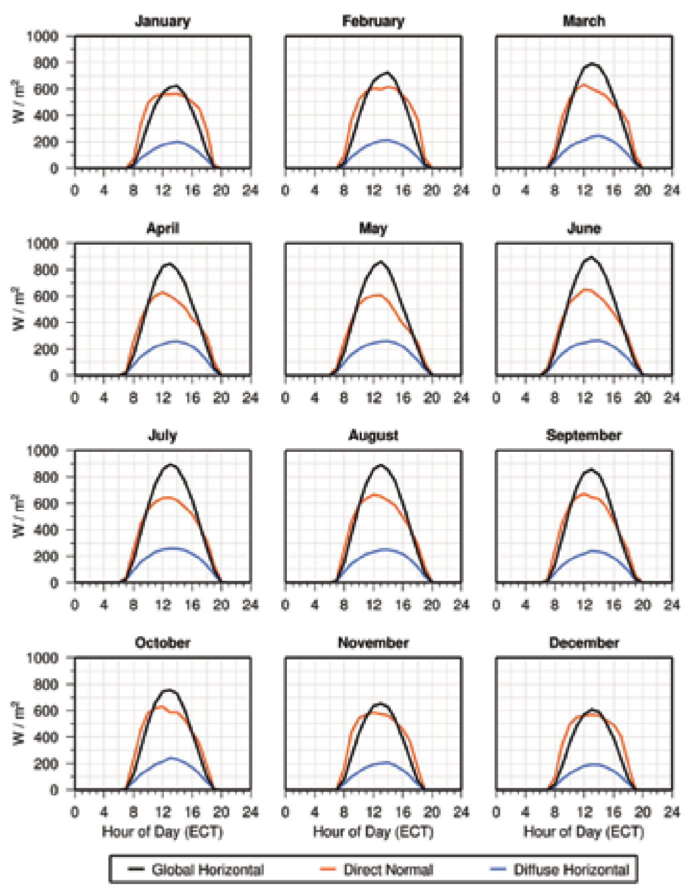


Figure 6. Average Wind Resource Over the Dominican Republic at 80 Meters Above the Land Surface, 1999–2008

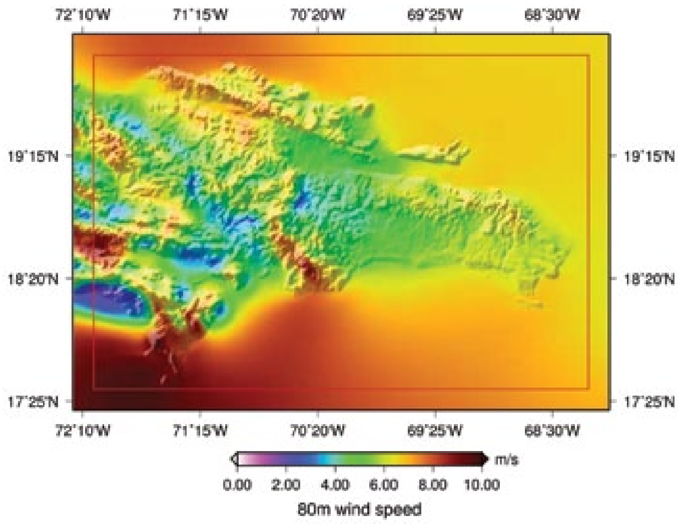


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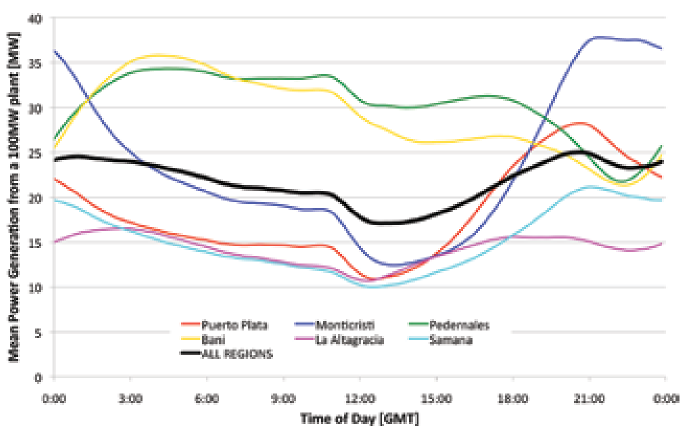
Figure 7. Hourly Variation in Wind Generation in the Dominican Republic, by Province



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electricity grid to develop recommendations for how the country can best facilitate the integration of variable generation from renewable sources. We found that upgrading and expanding the transmission and distribution networks, boosting the rate at which conventional power plants can increase or decrease power generation in response to demand, moving to a sub-hourly electricity market, and exploring interconnection with the neighboring country of Puerto Rico would all positively affect grid flexibility. Improvements to grid infrastructure, however, were the most pressing need.

