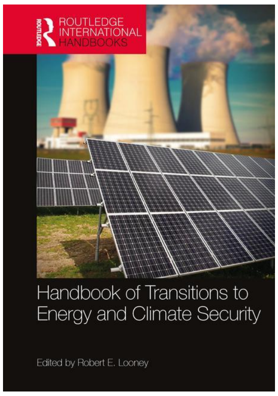

Handbook of Transitions to Energy and Climate Security

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Twins of 1713

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27

Twins of 1713

Energy security and sustainability in Germany

R. Andreas Kraemer

Introduction, background and context

Energy security and sustainability are twins, born in 1713. As key concepts they were explained and made practicable through management rules in the seminal 'Sylvicultura oeconomica' by Hans Carl von Carlowitz, and have guided policy-making ever since.[1] As conceptual foundations of Germany's present-day '*Energiewende*' – the country's green energy shift away from fossil and nuclear energy towards renewable energy supply – energy security and sustainability are topical and ever more relevant for many countries.

The thinking in Germany, or rather its precursor states, is much broader and predates the modern concept of energy security as it was developed notably in the OECD in response to the politically induced oil crises of the 1970s. Furthermore, energy security is part of a broader agenda of rational resource management, including the principles of sustainability.[2]

Germany's energy endowments

Germany is well endowed, to varying degrees, with all forms of energy, starting with relatively abundant forest cover over about one-third of its territory. The potential for hydropower is dispersed: there are few options for large impounding dams, but thousands of small dams exist, mostly in mountain regions of the South and the South-East, as do run-of-river plants integrated into weirs to increase river depth and assist navigation along the large rivers. Windmills were prominent as they were in other developed countries, but gave way to fuel-powered engines and later electric motors. Modern-day wind turbines for electricity generation harvest a wind resource of medium quality (if compared to other countries), notably in the North and the East of the country, but also increasingly on the high plains and ridges of the South. The strength of the sun, the insolation, in Germany is similar to that of Alaska, and yet solar energy, notably photovoltaic cells, have been installed on millions of rooftops as well as in large arrays on agricultural and other land. The farming sector produces enough waste for a dynamic bio-energy industry to develop and thrive. Although Germany has no notable present-day volcanic activity, there is reasonable potential for geo-thermal energy in some areas where hot rock is found at accessible depth, and heat-pumps can tap near-surface strata for both heating and cooling. Other than offshore wind power, which is being developed, the potential for ocean or marine energy is limited because of the physical characteristics of Germany's coasts. This energy endowment is enough, models show, to provide 100% clean, safe, and secure renewable energy even for a densely populated and heavily industrialized country like Germany.

During industrialization, Germany used up a large part of the stock of fossil energy on its territory. Remaining hard coal is in deep mines and uneconomic to extract. Surface mining of soft brown coal continues in various parts of Northern Germany, but is now threatened by competition from ever cheaper renewable power. Very small oil resources have been exploited in the past, and what is left would be uneconomic to extract. Natural gas, a fossil form of the greenhouse gas methane the Germans call *Erdgas* (earth gas), is found in some locations, mostly in Northern Germany, but the quantities extracted are declining fast. In fact, the remaining gas fields may be used better to store imported gas as a strategic reserve. There are also small, almost symbolic, uranium mines of local historical significance. Uranium mining was uneconomic and ended in the 1990s after German unification.

The most abundant energy resource in Germany is perhaps ingenuity, with high standards in the natural sciences, engineering and materials sciences, and effective training for technical professions and trades. The German national innovation system, if that concept is still valid for any country deeply embedded in the European Union, is generally good at continuous incremental improvement, rather than disruptive innovations of the kind associated with Silicon Valley. This innovation system, surrounded by a political system that forms ruling coalitions around the political centre and provides for comparatively high levels of policy continuity, permits industries to grow around key technologies and along the value chains. The strength of this system is perhaps demonstrated best, but also perversely in the larger context of energy policy, by the breadth and depth of nuclear technology in Germany, a country that had no significant uranium resources and no nuclear weapons of its own.[3] In spite of this, and in the absence of any sustainable economic rationale, Germany has practically all the technologies needed to manage the full nuclear fuel cycle for nuclear power, and the capacity to avail itself of all technologies needed to build, maintain and operate nuclear weapons. Yet, there are no plans to do so, and the decision to phase-out nuclear power is final; a reversal is politically unimaginable.

The current energy system transformation builds on energy security as a key objective and is motivated by sustainability concerns. It is a 'grass-roots', socially desired and politically directed shift towards energy efficiency, renewable energy supply and energy storage, with a smart electricity grid enabling demand flexibility. It increases energy security by most measures, if not all. It does so in part by creating novel links between the energy and transport systems, between electricity and gas, and between the electricity and the heating systems. These links all contribute to higher system reliability and resilience of the whole.

Contemporary context: global overheating

For years, the acute effects of climate change within Germany were not the main concern, but rather climate-change driven events around the world that might harm political stability in other countries, result in a loss of trade, induce migration, and ultimately cause conflict. Promoting good climate policies abroad was seen as being in Germany's best interest and as good global citizenship. The contribution of global warming to the various crises around the world is generally assumed if not always understood in Germany.

