بسم الله الرحمن الرحیم

In The Name of God

Economics of Renewable Energy

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Preface

The book, The Economics of Renewable Energy, is divided into five chapters that were produced by economists and energy experts.

The first chapter discusses the introduction and the importance of paying attention to the economics of renewable energy, while the second chapter discusses the economics of offshore wind power. The second chapter discusses critical problems such as the worldwide installed capacity of offshore wind power, the most recent offshore wind power technology, and a full economic analysis of offshore wind power. Hydrogen fuel and CHP systems are addressed in the third chapter. The fourth chapter explicitly examines the solar economy, and the last chapter, which is the most significant chapter of this book, deals with the subject of energy sustainability. It also emphasizes the need to transition from fossil fuels to renewables. This chapter assesses the environmental effects of various forms of energy.

I'd like to thank the lecturers at Sharif University of Technology and Tehran University for their assistance in creating this book, as well as everyone else who assisted us.

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Chapter 1

Introduction

Introduction

There will be a significant and global energy change during the next several decades. By the end of the century, civilization will rely mostly on renewable energy sources including solar, wind, biomass, and geo thermal power, as opposed to the current situation where fossil fuels provide the vast bulk of its energy.

This momentous change will be driven by two powerful factors.

The first is the need to stop global warming before it becomes disastrous. 196 countries unanimously agreed in December 2015 to keep global warming to two degrees Celsius above preindustrial levels. 1 Despite the fact that some of this reduction could theoretically be accomplished through carbon capture and storage from coal power plants, carbon sequestration in soils and forests, and other "negative emissions" technologies and efforts, the vast majority of it will require drastic reductions in fossil fuel consumption.

The world's supplies of oil, coal, and natural gas are continuously being depleted, which is the second factor causing a post carbon energy transition. Our existing energy system is unsustainable even if we do nothing to stop climate change.

The fossil fuel business has traditionally focused on the highest quality, most accessible resources first, despite the fact that the Earth's crust still contains massive amounts of fossil fuels. Economically usable sections of this resource base are substantially smaller.

Although diminishing resource quality is a challenge for all fossil fuel producers, it is particularly noticeable in the petroleum industry. The world's inexpensive, conventional oil reserves—the "low hanging fruit"—have been declining recently, which has caused the cost of production in the oil sector to increase by more than 10% annually. New extraction techniques open up lower quality resources (such tar sands and tight oil from fracking), but they also need more expenditure and also come with increased environmental concerns. Despite the fact that global supplies of coal and gas have not yet reached the same price tipping point, a number of recent analyses indicate that the end of these fuels' accessible sources may only be a matter of years rather than decades. No question, we will continue to use fossil fuels for many years to come, but their demise is inescapable. Whether or not we are prepared, we are moving toward a post fossil world.

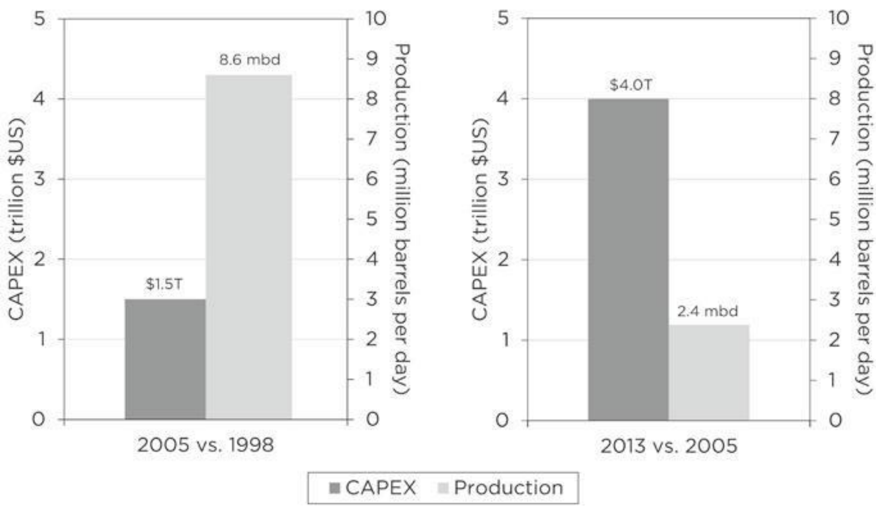

Figure 1. Change in world oil industry capital expenditures (CAPEX) and crude oil pro duction, 2005 vs. 1998 and 2013 vs. 2005.

