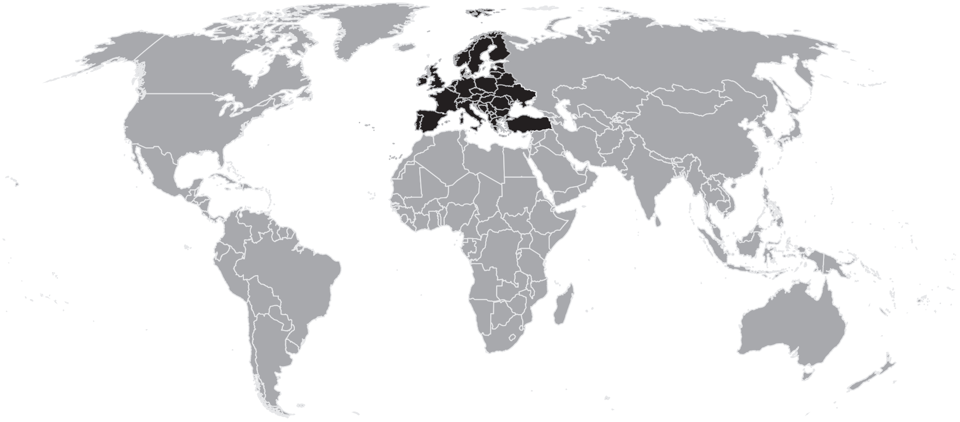

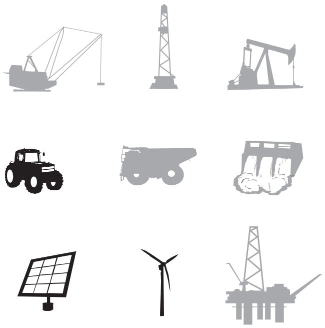

CHAPTER 2

Challenges of a Green Future

Gert Jan Kramer

In the book *Nature's Economy*, the intellectual historian and writer Donald Worster describes how humans' view of nature has been bookended by two different intellectual traditions through the centuries: Arcadianism and imperialism.[1] The idea of Arcadia is inspired by humans' desire to live in harmony with nature, while imperialism represents the equally human urge to dominate it. Most of us are torn between the two, dreaming about and striving for harmony with nature, yet in our actions we are utter imperialists.

In this chapter we explore the challenge of building a sustainable energy system. As we work toward a sustainable and mostly renewable energy system, we're perhaps guided by those Arcadian values, but the reality of such a system is steeped in the imperialism that has reshaped the Earth over the past millennia. A green future won't necessarily be one in perfect harmony with nature. Industrialization of the landscape is perhaps inevitable in the fight against a greater evil: a landscape completely changed for the worse by climate change.

Building a mostly renewable energy system demands concrete planning (and actual concrete!). Much of the talk about the energy transition overlooks the land requirements needed to build the solar panels and wind turbines and to grow the biofuels that will produce gigawatts and reduce CO_2. In this chapter we provide first-order estimates of the acreage that will be covered by solar panels, dotted with wind turbines, and

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inundated for hydro reservoirs, and the vast land claim associated with the sustainable production of bioenergy.

Plans on the Map

Land-use estimates for energy must start with projections of future energy use. For this we use the Shell New Lens Scenarios,[2] along with more recent work by Shell that explores the makeup of an energy system with (net) zero greenhouse gas emissions.[3]

Once we have an estimate of the future energy requirements, we can "put the plan on the map," to use a phrase coined by David MacKay, who did this for the United Kingdom.[4] All that is required are estimates of how much the various renewable energy sources produce each year per square kilometer. Such estimates are necessarily indicative, as the numbers will vary from place to place (as for instance the difference in photovoltaic yield between sunny and not-so-sunny locations) and between different authors. We base ourselves here on work by Vaclav Smil, augmented by our own earlier estimates.[5]

With these inputs, a first estimate of the impact of the energy transition can be done and—for Europe—is shown in figure 2-1.

In addition to a physical footprint, a renewable energy system will require greater integration across political boundaries given the variation in resource potential and seasonal variability of renewables. The European Climate Foundation's Roadmap 2050 illustrates this well.[6] The report shows that the key requirements for an efficient and effective renewables-dominated European energy system are a regional differentiation of renewable energy production according to the local resource (in particular, wind in the north and solar in the south) and a strong physical integration of the energy grid across Europe to deal with the momentary and seasonal variability of renewables.