With its place, geographically and politically, at the heart of Europe, with all neighbours being Member States of the European Union (EU)[4], Germany is in a favourable position. Some

EU countries like Belgium, the Netherlands, Britain, or Denmark will likely suffer more from rising sea levels, while others around the Mediterranean will feel stronger effects from changing rainfall patterns.[5] Germany has comparatively strong, well-organized, and efficient government and can respond to emerging threats more effectively than countries with more limited statehood, especially countries outside the EU, from where refugees now come.

Germany is most vulnerable to the effects of climate change along the North Sea and Baltic coasts, but these are not densely populated. However, many houses, businesses, and much transport infrastructure is located along the rivers. Seasonally low flow already forces the occasional shutdown of nuclear plants and other installations. Recent record floods in all large rivers are seen as a consequence of changing climate, with a warmer atmosphere carrying more water and triggering stronger rainfall or snowfall. In time, a partial retreat from vulnerable areas will become necessary, yet there is no sense of urgency now.

Evolution of *Energiesicherheit* in Germany

While fossil energy sources were known from antiquity, their large-scale industrial use only developed in the past 200 years. Previously, wood had been the most important source of storable and transportable energy, not only in domestic heating and small trade activities such as blacksmithing but also in the industry of the time.

Since the Middle Ages, the region that is known as Germany today experienced episodes of energy scarcity with the consequence of industries collapsing and regimes weakening. The typical pattern was the harvesting of old-growth forest for mining purposes, without regard for the need to replant forests and consider the speed of tree growth to assess future energy availability. In some regions, hydropower was used, for instance for driving air bellows in metal processing, but that resource was always limited such that excessive energy needs were met by harvesting ever larger parts of the energy stock represented by standing trees.

One example is the history of the Harz mountains in the centre of Northern Germany. Mining and metal processing on an industrial scale developed since the Middle Ages, resulting in unsustainable pressure on the forest very early on. The Harz mountains became increasingly denuded, and many of the foresters and miners moved on, eastwards and southwards into other areas of Saxony.

The story is similar to that of the Eifel mountain region in the West of Germany, near Luxemburg, which has been mined since antiquity, through the Bronze and Iron Ages, and into Roman times. Its scale was relatively small, and mining did not change the landscape much. However, that changed in the 17th and 18th centuries, during which the hills were cleared of trees and not much more than a grass-covered highland was left. The foresters and miners mostly moved away.

By now the pattern was recognized, and stronger states with longer time-horizons, better government and administration had emerged, so that the dangers of unsustainable energy and resource management could be understood and guarded against through policy, law, and management rules.

Wood and its sustainable resource management (1713)

In 1713, Hans Carl von Carlowitz first spelled out the foundations for sustainability as a concept and sustainable development as an objective by establishing principles and practical rules for forest management and the rational use of forest resources. He hailed from a family of forest masters, was a lawyer and public administrator by training, and had travelled widely to study industry, notably mining, as well as governmental systems and forestry practices.

As a long-time mining administrator, he was given responsibility, in 1711, for the mining industry at the court in Freiberg, a mining town in Saxony known for mining silver. Mining was the most important industry at the time, employing a very large work force, because metals were needed in the manufacture of weapons and minting of money. In modern terms, the defence sector and national security, and the money supply and thus economic stability were all directly dependent on mining output, and so energy security was at the heart of policy considerations.

The most pressing threat to the mining industry of the time was the supply of timber, which was used not only for structural purposes inside the mines and at the mine heads, but also for setting up hot fires underground in the mines at the lodes with the metal ores. The heat would induce splitting in the rock to make the ore easier to mine. Wood was also used to fuel fires that needed to be hot enough for metal to melt from the ores. Mining and metal processing were similarly dependent on a continuous supply of good timber, wood that would burn hot enough to reach smelting point.

The seminal work 'Sylvicultura oeconomica' is the essence of von Carlowitz's understanding of forestry, which he understood to be about much more than the harvesting of timber. He laid out the principles of sustainable management of natural resources, addressed the optimal and sustainable management of forests and the rational use of forest products under the threat of overexploitation. On the basis of the understanding and management rules provided by von Carlowitz, reforestation of denuded areas and protection of forests were so successful that Germany could maintain mobility and fuel a large part of its vehicle fleet from wood gas derived from special burners mounted on cars and trucks under fuel oil embargo during World War II.