With the exception of China and a few other countries, nuclear fission power is unlikely to have a greater impact on our energy future than it does right now if present trends continue. Indeed, by the end of the century, the nuclear industry may have significantly shrunk overall as a result of high investment and safety requirements (following Fukushima), increasing difficulties with waste storage and disposal, and the dangers of catastrophic accidents and the proliferation of weapons. Despite recent news stories regarding hot fusion power advancements and "cold fusion" claims, these energy sources don't now generate any commercial energy and aren't anticipated to do so on a large scale for decades to come, even if claims are shown to be true.

In one way or another, fossil fuels will run out, and nuclear power is a lost cause. The onus of sustaining a future civilization rests on renewable energy sources including solar, wind, hydro, geothermal, and biomass. Saying that humans would live in a world powered entirely by renewable resources in the not too distant future is certainly oversimplifying things, but it is still important to consider what a total, or almost complete, transition in our energy systems would truly entail. Energy is essentially the source of our existence since it is inherent in everything we do as well as in the constructed world that surrounds us (which needs energy for its development, maintenance, disposal, and decommissioning). The ultimate effects of the world's transition of its energy sources may include a significant adjustment of people's individual and societal habits and expectations, as well as a transformation of the buildings and infrastructure around us. When we switched from using wood and muscle power to using fossil fuels, our lives, communities, and economies underwent significant change. It follows that when we switch from fossil fuels to renewable energy sources, the quantity and quality of energy available to power human civilization will fundamentally change, as well as the way we live.

How would a planet that was entirely regenerated feel and look like? How might today's college students' great grandchildren go about their daily lives without directly or indirectly using fossil fuels? Where will they get their food? How will they travel between locations? What will the structures people live in look like, and how will they work? Future predictions are often inaccurate, even in broad strokes, yet they can include beneficial errors. Even if we are unsure of which reality will materialize, scenario exercises may help us assess and prepare for a number of scenarios. Furthermore, by picturing the future, we often contribute to its creation. Advertisers and businessmen have long understood the power of imaginative product designers, marketers, and commercial artists to influence the decisions, behaviors, and expectations of whole civilizations. Even though the process will undoubtedly include guesswork and oversimplification, we should make an attempt to envision an entirely renewable future today if we are starting what might wind up being history's most momentous energy shift.

Investigating how and why we came to create our present "normal" reality of energy use may be a good place to start when trying to visualize the post carbon future.

Why Life Will Be Different in a Renewable World?

Electricity is produced by solar, wind, hydro, and geothermal generators, and we already have a wide range of technologies that depend on it. Why therefore should we alter the way we utilize energy? All that is presumably required is to turn off coal power facilities, turn on solar and wind electricity, and go on living as we do now.

For six crucial reasons, this conception of the energy transition is false.

1. Intermittency. The on demand manner in which we now consume power, as we shall see in chapter 3, is not compatible with variable renewable energy sources like solar and wind. Our present electricity generation, transmission, and consumption systems were built by power engineers around controlled inputs (hydro, coal, natural gas, and nuclear), but solar and wind energy are essentially uncontrollable since we cannot make the sun shine or the wind blow the way we want. By storing part of the power produced for later use, adding more capacity, or restructuring

electrical systems, it would be feasible to some extent to make intermittent solar or wind energy behave like fossil fuels. However, doing this costs money and energy. It will be necessary to continually find new ways to shift electricity demand from times of convenience to times of abundant supply and to significantly reduce overall demand in order to avoid enormous overall system costs for capacity redundancy, energy storage, and numerous long distance grid interconnections.

2. The issue with liquid fuels. As we'll see in chapter 4, electricity doesn't now provide all of our energy needs and isn't likely to in the future when we're using renewable resources. Oil is still the main source of energy for almost all of our transportation and industrial activities. While there are renewable alternatives to some oil products (such as biofuels), these are typically not direct replacements and have a number of other significant drawbacks and limitations. For example, few cars, trucks, ships, or airplanes can burn pure biofuel without expensive engine retrofitting. 4 Our transportation infrastructure can only be readily electrified in some areas, which is another alternative. Therefore, a future powered by renewable energy is probably going to be less mobile, which has huge economic ramifications.
3. Other applications for fossil fuels. Currently, society utilizes energy from fossil fuels for a variety of other critical functions, such as creating high temperatures for the creation of cement, rubber, ceramics, glass, steel, and other metals, as well as other manufactured items. Additionally, fossil fuels are used as raw materials (e.g., plastics, chemicals, and pharmaceuticals). As we shall see in chapter 5, each of them raises questions about replacement or adaptation.
4. The density of energy gathering activities in the area. As we migrate to a more sustainable energy future, we will shift away from sources with modest regional footprints (like a natural gas well) and toward sources with much greater footprints (large wind and solar farms collecting diffuse or ambient sources of energy). As we proceed, the expanding geographical breadth of energy