For the United States, a more near-term look at land-use impact of new energy deployment shows that nations have a choice as to how they develop their energy system.[7] In the paper "Energy Sprawl or Energy Efficiency," the authors point out that in the absence of a strong focus on

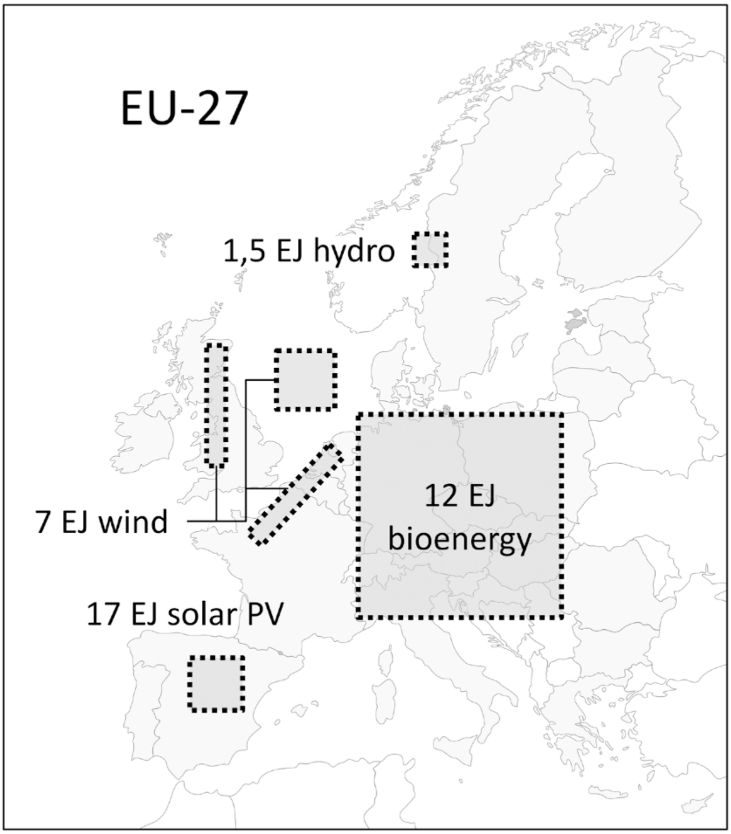

Figure 2-1. *The land-use implications of deep decarbonization scenarios. This one is based on Shell's Oceans scenario, circa 2100. The total energy use is circa 66 EJ/year, of which two thirds comes from renewables (from* New Lens Scenarios*). The energy production density estimates are based on* Energy in Nature and Society: General Energetics of Complex Systems.

energy efficiency, energy policy targets in the United States would—already by 2030—impact 200,000 square kilometers of land in the lower forty-eight states.

As the energy transition unfolds over the course of this century, the landscape will also undergo a transition. Humans will likely resist this transformation of the landscapes that we know, love, and cherish. But we need to accept some changes in order to stave off the far more threatening and devastating modification of the landscape (and of nature itself) that would result from climate change if we do *not* overhaul the energy system.

This presents society with a dilemma. We are emotionally attached to the landscape we have, but we are equally attached to our consumption patterns. These consumption patterns are underwritten by copious amounts of fossil fuels, whose land footprint is small relative to renewables. People might be surprised to hear this, but the average shale oil well has an energy production more than ten times what a modern wind turbine can produce. The global fossil fuel infrastructure would fit within the land area of Qatar, while the footprint of a future renewable energy system will have a continent-size footprint (fig. 2-2).

Society has hardly begun to come to grips with this aspect of the energy transition. For example, the World Wildlife Fund highlights major lifestyle and behavioral changes needed to reach a renewable energy future.[8] They call out two lifestyle changes critical to achieving this goal: the reduction of both meat consumption and air travel. Neither looks like an easy sell to an ever more affluent world community.

Biofuels and bioenergy stand out as the most prominent land-use challenge for a sustainable energy system. But photovoltaics and wind are not without their challenges—as anyone who has seen the acrimonious fights over wind turbines in their municipality can attest. One way to delve into this complex dilemma is through energy scenarios. Scenarios can demonstrate for us different pathways toward a low-carbon energy system.

Energy Scenarios

One approach to assessing the future prospects of different energy technologies and how they might reshape the energy system is to ask whether the energy system will be rebuilt top-down or bottom-up. Are governments pulling the strings, driven by supranational climate agreements and national energy agendas? Or are consumers and producers of energy ultimately in charge, through their purchase and investment decisions?