Von Carlowitz's legacy includes a present-day legal framework for forestry in Germany on the basis of the 1975 Federal Law for the Protection of the Forest and the Promotion of Forestry (*Gesetz zur Erhaltung des Waldes und zur Förderung der Forstwirtschaft (Bundeswaldgesetz)*). The stated purpose of the law is primarily:

> To protect and maintain the forest, to enlarge it as necessary, and to safeguard its rational management in a sustainable manner, and to do so in view of the forest's economic use (use function) and its importance for the natural environment, notably for sustaining its ability to provide ecosystem services, for the climate, water resources, air quality, soil fertility, the landscape, agriculture and infrastructure, and the recreation of the population (protection and recreation function). (own translation)

As a consequence of the law and the philosophy behind it, about one-third of land in Germany is forest, and the share of forest in total land use is rising, if slowly. The protection of the nation's forests is embedded deeply in German culture. When long-range air pollution threatened the forests' survival in the 1970s, '*Waldsterben*', forest die-back, became a rallying cry for the environmental movement and motivator for strong national and EU policies on air pollution control, which eventually achieved a turn-around in pollution and forest health. The impact of those policies was to force notably coal-fired power stations to retrofit with flue-gas desulphurization and controls to reduce other pollutants, including nitrogen oxides.

Harvest of eons: coal, the idea of autarchy, and its demise

Limitations to the availability and supply of wood in Germany would eventually have resulted in industrial decline, had it not been for the rise of coal as a consequence of James Watt's invention of the steam engine. The steam engine allowed water to be pumped from deeper mines, so that more hard coal of higher quality could be extracted. Hard coal is relatively easy and cheap to transport and store, and could thus be brought to locations that were otherwise attractive for industry.[6] Coal differs from wood in that it is not a growing resource but a fossil stock of energy built up over millions of years. As such, it held the promise of abundance, of economic growth without limits, at least as long as there was no end to coal supplies in sight, and the negative consequences of its use could be ignored.

Germany had a number of hard-coal-producing areas, where the last pits are now being closed, and still has several lignite-mining areas, where mines are co-located with lignite-burning power plants, as electricity is easier and cheaper to transport than heavy lignite coal. The timing of phasing out lignite mining is currently being debated, with end dates falling maybe in the 2035 to 2045 range. The political motivation for the coal phase-out is climate protection, but cost reductions in renewable energies and advances in information and communication technologies also make coal-fired power increasingly uncompetitive.

Past energy security concerns that would argue in favour of keeping lignite mines running are losing weight as a stable electricity supply from a portfolio of renewable energy systems and storage in a smart grid becomes ever more credible, especially as the European energy grids are increasingly integrated.

Its reserves of first cheap-to-mine hard coal close to the surface and later deeper hard coal gave Germany, for a while, the option of achieving autarchy in energy supply as well as a supply of carbon-molecules as feed-stock for the chemical industry. Until the end of World War II and the subsequent restructuring of the chemical industry, Germany built this industry on carbochemistry using coal (with ring-shaped molecules containing carbon) as feed stock.

Coal liquefaction, deriving liquids from coal using the Bergius (1913) and Fischer-Tropsch (1925) processes, provided an important option for Germany to achieve energy autarchy on the basis of domestic coal resources. Coal gasification was as important for maintaining gas supply for industries and cities in Germany as it was in other countries. The practice ended in Germany when the country switched to mostly imported natural gas and retired its gas works.

After 1945, the chemical industry in West Germany changed from carbochemistry to petrochemical processes using long-chained molecules containing carbon (and more hydrogen than in coal-derived molecules); the switch in East Germany with its lignite mines occurred after the fall of the Berlin Wall in 1989, in the context of a rapidly shrinking, even collapsing industry.

Collective energy security: oil and sea-lanes (post-1945)

The German Federal Republic (founded in 1949) changed its outlook from national energy security (with the option of autarchy) toward collective energy security, or energy policy in the context of the collective security framework provided by the West.

The development of (West) Germany's coal industry was placed under the High Authority of the European Coal and Steel Community (ECSC). The ECSC built on an earlier precedent in the Act of Mannheim (1868) on navigation on the Rhine as a shared river,[7] and laid the foundation for the adoption of the European Economic Community (EEC) and the European Atomic Energy Treaty (Euratom Treaty) in 1957. The 1951 Paris Treaty establishing the ECSC essentially ended national autonomy in energy policy as it was conceived before, not only for West Germany, but also for France, Italy and the three Benelux countries Belgium, Luxembourg, and the Netherlands. These countries, and later all members of the EEC and now the EU increasingly shared political and regulatory oversight over their energy industries in a process that has resulted in the European Energy Community Treaty and the European Energy Union now being developed.

The switch from carbochemistry to petrochemistry resulted in Germany becoming more reliant on the openness and security of sea-lanes (bringing crude oil) and thus served to tie Germany into the Western alliance. The switch was helped by the fact that the locations of major chemical works in Germany were along the Rhine river and its tributaries. Shipping costs on the Rhine were low enough to make the use of oil advantageous in economic terms.

The market share of oil rose until the oil-crises in the 1970s and early 1980s. The 'oil shocks' induced by the Organization of Petroleum Exporting Countries (OPEC) revealed an economic component of energy security that had been neglected in the decades before. The response of the oil-consuming, industrialized countries to OPEC's challenge was coordinated in the OECD and resulted in the establishment of the International Energy Agency (IEA). The IEA was given the mandate to orchestrate the building of strategic oil reserves and coordinate the release of those reserves at times of crisis.