gathering operations will have inescapable costs, inefficiencies, and environmental effects. Even though the environmental effects of a wind farm are significantly less than those of mining, transporting, and burning coal or drilling for, distributing, and burning natural gas, capturing renewable energy at the scale necessary to completely replace gas and coal energy would still have significant environmental effects. Planning and adaption will be required to reduce these expenses.

5. Location. There are certain regions where solar, wind, hydropower, and biomass are more accessible than others. Transmission across long distances results in substantial energy and financial losses. Additionally, the total energy profitability of using biomass energy resources (such biofuels or wood) is decreased during transportation. Since the same amount of "feedstock" cannot be concentrated in one location, it follows that, as the energy transition quickens, energy production will move away from large, centralized processing and distribution centers (like a 500,000 barrel per day refinery) and toward distributed, smaller scale facilities (like a local or regional biofuel factory within a defined collection zone or "shed"). It also suggests that population centers could have a propensity to redesign their geographic layouts to revolve around their access to energy sources.
6. The amount of energy that is accessible will also alter throughout the changeover. The yearly global energy consumption has increased exponentially to about 500 exajoules since the middle of the eighteenth century. Renewable energy sources are likely to fall short of replacing all of the energy now produced by fossil fuels, much alone being able to keep up with anticipated demand increases, even if enormous expansions of solar and wind power are made over the course of the next 35 years. The amount of energy that will be accessible and prevailing expectations and assumptions about global economic development are both seriously questioned by this.

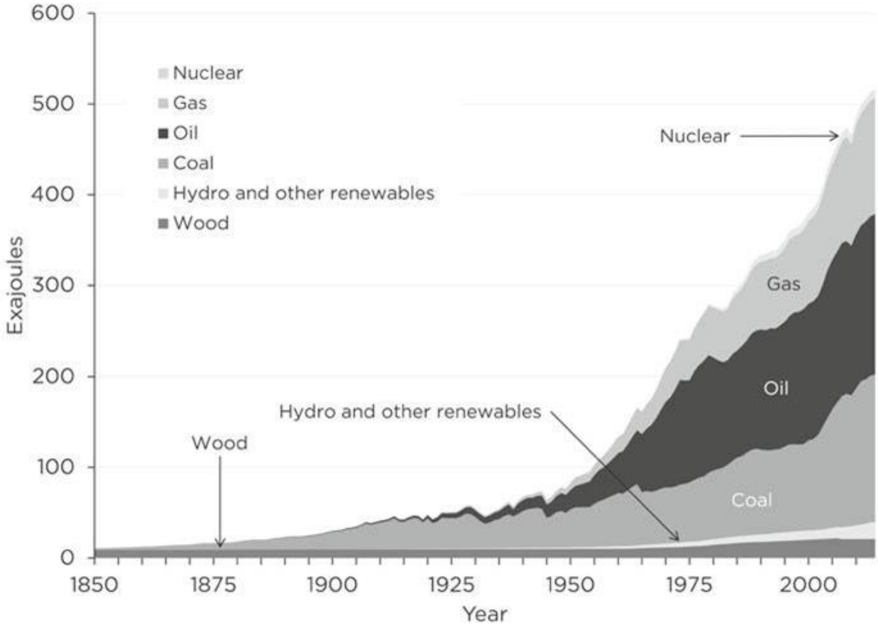

Figure 2. World primary energy consumption by fuel type, 1850–2014

We should investigate today how energy demand will change over the next decades as the globe switches to renewable energy, whether voluntarily or not, in light of these six reasons. As we've previously seen, the types and amounts of energy that were available to us during the last century influenced how we now utilize energy. Fossil fuels have several benefits, including being readily accessible, affordable, transportable, and energy dense. They also have drawbacks, including as repercussions on the environment and society, such as climate change. 5 The most evident benefit of renewable energy sources like sun and wind is that there is no fuel expense and that they have little negative effects on the environment and human health. The instruments used to harvest energy from sunshine and wind, however, need materials and embodied energy, thus this does not imply that they are genuinely free or limitless energy sources. Furthermore, the energy we get from these sources varies and cannot completely replace the existing consumption of fossil fuels. Additionally, the technologies we use to capture wind and sunshine for electricity have an influence on the environment.