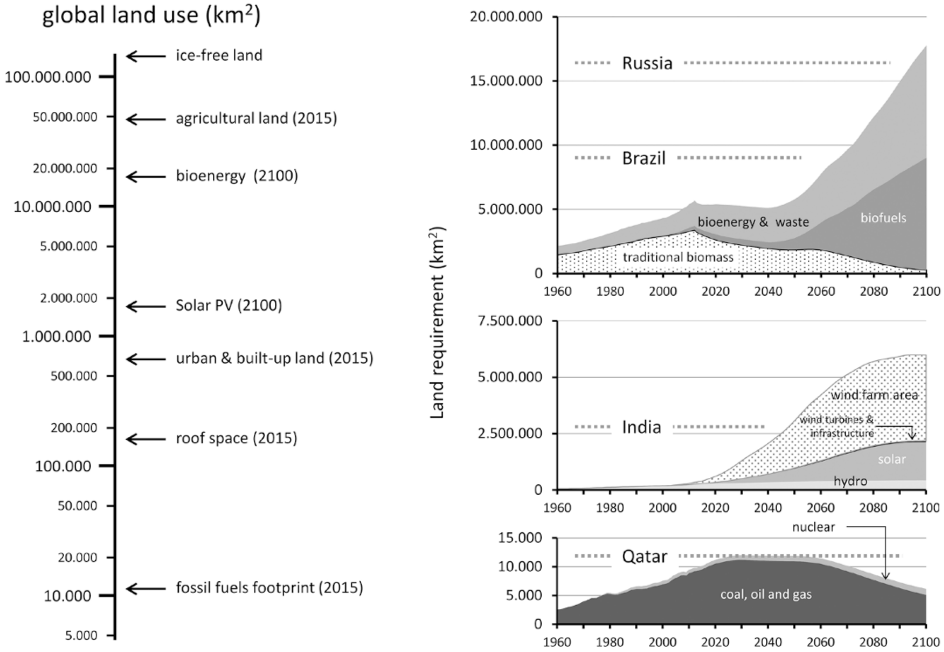

Figure 2-2. *The right-hand side shows forward projections of land used for energy production purposes, based on Shell's Oceans scenario found in* New Lens Scenarios. *Notice that from bottom to top, the scales increases approximately tenfold between the charts; the horizontal dotted lines indicate the land area of the corresponding nations. The left-hand logarithmic scale puts the numbers in further perspective. As in Figure 1, the underlying estimates in this chart are based on* Energy in Nature and Society: General Energetics of Complex Systems.

In the latest set of Shell energy scenarios, the top-down narrative is called Mountains, and the bottom-up story is named Oceans.[9] In Mountains, governments and powerful stakeholders, aware of the need to act decisively on climate change, try to change the energy system to optimize costs across the full energy system. Ideally this means investments phased in time so as to minimize early write-off of existing infrastructure and with the pace of new technology deployment set by their commerciality. As always, reality falls short of the aspirations, but in the Mountains scenario, carbon price is put in place early, allowing private enterprise to build out new energies while avoiding as much as possible disruption of the existing system.

The energy choices that fit this model are

- A rapid switch from coal to gas
- The concurrent deployment of carbon capture and storage and nuclear alongside renewables
- The development of hydrogen as a carbon-neutral energy carrier

These are set against the backdrop of a world in which cities follow a compact development model and moderate the energy service demand to keep the energy requirement relatively low.[10]

The Oceans scenario, by contrast, paints a world in which the initiatives of individuals and companies, encouraged by patchwork of (local) government initiatives, are the main drivers of change. Each does what it can, often without a clear combined plan at the (inter) national level. This is a world in which global agreements are elusive or ineffective, but the local actors are driven by a care for the environment, concern about climate change, and a desire for energy independence in a fragmented world. The outcome is not necessarily efficient, but it does deliver a strong growth of renewables.

Photovoltaics are the most obvious winner, as solar is appealing and accessible to everyone, everywhere. Another winner is onshore wind. As wind systems grow, their intermittent power output will increasingly burden the power system, but this is managed by ad hoc storage and demand-management measures. Biofuels are a winner, too, albeit with marked regional variation: for some countries, especially those with low to medium population densities, biofuels are a renewable, local, and secure fuel. Rapid renewables deployment is the positive side of bottom-up. The downside is a failure to lower the carbon footprint of fossil fuels, which remain a significant part of the mix for decades to come.

Neither the switch from coal to gas, nor the development of carbon capture and storage are priorities in the Oceans scenario. They are seen as too expensive (coal-to-gas) or pointless and unaffordable (carbon capture and storage) in the absence of a transnational climate and carbon pricing agreement. As the story unfolds through time, the world eventually turns to them—out of necessity.

