Electricity Generation and the Environment

Paul Breeze

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CHAPTER 1

Introduction to Electricity and the Environment

The power generation industry is one of the world's largest and most extensive industrial sectors, and one of its most vital. A supply of electricity has become essential to modern life, and economic prosperity of a nation can often gauged by the level of access of its population to electrical power. The provision of that access requires investment in power stations, a transmission network to convey the energy to different regions of the nation and distribution systems to bring the electricity to the consumers. Modern renewable and distributed energy systems can provide power locally rather than from a central source but even so, security of supply still demands a high level of interconnection as well as central management and planning.

The electricity industry that supplies this resource is now highly developed. Globally there is probably around 6000 GW of generating capacity in operation, equating to thousands of power stations, and millions of kilometers of associated transmission and distribution lines. Industrial activity on this scale will inevitably have an impact on the environment at all levels at which it operates.

The earliest power stations, built at the end of the 19th century, were based on either hydropower or used oil or coal to generate heat and raise steam to drive a turbine. Both were extensions of established technologies; water had been exploited for centuries using dams to provide water for drinking and irrigation while industrial use of coal was a century old. Coal-fired power generation became the mainstay of power generation in many countries during the 20th century, and much of the industrial growth and prosperity of the advanced nations of the world was built on the back of coal combustion. Both hydropower and coal-fired power continue to be important sources of electricity. However, the environmental impact of fossil fuel combustion, of which coal is the primary component, is now seen as a threat to global security.

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Nuclear power was added to the generating mix in the middle of the 20th century and soon presented its own environmental challenges, while gas-fired power plants began to be used widely during the last 20 years of the decade. New renewable technologies started to advance from the 1970s onwards, but these did not become economically competitive until the beginning of the 21st century. These technologies are generally more benign, environmentally, than their predecessors but the scale of their deployment brings its own problems. This was becoming apparent at the end of the second decade of the 21st century when two new technologies, wind power, and solar power were advancing rapidly. Meanwhile the complex generating mix that has evolved from the combination of all these technologies needs much more sophisticated technology to manage effectively and to fully exploit the renewable potential. The challenge for the remainder of the 21st century is to provide the population of the world with electricity, while limiting the environmental impact of its production to ensure the global community remains secure and safe.

1.1 THE AWAKENING OF ENVIRONMENTAL AWARENESS

The human species has been changing the environment for thousands of years. We no longer even recognize some of those changes, for example, the clearing of forests to create the agricultural farmlands of Europe. No one now sees these fields as forests that once were. Similar changes elsewhere are more obviously detrimental to local or global conditions. Tropical rain forests grow in the poorest of soils. Clearing them, as is happening in many parts of the world, and the ground is of very little use. Not only that but also the removal of forest cover can lead to erosion and flooding as well as the loss of ground water. Most of these effects are negative.

Part of the problem is the ever-increasing size of the human population. Where native tribes could survive in the rain forests in Brazil, the encroachment of outsiders has led to their erosion. A similar pressure resulting from the volume of human demand is at work in power generation. When the demand for electricity was limited, the effect of the few power stations needed to supply that demand was small. But, as demand has risen, so has the cumulative effect of those plants on the environment. Today, that effect is of such a magnitude that it cannot be ignored.

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While power generation developments have in recent years been driven by environmental demands, this was not the case when the industry was born. Take hydropower, for example, one of the earliest sources of electric power and still a clean source. In the 19th century hydropower dams were known to fail and in rare cases these failures were catastrophic. However, the effects were local and were not considered as a major hazard that required hydropower should be treated with excessive caution globally. Nor was it considered that a stable dam and reservoir could be a potential cause of concern for other reasons. Today, any new hydropower project requires an extensive environmental assessment within which every aspect of its potential impact should be evaluated.

Coal combustion was likewise considered relatively benign until around the middle of the 20th century when concern started to be raised about its effect on air quality. Consumption of coal has grown steadily since the industrial revolution. The first sign of trouble resulting from this practice was the ever-worsening pollution in some major cities. In London the word "smog" was invented at the beginning of the 20th century to describe the terrible clouds of fog and smoke that could remain for days. That city had been prone to smog since the beginning of the 19th century but it was a great smog in December 1952 that finally stimulated action, resulting in Clean Air Acts that sought finally to limit local emissions. While much of the problem was caused by the domestic use of coal, industry was also culpable. Measures to limit the industrial effects included building tall stacks to dissipate the emissions from power plants higher into the atmosphere. This was to have its own repercussions that were finally recognized later in the century.

Nuclear power arrived in the 1950s and was heralded as the great new source of cheap, clean, and limitless power. The technology was known to be dangerous if not carefully controlled, but this was an era in which such scientific and technological advances were a sign of hope for the future. By the end of the 1970s, however, the dangers were more fully recognized, and by the middle of the 1980s, construction of nuclear power plants had all but halted in the west at least. The main cause was environmental concern.