Our assessments for wind and solar were essential first steps for the advancement of these key renewable energy technologies in the Dominican Republic. Any strategy to promote the integration of these variable sources in the country must now estimate the costs of network expansion. This involves narrowing the analysis by transmission subsystem to assess the conditions for granting wind and solar projects access to the network, and estimating in detail the cost of developing the project independently. Our roadmap gives important first insights for the further exploration of wind and solar development and frames the research that needs to follow.

At the same time, collaboration among key domestic stakeholders needs to be strengthened, including among key government institutions (Dominican Corporation of State Electricity Companies, Electricity Superintendence, Ministry of Environment, Ministry of Tourism, etc.), the many private entities related to electricity generation, and international support organizations. This dialogue will help stakeholders forge consensus on the most promising and agreeable location, design, and implementation plan for new renewable projects.

For this initial roadmap, we limited our socioeconomic analysis of the Dominican Republic to an assessment of the job creation potential from developing renewable energy resources. We found that renewable electricity development would likely provide more temporary and long-term direct jobs than meeting the same capacity needs with oil-fired power plants, which currently dominate the country's power sector. Many of these jobs, however, would be created during the manufacturing of the renewables technologies, meaning that the Dominican Republic would need to expand its manufacturing base and invest in workforce training to capture the full employment opportunities of domestic renewable power development.

Transitioning to wind and solar energy will provide additional economic, social, and health benefits. In future studies in the Dominican Republic, as well as other study areas, we will examine impacts including reduced local air pollution and associated improved public health, reduced import reliance and expenditures on fossil fuels, strengthened domestic energy industries, and lower long-term energy costs.

Policy Reform and Financing Options

The Dominican Republic has a comprehensive body of institutions, targets, and laws related to renewable energy. Unlike most countries, it has recognized the importance of a clean energy supply in its Constitution: Article 67 elevates clean energy development to a high-profile national goal, stating that, "The State shall promote in the public and the private sector the use of clean alternative technologies to preserve the environment."[7] Most industrialized countries, including the United States, lack such strong endorsement of clean energy as a priority in national policies, let alone the Constitution.

The targets for renewable energy development are no less ambitious. Fostered by strong political will that extends beyond party lines, the Dominican Republic has published a large set of written laws to incentivize renewables. Law 57-07, on *Renewable Sources of Energy Incentives and Its Special Regimes*, sets a target for a 25 percent share of renewable energy in the country's final energy consumption by 2025, again a target that is on par with or even exceeds standards in most industrialized countries.[8] The question of the effective implementation of these targets remains, however.

Law 57-07, with its associated regulations, sets a solid legal foundation for renewable energy development and, in the words of its prologue, "opens the door" to sustained commercial financing for the sector through financial incentives such as a feed-in tariff, tax exemptions, and a renewable energy fund. The law has helped increase investor confidence and creates a favorable environment for investment planning.

Yet some major barriers remain, hindering sustained growth in the renewables sector. Although the process has improved considerably in recent years, the administrative process for obtaining a concession and benefiting from the tax credits and tax exemptions laid out in Law 57-07 remains long and unpredictable. Further, implementation of the feed-in tariff laid out in Law 57-07 and its regulation remains uncertain, particularly for solar development, due to ongoing negotiations between the energy regulator and utilities to redefine the tariff rate. Other barriers include the lack of available capital; the absence of long-term, concessional commercial loans; the difficulty in accessing international financing for renewable energy and energy efficiency; and a lack of knowledge and awareness of financing opportunities and of the conditions of international climate finance institutions.

Some of these barriers could be effectively addressed simply through better execution of existing laws and regulations. Law 57-07, for example, has to-date been implemented only partially. At the time of the roadmap study, no feed-in tariff payments had been carried out. Complete implementation is thus the most immediate and urgent step for the Dominican government to take. This should include full enactment of net-metering legislation that was passed in 2011. To ensure that these policies are properly enacted, the Dominican Republic needs an integrated system to monitor and track progress toward its renewable energy targets, feed-in tariffs, and other measures. Independent monitoring of implementation measures by civil society groups would also help ensure transparency in communicating the results of renewable energy policies.

Improving predictability and transparency of procedures for obtaining renewable energy incentives is another important measure. For example, some companies in the Dominican Republic that have gone through the import-tax exemption process for wind technologies have expressed concern that the procedure still lacks predictability and can be lengthy. The process could be improved by better communicating the criteria by which tax exemptions are considered.

