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DRIVERS AND BARRIERS FOR RENEWABLE POWER

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RENEWABLE POWER MAY PROVIDE FOR GLOBAL LONG TERM PROSPERITY

The use of non-renewable energy will result in resource scarcity, and is often causing immediate environmental deterioration or consequences reducing the economic prospects for coming generations. Renewable energy may provide for wealth for all people in the world and for generations to come. Making this opportunity into reality, by skillful engineering and industrial development of the necessary technologies, is a driving force for many people in the world and the motive for writing this book.

Electricity from renewable sources of energy is the topic here. Renewable in this context implies that it is possible to utilise a source without reducing the future potential of that resource. Some renewable resources are at the same time exhaustible. Unsustainable harvesting of forest biomass may result in permanent deforestation or even desertification destroying the resource, while proper sustainable forest management may result in a continued or even increased renewable resource for future generations.

This book is mainly about non-exhaustible energy resources, such as solar energy, wind energy, hydro power, waves or tidal energy[1]. The future availability of such energy sources are not affected by the utilisation today. Still, in a very long perspective the rotation of the earth and the moon will have the same period and there will be no tides to harvest, and the sun is predicted to change and make the world uninhabitable in a few billion years. But we have no way of influencing these processes, and they are distant in relation to the future opportunities of mankind.

1 For issues related to bioenergy see *Systems Perspectives on Biorefineries*. (2014) 3rd edition. Chalmers Univeristy of Technology, Göteborg, Sweden.

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In thermodynamics the first law states that energy is conserved, whatever happens, the total sum of energies afterwards is exactly the same as the total amount before. What is important from a scientific point of view however is that different forms of energy are more or less useful. The second law of thermodynamics says that in all processes the entropy increases, which is the same as that the part of the energy that can be transformed into any other form of energy, the exergy, is lost. This irreversible character of energy transformations is vital to the understanding of energy systems in nature or society.

Our planet enjoys an inflow of energy in the form of solar radiation with little entropy.[2] By many different energy transformations this radiation is converted into heat with increasing entropy until it is finally radiated into space at other wave lengths as energy useless to us. However, the solar radiation drives winds, the hydrological cycles and provides the exergy necessary to form molecules in plants that is the main source of useful energy to the living ecosystems on earth (Chapter 3).

Electricity is a form of energy that can be fully converted into any other form of energy, it has no entropy and is therefore 100% exergy. Producing electricity from other forms of energy is done in different ways with different efficiencies. In a hydro power plant, turbines and generators typically convert more than 90% of the potential energy of the water into electricity. In a thermal power station where fuels are used to boil water 25-50% of the energy released in the boiler may end up as electricity, while a solar PV panel may typically transform 10-20% of the solar energy hitting the panel into electric energy (Chapter 3-4).

If we have a fixed amount of oil, high energy efficiency is important, as it decides the total benefit we can get from the oil consumed. However, putting a PV-panel on a roof where 100% of the solar radiation was otherwise directly converted into useless heat, the energy efficiency is less important. Instead, cost efficiencies in terms of other costs to achieve the electricity generated are of interest.

The fact that electricity is produced from a renewed source of energy is not sufficient for the societal energy supply to be sustainable. There may be relevant material constraints on the conversion technologies that may result in unsustainable use of renewable energy sources.

Elements, such as various metals are only produced or consumed in nuclear reactors. That renewable energy technologies rely on use of metals is not a sustainability problem as long as the metals are managed in such ways that they are recyclable. The limitation to what is possible to recycle is partially a matter of the exergy necessary to re-concentrate the metal. Ample availability of electricity with, at least temporary, low marginal cost could make more re-cycling economically achievable.

However, processes to produce the equipment must be managed so as to avoid unsustainable pollution practices in order to prove sustainable (see Chapter 6 on environmental issues in general and Chapter 7 on life-cycle energy and greenhouse gas balances in particular).

2 Karlsson, S. (1990) *Energy, Entropy and Exergy in the Atmosphere*. Doctoral Thesis, Chalmers University of Technology. See also Chapter 3.

MARKETS FOR ELECTRICITY

During most of the twentieth century, electricity systems were operated as large, vertically integrated monopolies. They were vertically integrated as the same company controlled the electricity grid and sold electricity to the consumers. Most often, they also controlled the electricity production facilities in order to be able to command production that matched demand in order to keep voltage and frequency stable.

The grid was monopolised, as it was difficult and uneconomical to run parallel power grids. The power generation was monopolised to manage balance by commanding production facilities, but also as the thermal power plants that dominated the global electricity generation during the last century presented significant economies of scales, making competition difficult to achieve. Economies of scale refers to the situation where the competitiveness of a production facility increases the larges the facility is.