In (West) Germany, the national response was manifold: oil-fired power generation was phased out, nuclear power generation was promoted (until it was stopped again by the nuclear catastrophe at Chernobyl in 1986), and energy efficiency including fuel efficiency in the transport sector was given more emphasis. The promotion of diesel that ultimately resulted in the Volkswagen scandal of 2015, can be seen as a consequence of the desire to make the German economy as fuel efficient as possible, and thus to increase economic energy security as an important factor in the competitive position of Germany as a trading nation.

Gas, the North Sea, and the embrace of Russia (1980–2014)

One of the key elements in reducing Germany's dependence on imported oil was to develop the small domestic gas fields and begin importing from neighbouring countries. The Netherlands, the UK and Norway, which developed oil and gas fields on land and in the North Sea, were close and reliable partners in Western Europe, and they provided additional energy security to Germany. The challenge at the time lay to the East.

From the 1970s, with the beginning of the '*Ostpolitik*' – ushered in by the then Chancellor Willy Brandt of the Social Democratic Party and a cornerstone of German foreign policy ever since – a new approach began to shape relations with the Soviet Union and the countries of the Warsaw Pact. In the 1980s, establishing good trading relations was seen to be key to reducing the risk of armed conflict in Europe, when any conflict at the time would have left Germany as a radioactive wasteland. The Soviet Union had gas but needed technological and financial support to develop the industry and build the pipelines necessary to deliver its gas to markets in Western Europe.[8]

The resulting 'gas for pipelines'-deal between (West) Germany and the Soviet Union resulted in increased diversification of fuels and their sources and thus improved energy security as it was understood at the time, and improved the geopolitical environment for Germany and thus, in a limited way, enhanced national security through energy cooperation. The deal was upheld by both sides through the collapse of the Soviet Union and the re-establishment of Russia, the new independence of some Soviet Republics that would become transit countries, and the political changes in the Warsaw Pact countries, including German unification. It even holds up after Russia's attack on and invasion of (part of) Ukraine in 2014.

Nuclear power and the dead-end military option (1957–1986)

Like the US with the 'Atoms for Peace' programme in the 1950s and together with the other founding members of the Euratom Treaty, Germany was swept along in the illusion that nuclear power would be a safe source of energy and a fountain of peace and prosperity.[9] The Euratom Treaty, Europe's quasi-constitutional commitment to subsidize nuclear power, was signed in March 1957, the year of the nuclear catastrophes in Windscale, UK, and the Mayak reactor near Kyshtym in the Soviet Union.

Plans to build a nuclear reactor in Wyhl in the South-West of Germany near France and Switzerland, aroused local resistance which stopped construction and triggered the development of an organized and increasingly influential anti-nuclear environmental movement. It included scientists and technical experts that could question and contradict the pro-nuclear narratives of the plant's promoters.

The movement found strength in the German tradition of providing energy supply through local utilities, usually controlled by municipalities, and a general suspicion of central government and big business involvement in the sector. Another contributing factor was the fact that Germany is not a nuclear weapons state with two important consequences: the links between the nuclear industry and the military and security policy community were considerably weaker than in other countries, notably neighbouring France, and it was easier to criticize nuclear technology or question the dominant nuclear scientists without being accused of sedition or treason. The political balance was more level than in other countries, and there was significantly more room for open political debate.

The movement established the Institute for Applied Ecology (Öko-Institut) in Freiburg,[10] the first of a cluster of privately initiated, independent policy institutes and think tanks.[11] In 1980, experts from the Öko-Institut published the book *Energiewende – Growth and Prosperity without Oil and Uranium* as a blueprint for the energy transformation that is now underway.[12] The energy system analysis and transformational strategy developed at the time was influenced by Amory Lovins's work at the Rocky Mountain Institute and notably his 1976 article in *Foreign Affairs*,[13] which opened eyes to the wider international implications of domestic energy policy choices.[14]

With the oil crisis in 1980/1981, German energy policy focused on reducing its dependence on imported oil. But the 1986 nuclear catastrophe in Chernobyl, Ukraine (then part of the Soviet Union) focused German minds again on the need to invest in 'anything but nuclear' and develop technologies, regulatory frameworks and political strategies to phase out this dangerous and ultimately uneconomic technology. The ideas in the 1980 book *Energiewende*, and the critical mass attained by the anti-nuclear movement and the community of anti-nuclear scientists and experts were available at this critical moment when German energy policy looked for new orientation.

Feed-in tariff: innovation of an effective policy instrument (1990)

In 1990, a seminal element of the political strategy was adopted: the German Power Feed-in Law (*Stromeinspeisegesetz*) guaranteeing grid access and establishing a feed-in tariff for renewable power. Influential, land-owning and politically conservative owners of hydropower dams in Germany's South obtained this federal law mandating power utilities to buy renewable electricity from them at stable rates. It is the achievement of an early alliance of conservative and progressive or 'green' political forces,[15] and it triggered innovation and business development in renewable energies.