Maxing Out the Energy Mix

More recent work of Shell's scenario group shows how difficult it is to replace hydrocarbons across the full spectrum of energy services. Electrification of personal transport and of the home is possible and might eventually be nearly universal. But heavy industry, long-distance freight transport, and aviation will continue to rely on hydrocarbons for lack of practical alternatives. Without a massive and global change in lifestyle and energy service demands, hydrocarbons could easily be a third or more of the world's primary energy—350 out of 1,000 exajoules (EJ).[11]

This analysis predicts that at most approximately 200 EJ of primary biomass energy will be available for energy purposes—not quite half of what is likely to be required.[12] This leaves the world with no other choice than to develop carbon capture and storage technology—unless we can make up for the shortfall of bio-based hydrocarbons by making them artificially. This inspires the dream of artificial photosynthesis,[13] which is unfortunately not yet developed enough to see it as a get-out-of-jail-free card.

Both the work on net-zero emissions and the long-term developments in Mountains and Oceans show a diverse energy mix toward the end of the century. In order to deliver 1,000 EJ of primary energy for the full range of energy services at net-zero emissions, all available energy resources must be deployed to their maximum acceptable potential. These limits include for solar and wind, as much as can be accommodated in the system; for hydropower and geothermal energy, as much as is available; for bioenergy, as much as sustainable land use and the requirements for food, feed, and fiber allow; for nuclear, as much as the national governments choose to champion it; and finally, for fossil fuels, where they are irreplaceable, and with carbon capture and storage to mitigate and net out emissions to zero.

Land Claims and Governance

The estimated consequences for land use are mindboggling. In Shell's analysis, about half of the 1,000 EJ primary energy can come from nonbiomass renewables, with solar, wind, and hydro as the major sources. The land requirements and the development over time, according to the Oceans scenario, are shown in figure 2-2. The analysis also predicts about half the 1,000 EJ of primary energy can come from nonbiomass renewables, and biomass is used to its 200 EJ maximum. This leaves about a third to be supplied from nuclear (about 8 percent, or 80 EJ, well over two times today's nuclear energy production) and approximately a quarter from fossil energy—25 percent, or 250 EJ, just about half of what the world uses today (in an energy system that by 2100 will be twice as large as today's).

Scenarios paint different pictures of the future, and so it's no surprise that plots of emissions and energy land-use requirements show different trajectories over time (fig. 2-3).

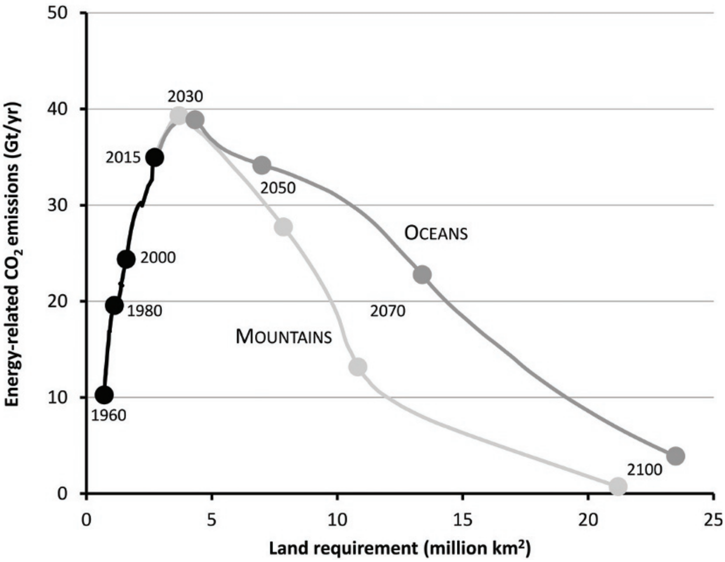

__Figure 2-3.__ Energy-related CO_2 emissions and land requirement for energy as they have developed over time, and as they might develop into the future, according to the Shell scenarios Mountains and Oceans.

The divergence in the midterm creates a conundrum for the management of energy and land, especially for the Oceans scenario: the weak global governance in this scenario must somehow be paired with strong—or at least effective—land-use management, lest the development of renewables runs afoul. Poorly planned large-scale photovoltaic and wind projects will be met with resistance, and large-scale bioenergy production may even be counterproductive when land-use change and agricultural practices are poorly managed.

A Simple Conclusion

We made a first, simple estimate of how low-carbon energy scenarios plot out on the map (figs. 2-2 and 2-3). The main point is simply this: it's a lot of land! The fact that it is a lot clearly underscores the need for planning that will guide site selection and will mitigate impacts of energy development that is the focus of part II of this book.

Acknowledgments

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