The 1980s brought recognition of another major environmental effect of fossil fuels, acid rain. Consumption of coal had continued to increase since the 1950s, but with the use of smokeless fuel in cities and tall stacks

outside, problems associated with its combustion appeared to have been solved. Until, that is, it was discovered that forests in parts of northern Europe and North America were dying and lakes were becoming lifeless. During the 1980s the cause was identified—acid rain resulting from coal combustion. Tall stacks simply shifted the problem to more distant regions. More legislation, aimed at controlling the emission of acidic gases such as sulfur dioxide and nitrogen oxides, was introduced. As with smog earlier, this was a problem that had been growing for decades. Eventually the sheer scale of the industry and the volumes of pollution it was generating became too large to ignore. During the 1980s and the 1990s, too, there were critical reviews of a range of large hydropower schemes, which eventually prompted a change in the way such projects were evaluated. Even this seemingly benign technology could be the cause of major environmental problems.

Worse was to follow. By the end of the 1980s, scientists began to fear that the temperature on the surface of the earth was gradually rising. This has the potential to affect living conditions in every part of the globe. Scientists did not know whether this change was natural or man-made.

As studies continued, evidence suggested that the effect was, in part at least, man-made. The rise in temperature followed a rise in the concentration of certain gases in the atmosphere and could be traced back to the industrial revolution of the mid-18th century. Chief among these gases—now often known as greenhouse gases—was carbon dioxide. One of the main sources of extra carbon dioxide was the combustion of fossil fuels such as coal. Since then, the evidence has hardened so that the most recent report from the United Nations Intergovernmental Panel on Climate Change (UN IPCC) has concluded with a certainty of 95% that humans are the main cause of the current global warming[1].

Action to combat the causes of global warming were slow to take off, but the United Nations finally managed to persuade nations to adopt a global agreement, the Kyoto Protocol, in December 1997, which would limit carbon dioxide emissions. Action continues to evolve under UN auspices with a more far-reaching agreement adopted in

[1]Climate Change 2014 Synthesis Report, Intergovernmental Panel on Climate Change, 2015.

Paris in 2015. The current target is to limit global warming to no more than 2°C above the temperature at around 1750, but the long-term goal must be to reduce global temperatures again.

The recognition of the dangers of global warming has brought about a slow but accelerating change in the power generation industry. The most significant has been the development of new renewable generation technologies[2], particularly wind power and solar power, which produce no net addition to the amount of carbon dioxide in the atmosphere. These are advancing rapidly, and both are beginning to challenge traditional generating technologies economically as well as environmentally. At the same time, fossil fuel combustion technology is being adapted to make it cleaner. Energy efficiency is also being targeted.

These changes will continue throughout the century, so that by the end of the century the electricity supply industry may well be unrecognizable to somebody used to the configuration today. But these changes, too, will have environmental consequences. Already there are signs of what is to come with many more wind farms and large area solar power plants found both in the landscape and offshore. Such changes will inevitably lead to new problems. An industry as significant as power generation cannot avoid being in conflict, at one level or another, with the global environment.

At the same time, electricity is vital to modern living. Therefore, unless the world is going to regress technically the supply of electricity must continue and grow. On that basis, compromises must be sought and technical solutions found that do not result in irrevocable damage. These are the challenges that the power industry faces and with it the world.

1.2 THE STATE OF THE ELECTRIC POWER INDUSTRY

The electric power industry has evolved in stages, and each stage has brought its own environmental problems. Fossil fuels, which form the backbone of the generation industry, have brought the most widespread problems although nuclear power is perhaps potentially the most devastating if a plant were to fail catastrophically. Renewable generating technologies usually have more limitedocal impact but the

[2]Hydropower is often considered an old renewable generation technology.

scale of development required if these are to replace traditional combustion technologies is likely to bring its own difficulties.

Table 1.1 shows a breakdown of the electricity-generating industry by energy source for 1973 and 2014, based on figures collated by the International Energy Agency (IEA). During the 40 years covered by the figures the total amount of electricity generated globally has increased from 6131 to 23,816 TWh, not far short of four times the energy in 2014 compared to 1973. Similar figures for global generating capacity are not available, but the global capacity in 1950 has been put at 213 GW, while in 2010 the comparable figure was 5082 GW[3]. By 2020 this is predicted to exceed 7000 GW.