The then newly elected red-green federal government consisting of the Social Democratic and the Green parties, in 1999 and 2000, negotiated a phase-out of nuclear power with the industry and upgraded the *Stromeinspeisegesetz* to become the Renewable Energy Act (*Erneuerbare-Energien-Gesetz* or EEG), the much-copied law that has undergone a number of upgrades and revisions since then.

The negotiated phase-out of 2000 guaranteed nuclear power plant operators residual operating time for each of their plants, roughly in line with their expected technical life and safety records. Newer plants would run longer than older ones. Power sales from the plants were expected to be sufficient to cover depreciation and allow operators to build sufficient reserves for future decommissioning and legacy costs.

It was also agreed that regulators could not demand safety retrofits at the expense of operators, but would have to reimburse the cost of any retrofits. This in effect avoided any 'expropriation in kind' (through regulatory action) by government fiat. Residual running time could be transferred from older plants, which presented the highest risk profile, to new plants, which were regarded as safer, in 'trades' that allowed operators to consolidate operating time for economic gain. The end of the nuclear age in Germany would have come sometime between 2021 and 2023, depending on the rate of power production over the two decades of the phase-out.

The futile attempt to reverse the nuclear phase-out (2010)

Legislative ambush by government on parliament is the best way to describe the ill-fated 2010 decision to delay the closure of Germany's nuclear power plants beyond the agreed phase-out date. It was adopted after the law was presented and pushed through in a very short time and without normal scrutiny by ministerial officials and legislators in parliament. As a consequence, the law was challenged as being unconstitutional for several reasons and may well have threatened the survival of the government of the day. It was ultimately defeated, for good reason, because it broke a long-standing cross-party consensus on nuclear phase-out, formed after the tragedy in Chernobyl in 1986.

At least since the 1970s, when the country was divided in a frozen conflict during the Cold War, nuclear technology and its ostensibly 'civilian' use in electricity generation was controversial in Germany. The controversy evolved into a Great Societal Conflict (*Gesellschaftlicher Grosskonflikt*) that involves large segments of society, and defines not just one generation but several. It called into question the four-sided relationship between citizens and ratepayers, municipalities as democratic local governments engaged in energy services, industry as operators of nuclear plants, and the central or federal government as regulator and promoter of energy policy choices. Pitched battles were fought in legislative chambers, before courts, and in the streets, until a phase-out of nuclear power was agreed between operators and the federal government in 2000. The Grand Societal Conflict subsided. Some mistakenly saw it as resolved, others knew it was dormant and ready to break out again if the phase-out were ever revoked.

What then drove the German parliament in the autumn of 2010 to extend the allowed operating time for the country's nuclear power plants? Lobbying by the plant operators, the four big incumbent utilities, seeking to overturn the nuclear phase-out they agreed to in 2000 is the obvious answer. Extending required pretending the untenable, when the truth was already widely known that nuclear power is too expensive, polluting, wasteful, and dangerous even for a rich, technologically advanced country like Germany.

Germans saw through the false pretences and took to the streets in ever-larger numbers to protest for a continuation and acceleration of the *Energiewende*, Germany's energy transition towards clean, safe, and increasingly cheap renewable energies. The 2010 extension of nuclear running time made no sense in the larger framework of energy policy, economic policy, or technology policy. The vote in the German parliament, the Bundestag, on 28 October 2010 is the most prominent and in many ways surprising outlier in an otherwise smooth process, of envisioning, preparing, planning, initiating and managing a grand transformation of an industrial country away from costly, dirty and dangerous fossil and nuclear power towards a future based on increasingly cheap, clean and safe renewable energies.

Fukushima and the restoration of the nuclear phase-out (2011)

Into 2011, the anti-nuclear demonstrations continued with increasing numbers of participants. The anti-nuclear Green Party was rising in opinion polls, approaching 30 per cent, and threatening to overtake the ruling conservative Christian Democratic Party (CDU) of the Chancellor, Angela Merkel. Among the demonstrators were grandparents carrying grandchildren on their shoulders; they were not young anti-industrialist or anti-capitalist rebels, but from the conservative core of society. Young people, in their teens, had their political awakening in that context.

The CDU faced not just the ignominy of having a high-profile law overturned by the courts or the embarrassment of losing upcoming elections at state (*Land*) or federal level, it faced the erosion of its electoral prospects for a generation. It was clear to most observers that the CDU-led federal government would have no choice but to annul the contested extension of the nuclear power plants' running time.

The tragic nuclear catastrophe at the Fukushima nuclear plant that started on 11 March 2011 and has been unfolding ever since, provided Angela Merkel with a face-saving opportunity for a deft U-turn to restore the nuclear phase-out. She used it without hesitation, and a new nuclear phase-out law was adopted by the German parliament on 31 July 2011.

The 2011 nuclear phase-out law differed from the negotiated nuclear phase-out of 2000 in important nuances. While the earlier agreement fixed the number of residual run-time hours for each plant, and made provisions for them to be transferred among plants to improve the economics and safety of operations, the new law set fixed end-dates for each nuclear plant to shut down. Overall, the plant owners actually gained operating hours, as long as they did not have to interrupt operations for lengthy retrofits. The new law sets incentives to skimp on maintenance and run the plants without interruption.