Engineers will undoubtedly use every possible means to adapt new energy sources to current use patterns (e.g., by replacing gasoline fueled cars with electric cars). By mitigating their fluctuation with energy storage technologies and grid improvements, we can, to a certain degree, force solar and wind energy into the shape of our current energy system. However, the greater the share of our overall energy that comes from these sources, the more money and energy our buffering efforts will need. As we get more used to using renewable energy sources, consumption patterns will very definitely shift significantly over time.

The issue with our existing energy consumption habits is not only that they are inefficient (though they often are) or that we use it for bad activities (though we often do). Even putting aside those valid worries, many of the existing energy use patterns most likely won't function in a world where everything is renewable.

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Chapter 2

Economics of offshore wind power

Introduction

Although fossil fuels like coal, oil, and natural gas dominate the world's power production, the energy sector is undergoing a fast shift globally. The percentage of renewable energy in the generating mix is rising quickly, and this trend is anticipated to continue into the future. Around $7.4 trillion, or 75% of new expenditures in power production globally between now and 2040, will be spent on wind and solar technologies, claims Bloomberg New Energy Finance (2017). The offshore wind sector now has a fantastic chance to absorb some of this money and maintain its place in the global power mix.

The offshore wind business is now spreading over the whole planet. This is categorically no longer true; it was formerly thought to be an entirely European company. The European supply chain has been expanding into emerging markets and contributing their knowledge in all technological and political aspects, including the very real consideration of all parties involved in our planet's ocean resources. When ranked according to nameplate capacity, China presently has the third largest offshore wind fleet. The first commercial scale wind farms have just begun generating electricity in the United States and Korea. Australia, whose energy sector has traditionally been dominated by coal, is now beginning to investigate offshore wind as well.

A broader distribution of development would have various benefits for the sector, despite the fact that the European offshore wind market is the largest in the world and that worldwide trends are heavily influenced by European experience. For instance, the future Asian supply chain may act as a counterbalance to European providers and heighten industry competitiveness. Furthermore, since site circumstances in many Asian markets vary from those in Europe, it may provide considerable new experiences, knowledge, and chances for the development of new technologies in connection to foundation and turbine design.

The offshore wind business may gain from its shared operations with the established offshore oil and gas sector in addition to its worldwide development. For instance, this covers the installation and use of assets in the hazardous sea environment. Major oil and gas corporations have started getting into this market recently in an effort to take use of their resources, experience, and technological know how in the field of offshore operation. The amount of advantages for offshore wind, however, from the common elements of these two supply chains depends on a variety of variables. The level of activity in the offshore oil and gas industry, which is closely tied to the price of oil globally, is foremost among these.

Installed Global Capacity by Market

As of year end 2016, there was some 14,384 MW of offshore wind capac ity installed globally (GWEC 2017). European markets currently account for nearly 88% of globally installed offshore wind capacity, or 12,631 MW. By the end of 2016, there were 3589 offshore wind turbines installed and grid connected across 81 wind farms in European waters spread across ten countries (WindEurope 2017).

It is estimated that offshore wind generation capacity in Europe will effectively double to 24,600 MW by 2020 as projects currently under construction and in planning become grid connected (WindEurope 2017). The United Kingdom is the predominant market leader in offshore wind, with approximately 5100 MW of grid connected capacity and a tar get of reaching some 10,000 MW by 2020. Germany has been narrowing this gap significantly over 2015 and 2016 and now has over 4000 MW of installed capacity. China and Denmark follow in terms of capacity, each boasting over 1 GW of installed capacity. Denmark, Germany, and the United Kingdom together represent over 80% of Europe's total installed capacity.

However, a catalogue of obstacles (such as fluctuating incentive and support models in key markets such as the United Kingdom and Germany and delayed grid expansion or connection plans) has hindered the prog ress of offshore wind developments at different points over the past half decade. An uneven rollout of policies or bottlenecks in grid connectivity has led major markets such as the United Kingdom and Germany to falter for some