During the last decades this has changed. Significant cost reductions among technologies to utilise wind and solar energy have provided competitive alternatives without the economy of scale of thermal plants thus making competitive electricity markets feasible. Information technologies for metering and data management have made possible the control of how suppliers and customers live up to the required balance of supply and consumption to keep the power grid stable. Finally, the re-regulation of electricity markets, with the purpose of separating the grid as a regulated monopoly while establishing a competitive electricity market for producers and consumers of electric power, has enabled this development (see also Chapter 13).

In the most open of such markets any electricity consumer is free to choose who to buy electricity from, at what prices and under what other conditions. There is only one compulsory condition on such contracts and that is that someone has to take on the balancing responsibility. This responsibility is often assumed by the supplier. The supplier will then try to match the consumption of the customer at any moment in time. A Transmission System Operator, TSO, will check that the system is in balance and if some fail to balance in a contract the TSO will charge the failing party to pay for the balancing cost that occurred.

POWER AND ENERGY

Energy transformed or transported per unit time is called power. While energy is bought and stored as fuels, an electricity grid demands balance of production and consumption at each moment in time. If that balance of power is not kept, the voltage or frequency will change which in turn may result in other components failing and ultimately to a black-out. Much of what follows in this book is about the importance of power balance in an electricity grid and ways of achieving that balance (see Chapter 4 and 9-12).

PRODUCTION MEETING DEMAND

Last century, the production of most power plants was considered controllable. Consumption on the other hand was not something the monopoly power companies could control. As demand varied with time and weather the power company would adjust production to meet demand. Power plants were deployed in a merit order with the plants of lowest marginal cost of production first, typically coal fired power stations or nuclear reactors with low fuel costs, while power plants with higher fuels costs, those using oil or gas, would operate only when demand was at levels that could not be satisfied with cheaper sources (Chapter 11). Hydro power plants can serve different roles depending on availability of water in reservoirs and expected value of that water at later moments in time.

During the previous century one would spend a lot of money on investments in plants that had low fuel costs and expect them to operate almost every hour of the year to meet the base load in the system. The greatest threat to the stability of electricity grids was considered the sudden failure of the largest power plants or transmission link in the system. Often the largest nuclear reactors and largest coal fired station would dictate how much of reserve capacity was required to be on line to ensure the grid would not collapse if there was a sudden failure. The 1400 MW nuclear reactor currently under construction in Finland even requires a new power line to be built from Sweden as the Finnish grid otherwise would not be able to handle a sudden stop of the reactor.

BASE LOAD POWER PLANTS IS AN OBSOLETE TERM

As new power plants with zero, or close to zero, marginal cost of production have come into the electricity system, even the old kinds of "base load supply" are out-competed. When available, solar and wind will produce at lower cost. They will save costs as their production makes it possible to avoid using production facilities consuming fuels.

For the TSO, the failure of a nuclear reactors or coal fired power station is a major problem as such a failure is unpredictable, sudden, and a relatively large loss of supply. The technical failure of a wind power plant or a solar plant is a minor problem as the loss of supply is relatively small.

However, the solar and wind facilities are not controllable, they are 'intermittent'. When the wind blows they produce, when not – they do not. Even if they are not controllable, they are to some degree predictable.[3] They pose a challenge similar to the consumption. Thus, the challenge of balancing the electricity system may be seen as increasing. As we will show in the following chapters there are many competing opportunities evolving to meet this challenge.

PRICE GUIDING BOTH SUPPLY AND DEMAND

If we had still been in the old kind of non-market setting where demand was out of control and the power company had to manage all the balancing efforts this would result in higher costs of high marginal cost power generation. Most traditional

3 The degree to which renewable power are variable, predictable and possible to control differ between the different forms of renewable energy (see Chapter 3-5) Variability and predictability also depends on the spatial size of the system. Over a large area local variations will even out.

power companies have entered the competitive electricity market with a business model still offering customers to consume power at any time at a fixed price. Some of them are now realising that their contractual position with balancing responsibility for such contracts is threatening their economic survival.

As we will see in the remaining parts of this book there are many technical opportunities to achieve power balance where new kinds of price driven consumption patterns are essential (Chapter 10). While the electricity spot market pricing has until now mainly been seen as a public mechanism to achieve a rational order of deploying power plants, we will see more interaction of consumption relating to the cost of power in the years ahead of us.