In practice, because of the low electricity prices on the German market, nuclear plants are unlikely to operate to the deadline in the law, but be taken out of service when the last refuelling would be due. Refuelling incurs large costs, both in the fuel and in the legacy cost of dealing with spent fuel later. In the prevailing market conditions, even existing nuclear power plants are uneconomic to run, even though they still benefit from subsidies and privileges.

Return of autarchy? Home-grown renewable energies (1990–)

Since the 1950s, the German energy economy opened up and was increasingly integrated into the world markets (for oil and coal), the emerging integrated European economy (for traded fossil energy products, gas and later electricity) and with the Soviet Union, later Russia (mainly for gas, but also for other fossil energy carriers). Economic integration and diversification of fossil fuels and their sources were considered viable paths to improve energy supply security, while also producing wider strategic and security-policy benefits.

In the aftermath of the OPEC-induced oil crises of the 1970s and early 1980s, and with a living memory of energy autarchy and local control over energy services, the vision of an *Energiewende* (as in the 1980 book title) rekindled the desire to develop sufficient energy supply capacity at home and in the European internal market, and to do so without relying on fossil energies that harm the climate, or dangerous and costly nuclear power.

Scenarios and modelling have shown that combinations of renewable energies plus storage in a smart grid can supply Germany based on current and projected patterns of demand. The perhaps best-known simulation has been developed by the *Kombikraftwerk* project which documented that a combination of existing renewable plants and storage facilities connected in a virtual power utility can be operated to match a fixed percentage of the grid demand curve. Scenarios then demonstrated how the renewable energy industries can be scaled up, and the percentage of the load curve covered by a larger virtual 'combination power plant' be increased until it reaches 100% (or more) by 2050, with some imports from and exports to neighbouring countries in the EU's internal market.[16]

This simulation does not take account of the potential to reduce energy demand through efficiency, and notably the dynamic efficiency that can be provided by demand flexibility and response, including the possibility that large industrial power users can become 'swing consumers' of electricity and ramp production up and down to match the availability of fluctuating but highly predictable renewable energies.[17] It also does not yet take into account the potential storage becoming available as a consequence of a shift towards electric mobility, which would reduce the current dependence of the transport sector on liquid fossil fuels and thus enhance energy security.

Grand co-transformation of power, gas, heat and transport

The German energy transformation has already created interesting new links between the electricity and the gas market. At times when renewable energy is abundant and the spot-market price of electricity is low (or even negative), operators of gas heating systems switch to electric resistor heating units. The conversion of noble electricity into low-temperature heat is considered a sin against entropy, but it makes economic sense for the operators. The gas thus saved simply remains in the distribution pipeline system, which acts as a gas storage of very large capacity, to be burnt another day. The use of gas in combined heat-and-power plants in effect converts the gas back into electricity, as a welcome by-product of the heating process.

The next step in the German *Energiewende* vision is the creation of new inter-linkages among various energy sectors, as is depicted in Figure 27.1.

Some of the most promising emerging technologies that would provide new options for energy storage, transport and conveyance are (various approaches in) the conversion of power-to-gas or power-to-liquid fuels or feed-stock for the chemical industry. The idea at the centre of the image is simple: when there is insufficient demand, renewable wind or solar power, which is fluctuating in availability irrespective of demand, is used to split water (2 H_2O) into hydrogen (2 H_2) and O_2. The H_2 is then combined with carbon from CO_2, which is taken from the atmosphere or the off-gas from combustion processes, to form first methane (CH_4) and then longer chains of alkanes and their derivatives.

The products are gaseous and liquid fuels, which can be integrated in existing distribution or 'down-stream' infrastructure that is a legacy of the fossil oil and gas industries. Power-to-gas and power-to-liquid technologies are expected to be cost-competitive as soon as the penetration of renewable energies is such that there is 'surplus' renewable power often and long enough to operate the conversion plants thousands rather than hundreds of hours in a year.

The implications for strategic energy security are clear: synthetic gas, transport and heating fuels, and feed-stock for industry derived from domestic renewable energies can substitute for fossil energy that otherwise have to be imported. Each step in the conversion also improves the storability of the product, so the technology allows build-up of reserve stocks for times of no wind during a dark and cold winter period, when the derived gaseous and liquid fuels can be used to power efficient heat-and-power plants.