Much of the confusion and difficulty for obtaining certification and incentives for renewable energy projects results from several government agencies and laws being responsible for different aspects of the process to obtain these concessions. Creating a single administrative window within the government for renewable energy investors could expedite and simplify procedures significantly. Streamlining administrative procedures would also increase predictability and transparency of government implementation of clean energy policies and incentives.

Insights from a Case Study

Domestic financing for clean energy projects could also be strengthened. The 2000 Law on Hydrocarbons (Law 112-00) set up a fund to leverage the private capital necessary for renewable energy investment, including through feed-in tariff payments and a subsidy covering up to 75 percent of capital costs for small-scale renewable projects. The fund has not yet been implemented, however. The Dominican government could consider diversifying the source of revenues for its domestic fund, including from international donors.

Mark Konold

Solar PV installation on the roof of Dominican Republic Trace Solar Company in Santo Domingo.

Access to financing suitable for renewable energy projects remains a problem in the Dominican Republic. The World Bank is currently working with Banco Hipotecario Dominicano (BHD), a private bank, to develop a new credit line of low-interest medium-term loans for renewable energy projects. BHD will also ease the investment process by providing technical expertise and business assistance to clean energy developers throughout the project preparation process. This experience could be expanded and duplicated for new joint initiatives between international finance corporations and domestic commercial banks to increase the availability of viable loan packages for renewable energy developers. To harvest the country's full renewable energy potential, the government will need to accompany this implementation with effective additional international support.

Outlook for the Dominican Republic

The Dominican Republic has made significant progress in promoting renewable energy by establishing a strong long-term vision for and commitment to clean energy development and by putting in place policies to spur investment. These efforts have been successful in both increasing the number of renewable energy projects currently under way and securing concessions for future planned projects.

Stakeholders in the Dominican Republic widely acknowledge the need for additional reforms to ensure that the country's clean energy aspirations and plans become reality. Our work has produced compelling technical and scientific evidence of the country's enormous renewable energy potential. Further and intensified collaboration will be central to finding best-practice solutions and strategies for low-emissions energy development moving forward.

Roadmaps for the Future

The wind and solar roadmap for the Dominican Republic is the first pilot project in a series of more complete and comprehensive Sustainable Energy Roadmaps that the Worldwatch Institute is producing to equip policymakers and stakeholders with an integrated picture of the challenges and opportunities for clean energy development in their respective countries and regions. The valuable insights from this preliminary roadmap demonstrate the promise and potential of this integrated, and widely scalable, approach.

While working on this report, we have started to implement the full energy roadmap approach in Haiti and Jamaica, in addition to the Dominican Republic, and at the regional level encompassing the seven countries of the Central American Integration System (SICA). Worldwatch hopes to soon extend our work to Africa, China, India, and beyond.

Developing and implementing Sustainable Energy Roadmaps around the world has the potential to build global expertise and capacity for advancing clean energy development and build the basis for the necessary transition to low-emissions economies, arguably one of the greatest transformational challenges humankind has ever faced. Widespread adoption of integrated resource, socioeconomic, and policy roadmaps can demonstrate the many benefits of sustainable energy systems, including cleaner air, reduced climate change risk, job opportunities, and more stable economies.

Yet roadmaps alone are not enough to bring about a rapid shift to sustainable energy and end our reliance on fossil fuels. This transition will require strong political will at all levels as well as widespread public participation to ensure that the energy systems of the future meet the energy needs of all, including the world's poorest and most vulnerable populations. Ideally, Worldwatch's Sustainable Energy Roadmaps will help lay the groundwork for commitments and actions under a binding global climate agreement to reduce net greenhouse gas emissions to zero. The ultimate goal of such work is to bring about a future in which roadmaps are no longer necessary—a world that is already well along the path to sustainable energy for all.

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WORLDWATCH REPORT 187

Sustainable Energy Roadmaps:

Guiding the Global Shift to Domestic Renewables

Worldwide, over 1.3 billion people lack access to electricity and another 1 billion have unreliable access, with enormous consequences for their everyday lives. In addition, many countries spend a high share of their GDP on fossil fuel imports, making them dependent on foreign energy supplies and vulnerable to price fluctuations. The burning of fossil fuels pollutes local environments, endangers the health of citizens, and exacerbates global climate change.

Fortunately, alternatives to our currently unsustainable energy system exist. Although progress has been slow on reaching a global agreement to address human-caused climate change, recent years have seen vast improvements in energy efficiency as well as unprecedented growth in renewable energy. Communities around the world are demonstrating the possibility of moving toward energy systems that are environmentally, socially, and economically sustainable.

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