As the breakdown by energy source in Table 1.1 shows, the largest source of electricity both in 1073 and in 2014 was coal. The fossil fuel was responsible for 2348 TWh of electrical energy in 1973 and 9791 TWh in 2014, an output increase of more than four times. In 2014 coal generated 40.8% of global electricity, up from 38.3% in 1973. Natural gas provided a relatively small amount of global power, 742 TWh or 12.1%, in 1973. In 2014 its share had risen to 5144 TWh, 21.6% of the total and the second largest contributor to global power. Oil, the other fossil fuel in the table, provided 1521 TWh in 1973, 24.8% of the total and only second to coal in terms of total output. In 2014 oil-fired generation provided 1024 TWh, 4.3% of the total. Taken together, these three fuels generated 4611 TWh in 1972, 75% of all the

Table 1.1 Global Electricity Supply by Energy Source, 1973 and 2014[4]

Energy Source	1973 (TWh)	2014 (TWh)
Coal	2348	9717
Oil	1521	1024
Hydropower	1281	3906
Natural gas	742	5144
Nuclear power	202	2525
Other	37	1500
Total	6131	23,816

Source: *International Energy Agency.*

[3]The evolution of global generating capacity, NRG Expert, June 2015.
[4]Key World Energy Statistics 2016, International Energy Agency.

electricity used. In 2014 the total fossil fuel production was 15,885 TWh, 66.7% of the total.

Over the same period the amount of electricity generated from nuclear power plants has risen more than tenfold. In 1973 nuclear plants accounted for 202 TWh of generation (3.3%). In 2014 this had risen to 2525 TWh, 10.6%. Nuclear power stations were still relatively new in 1973, and this was the era when their construction accelerated.

The other major source of electricity in 1973 was hydropower. Hydropower plants generated 1281 TWh that year, 20.1% of the total produced. In 2014 the output from the world's hydropower plants had risen to 3906 TWh, accounting for 16.4% of the total.

The final energy source in Table 1.1, other, includes all the renewable sources except hydropower, which is listed separately. This aggregates the output from wind power, solar power, geothermal power, biomass power plants, and marine sources. In 1973 the output from all these plants was only 37 TWh but by 2014 it had risen to 1500 TWh or 6.3% of the global total. This is still tiny compared to the total global production, but it does represent an increase of 40.5 times the output 40 years earlier.

Table 1.2 takes the same figures and breaks them down by region. In this case the breakdown in primarily between the countries of the Organisation for Economic Cooperation and Development (OECD)

Table 1.2 Global Electricity Supply by Region, 1973 and 2014[5]

Region	1973 (TWh)	2014 (TWh)
OECD	4463	10,765
Non-OECD Europe and Eurasia	1024	1739
China	178	5715
Non-OECD Americas	166	1215
Asia	159	2620
Africa	110	762
Middle East	31	1000
Total	6131	23,816

Source: *International Energy Agency.*

[5]Key World Energy Statistics 2016, International Energy Agency.

and other regions. The IEA is made up of 29 member countries, all members of the OECD, and includes most of the countries of the European Union as well as Norway and Switzerland, the United States and Canada, Japan, Korea, Australia, New Zealand, and Turkey.

Thus, the OECD includes the most highly developed nations in the world, and its energy demand is the greatest of any of the regions shown in the table. In 1973 the OECD nations produced 4463 TWh of electricity, 72.8% of the global total. In 2014 the aggregate production was 10,765 TWh or 45.2% of the total. While production has more than doubled over the 40-year period, the growth rate is much lower than the overall global rate of growth. By contrast the growth in other regions has been much faster.

Most notable in this respect is China. In 1973 the estimated electricity production in China was 178 TWh. In 2014 it was 5715 TWh, 24.0% of the global total and 32 times larger than 40 years earlier. Growth in Asia excluding China has been rapid too, although not on quite the same scale. From 159 TWh in 1973, production in this region rose to 2620 TWh in 2014, 16 times larger and 11.0% of the global total.

Growth in non-OECD Europe and Eurasia was much slower with production rising from 1024 TWh in 1973 to 1739 TWh in 2014. The increase in output in the non-OECD Americas was much more rapid, rising from 166 TWh in 1973 to 1215 TWh in 2014. Production in the Middle East rose rapidly as well, from 31 to 1000 TWh. Growth in Africa was significant, with output rising from 110 TWh in 1973 to 762 TWh in 2014. However, this still represents a tiny proportion, 3.2%, of global output. In terms of electricity, Africa remains the least developed region of the world.

The figures from these two tables illustrate both the scale of the problem that the world faces, the sheer size of the generating industry, and also the shift in the center of gravity of electricity production as countries in Asia have advanced and required more electric power to support their industries and populations. It also highlights the problem of coal, the largest global pollutant and yet a vital source of energy for many countries.

When trying to tackle the environmental problems created by the electricity industry, particularly with respect to global warming, this shift in the global breakdown of output brings its own difficulties.

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