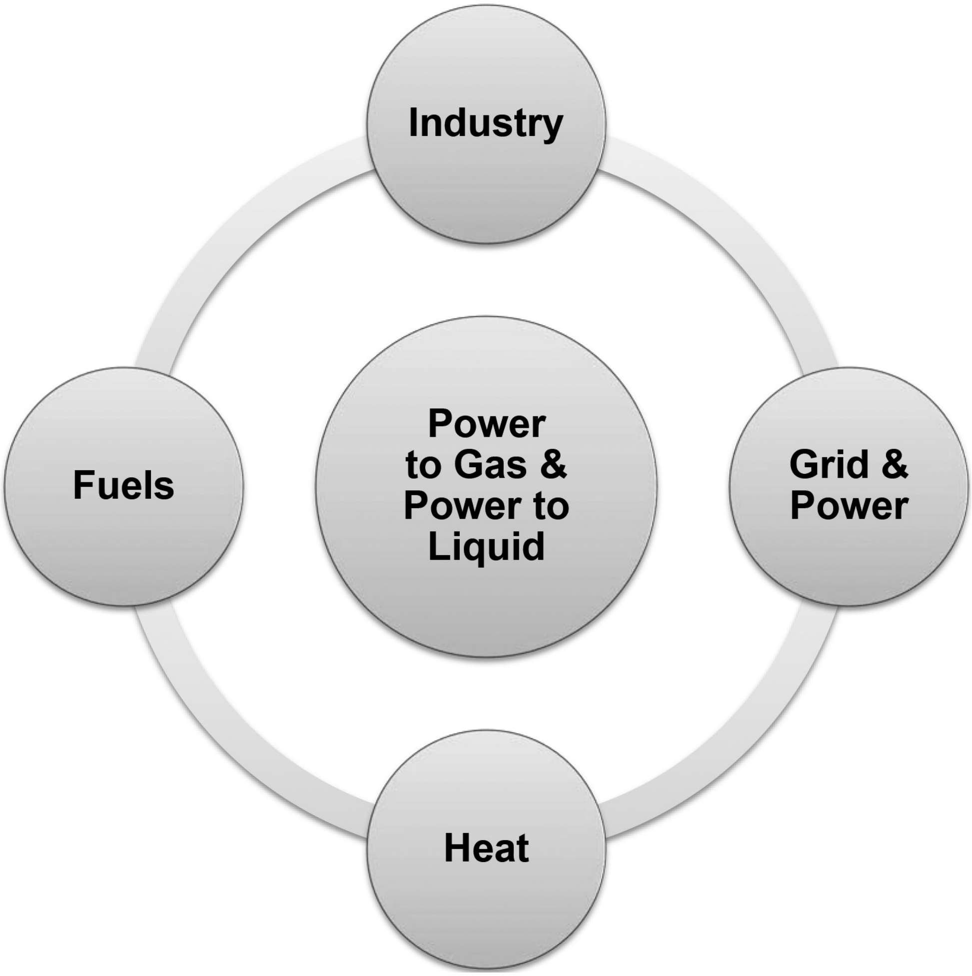

Figure 27.1 Conversion of power to gas and liquid fuels is key to sector coupling
Source: UBA, Umweltbundesamt (ed.) (2015, for English translation, p. 76), *Germany in 2050 – a greenhouse gas-neutral country*. Climate Change | 07/2014. Dessau-Rosslau, Umweltbundesamt. April 2014 (for original German publication). http://www.umweltbundesamt.de/en/publikationen/germany-in-2050-a-greenhouse-gas-neutral-country.

Security evaluation of the *Energiewende*

The 'green power shift' underway in Germany already produces manifold and large economic-policy benefits in terms of innovation, business creation and growth, qualification and employment especially in rural areas where there are few job alternatives, additional tax revenue and social security contributions, import substitution and added strength in the balances of trade and payments. The renewable energy sector even acts as an automatic economic stabilizer in a general downturn of the business cycle. Further, the policy adds to options in dealing with an aggressive and exploitative Russia, the importance of which became obvious when Russia invaded, occupied and annexed Ukraine's Crimea and involved itself in a 'civil war' in parts of the Donbas region since early 2014.

Economic energy security and other economic benefits

Since the 1980s, a new energy industry with an annual turnover of 40 billion euros and employing about 370,000 people has developed, of which perhaps 150,000 are net additional employment that would not exist in the absence of the *Energiewende*. This business and job creation in Germany is a consequence of domestic value generation in lieu of importing fossil energy commodities. The employment is across skill levels – from highly specialized technicians to farm hands – and geographically spread. This is particularly useful to stop the economic decline of rural areas and the migration to towns and cities, and thus to enhance the economic and social cohesion of Germany, where some regions are still struggling with the effects of industrial decline that came with the fall of the Berlin Wall and the collapse of the centrally planned economy of the former German Democratic Republic (or East Germany).

Substituting imported fuels with domestically produced energy strengthens the balances of trade and payments, and serves to isolate the German economy from price volatility on international energy markets. In fact, costs and prices for domestically produced renewable energy are not only predictable, but they are locked in by fixed investment in renewable generating plants. The *Energiewende* simply removes the uncertainties associated with factor prices from a growing segment of its industry and national economy. In addition to enhancing economic security of energy supply, the policy reduces vulnerability to physical supply disruptions as a consequence of natural disaster or enemy action.[18] This 'import substitution' implies the development of a broad and deep value chain on energy efficiency, renewable energies, smart grids and storage within Germany. The development of this industry requires a one-off investment over one or two generations, but then pays off for much longer. One of the benefits is that the domestic renewable energy industry, because it is largely disconnected from international markets, acts as an automatic stabilizer in economic crises that result from external shocks.