COSTS OF NON-RENEWABLE ENERGY AND POLICY

Governments have had attention on energy policies for many centuries. Energy, or rather exergy, is an essential resource for society. What is now conventional energy supply, from limited deposits, once opened for economic development that earlier available energy technologies could not provide. Since some decades, the challenges to continue relying of these sources have accumulated.

ENERGY SECURITY OF SUPPLY

Of the fossil fuels, oil is concentrated in a few regions of the world. In most oil rich regions, the resource has become the economic basis for less democratic regimes and sometimes established by military interventions. The indirect costs to support continuous flow of oil to the import dependent countries have proved significant while still not ensuring security of supply.

Renewable energy is available everywhere. While some parts of the world have more sun, others have more wind resources and yet other parts of the world are rich in biomass. Specific locations may also be endowed by hydro and osmotic power, geothermal energy and various forms of ocean energy (Chapter 3).

ENERGY SCARCITY PRICES BLOCKING GROWTH

The limited resources of non-renewable fuels provide negative feedback on economic success, as prices tend to increase with increased consumption. For the government in China, aiming at providing a dramatically increased standard of living for another half a billion inhabitants, the prospects of that negative feedback calls for alternatives.

As we will describe in the following pages, energy supply cost of renewable electricity are not increasing with increased utilisation as large resources remaining to be utilised, and technology costs are decreasing with experience. There are limits beyond which this will not hold, but in particular for solar energy they are well beyond the possible utilisation in the coming decades.

ENVIRONMENTAL COSTS OF FUELS MAY OUTWEIGH ECONOMIC GROWTH

Another driving argument is the negative environmental feedback may take many forms. Local air pollution, climate change from greenhouse gas accumulation in the atmosphere or the costs and health effects of nuclear reactor core accidents have made the development of renewable energy technologies a major global activity (see also Chapter 14 on environmental costs).

Though security of supply, resource scarcity and environmental feedback may get different attention in different parts of the world, they contribute to the consistent support for the development of renewable energy technologies.

LEARNING ENERGY TECHNOLOGIES BY EXPERIENCE

As in many industries over the centuries, renewable energy technologies have become lower cost options the more experience that have accumulated. In 2000, OECD published evidence that the wind and solar industries would become competitive with conventional energy technologies.[4] When this would happen could not be predicted, as learning does not come with time but with experience. Experience requires investments before competitiveness is reached, something that may be achieved on niche markets. Niche markets may emerge due to specific performance characteristics (e.g. solar cells in space), develop out of demand from idealists and other early adopters, or be created through subsidy schemes set up by governments (see also Chapter 14-15 on learning and industrial development).

THE GLOBAL DEVELOPMENT RELAY

Regarding wind power, the modern industry started in Denmark in the 1980s. Initiated by idealists aiming to prove that wind power was technically feasible the industry later received government support and evolved into a commercial sector still making Denmark the home of a couple of the leading global suppliers of wind power plants. In the following decades, other countries took the lead. Irregular investments in the US were followed by more constant efforts in Germany and Spain and, in the last decade, in China.

Just as one could see from the early diagrams of learning the result is that wind power is now the cheapest source of new electric power in many parts of the world, with total cost of electricity reported as low as 3-4 eurocent (4-6 US cents) per kWh.[5]

A similar relay of industrial policy driven developments can be noted in the solar PV sector. Here, the first efforts were aimed at providing electricity for space crafts commissioned by the US. During the 1970s research and demonstration efforts resulted in early outdoor deployable panels that found niche-markets during the 1980s and 1990s. By the end of the 20th century the first government initiated roof-top programmes in Japan and Germany started to make the market grow.

Despite the high anticipated costs, Germany launched a system with guaranteed

4 IEA (2000) *Experience Curves for Energy Technology Policy*, Paris, France: OECD Publishing. See also Sandén, B. A. and Azar, C. (2005) Near-term technology policies for long-term climate targets - economy wide versus technology specific approaches, *Energy Policy*, 33(12):1557–1576.

5 U.S. DOE (2013) *2012 Wind Technologies Market Report*. Oak Ridge, TN , USA:U.S. Department of Energy

feed-in tariffs (FITs) paid to anyone who supplied electricity to the grid from solar PVs in 2000. The estimated costs were high, and the generous feed-in tariffs resulted in large scale investments and quickly dropping prices spurring further investments. Despite dramatic cuts in FITs over the year German households will continue to pay for installations done during this initial phase on PV industrialisation for many years to come (see Chapter 13-14 for further discussions on the politics of renewable energy in Germany).

The result, however, of the policy driven German development is that solar PV cost have come down for all potential customers around the world. This has opened opportunities for hundreds of millions of people without access to an electricity grid to get light, radio, TV and mobile phones powered by affordable PV electricity.

It has also resulted in the cost of solar PV electricity in a few countries with high insolation reaching "wholesale grid parity" or "busbar parity", implying PV investments being competitive with other sources of new power generation without subsidies, also in Europe. In even more countries "consumer grid parity" or "socket-parity" is reached, meaning it is cheaper to produce electricity than to buy from the grid.[6] Many expect this to be the early steps of an un-subsidised solar revolution that is no longer controlled by government policies and may have significant impact on all electricity markets and power companies in the world.

Thus the policies in just a few countries supporting renewable electricity have made the continued large scale deployment economically feasible without further subsidies or policy support. This is irreversibly altering the global energy market conditions.

RENEWABLE POWER AS DISRUPTIVE INNOVATION

In the book The innovators dilemma – how new technologies cause great firms to fail, Clayton Christensen describes the characteristics of disruptive innovations that broke down established industries.[7] He says the evolving technologies were systematically discredited, typically because they were too expensive, not up to conventional standards and, not least important, they did not fit the business models of the established companies. Solar and wind power fit this description well. Too expensive, intermittent, and decentralised thereby out of scope for the incumbents.

Still, the evolution and reduced cost, new investing actors and a re-regulated market have made the change possible. This is now threatening power companies. The book Explosive Growth by Michael and Susan Rogol published in December 2011 gave power companies 1000 days to modify their business models or perish.

POLITICAL POWER OF POWER COMPANIES

While some expect the continued development to run fast, there are reasons to expect further obstacles to the development. Many of these may come from the

6 Deutche Bank (2014) *Let the Second Gold Rush Begin*, Deutsche Bank Markets Research.

7 Clayton Christensen (1997) *When new technolgies cause great firms to fail,* Boston, MA., USA: Harvard Business School Press.

old power companies using their traditional powerful position in relation to national governments to slow or stop the processes that may deprive them of market shares, results and ultimately the value of their balance sheets (Chapter 13-14).

Governments may easily be convinced to remove support and introduce barriers towards new renewable supplies. Not only are some governments still owners of the incumbent power companies, these companies may, if going bankrupt, leave significant toxic assets in the hands of ill prepared governments – this may be coal mines or nuclear wastes where economic liabilities are uncovered or underestimated.

Mechanisms to block development of new renewable electricity may be demands from the incumbents to remove support mechanisms and subsidies, introduce new taxes or even retroactively change tariffs, examples are provided in Spain and a number of other European countries; allowing the power companies or related grid companies to veto new connections to the grid as is done in Japan; introducing subsidies for keeping old fossil-fueled stations on line to avoid that over-committed suppliers have to face costs of failed balancing that they are not able to handle, as European companies propose under the heading "capacity market" (see also Chapter 9 and 13-14).

INSTITUTIONAL INERTIA

While the electricity market reforms in the world have provided the opening of power markets for new actors there are still institutions and regulations that are not supporting or allowing the new technological opportunities. Such rules may block applications of new energy technologies, but may also result in individually rational and profitable, but from a systems perspective less efficient, solutions.

Examples may be electricity consumption taxation introduced for purposes of simulating carbon pricing on electricity generation, now being applied to households supplying solar electricity via the grid, or VAT-regulations that punish exchange of day-time peak power from family houses for low cost night time power.

Such rules will delay deployment. But such incentives may also result in households being tempted to invest further into batteries and disconnecting from the grid, though it would be economically more efficient to use the grid to balance supply and demand (see also Chapter 4 and 9).

Other examples of legislation of relevance may be regulation on land use that prohibits the application of solar energy installation to what could be agricultural land. Another is how the real estate and building and planning laws regulate the right of solar irradiation for estate owners who have invested in solar energy. There are also regulations related to electrical installations that may provide significant economic barriers for solar installations.

The ability of legislating bodies in the world to efficiently identify and adapt legislation, so as to remove barriers, is now more important than legislation on subsidies and support. Removing barriers reduces societal costs, while support and subsidies is redistributing costs that have not been avoided.

PROSPECTS OF EVOLUTION

The opportunities to avoid the severe constraints on global economic development posed by conventional energy sources by utilising renewable power instead, will provide strong driving forces for continued development.

This transformation will pose a magnificent challenge for incumbent industries in the sector, and attempts to block or slow down development will occur. Even without such deliberate attempts to block development there are real needs to develop auxiliary technologies and institutions to facilitate efficient deployment of new renewable energy in the electricity sector.

This e-book is about these challenges and opportunities. They are described and analysed, hopefully contributing to the reduction of barriers by providing knowledge of possible solutions.