The growth of the domestic energy industry drives up tax revenue and stabilizes the social security systems. In the international discussion, the German *Energiewende* policy is often described (falsely) as being based on generous government subsidies. In fact, the financial mechanism does not involve any public funds, but a legally mandated pool financing system paid for mainly by households and small businesses. Because the policy does not cost public funds but increases tax and social security revenue, it is 'fiscally positive' and enlarges the government's ability to deal, for instance, with the legacy costs of nuclear and coal power generation. The lesson that well-designed policies for energy transformation can help governments with high deficits and debts is sadly often lost in the debate about public finance in the euro-zone.

Wholesale electricity prices, the prices paid by large industrial power users and utilities that buy electricity to distribute it to their customers, are very low in Germany – at around 3 cents per kWh – and projected to remain there for years to come. This is attracting inward investment, or the expansion of some electricity-intensive industries, such as aluminium recycling. Internationally, the German *Energiewende* is often criticized as being expensive, with high and rising electricity prices (in cents per kWh) for household users being cited in evidence. In such criticisms, no mention is made of the fact that prices for industrial users and wholesale prices for distribution utilities are declining, which is to be expected as the share of renewable electricity with zero or near-zero marginal cost is increasing its share of the market.

Grid stability and the frequency and duration of electricity supply interruptions, and the number of people and businesses affected, are further important considerations in energy security (of supply). The experience in Germany (as well as in Denmark) shows that grid stability improves and interruptions become shorter and less frequent as the share of distributed renewable electricity supply rises.

Nuclear power plants are large and tend to go off, more often than their operators like to admit, within seconds and without warning. The loss of any such plant must then be compensated on the grid, which requires a sufficient spinning reserve of generating capacity to step in, and a long-distance, high-capacity, high-voltage transmission grid capable of redirecting power flows in seconds. The physical back-up and technical competence and preparedness are costly to maintain, and they are themselves vulnerable to disturbances.

Distributed renewable generation does not impose the same risk and cost for preparedness and response capacity on the grid. Even if a renewable generator suddenly fails, which they or the substations through which they feed into the grid occasionally do, the effect on the grid is not large and can be compensated in most cases automatically and within one distribution grid cell (for solar) or one mid-voltage regional grid (for wind). There are not risks of knock-on effects on the grid as a whole as are presented by nuclear power plants.

Energy security and security implications of energy

As a consequence of the nuclear phase-out, Germany is eliminating the un-insurable high risks of nuclear power, first on its own territory and, by showing that a nuclear phase-out is technically possible and makes economic sense, perhaps also on the territory of its neighbours. Currently, the builders, owners and operators of nuclear power plants benefit from generous caps and waivers that limit their liability for damages to others resulting from nuclear accidents. International agreements furthermore limit liability for transboundary damages. The economic value of those caps and waivers is disputed. It would be revealed in insurance premiums, but there is no commercial market for unlimited liability insurance for nuclear plants. Whatever the value of the risk or the insurance of it, Germany will no longer be exposed when its last nuclear power plant shuts down at the end of 2022 (at the latest).

Once the last nuclear power plant has gone cold, Germany will no longer be adding to the already high (and largely unfunded) legacy costs of nuclear power, and can address the issue of long-term nuclear waste storage. This is not only an important economic security aspect of the nuclear energy system, it is also an issue of security in broader terms. As long as nuclear waste remains stored at nuclear power plant sites, as opposed to specialized, dedicated, high-security waste management and storage facilities, those waste sites are targets for attacks by potential enemies in international armed conflict or terrorists, whether or not they are sponsored by a state.

The overall, macro-economic assessment shows that the total cost of electricity supply to end users in Germany, expressed as a percentage of gross domestic product (GDP), representing the size of the German economy, has not changed much as a consequence of the *Energiewende*. In essence, the benefits listed above are being obtained at low net cost to the German economy.

International security implications of the Energiewende

Domestic renewable energies reduce the need for imported fossil fuels thus enhance energy supply security, in economic and, as noted by Frank-Walter Steinmeier, in strategic terms. Their 'non-deniability' makes domestic renewable energy supply an asset for national security.

Developing countries and emerging economies that have large fossil (or mineral) resources very often suffer from the resource curse, while its milder cousin, the Dutch disease, affects developed countries with relatively strong institutions of government. While the latter is not necessarily of security concern, the resource curse leads to more autocratic and repressive government, internal strife between regions or communities for control over the resources, slower development generally, and sometimes strong militaries that can threaten neighbouring countries. Some of the regimes built on oil and gas tend to export conflict.

The growth of ever cheaper renewable energies effectively reduces the market for fossil energies, in terms of market revenue even more than in physical quantities. Autocratic regimes that benefited from fossil energy revenue are weakened and this in turn leaves room for the renewal of societies as the resource curse is partially lifted. The renewal may not be peaceful, but it is unavoidable. The ability of the regimes to export conflict is greatly reduced; there is a peace dividend from lifting the resource curse.

A similar argument can be made concerning nuclear power and the security policy price of nuclear proliferation, the spreading of nuclear technology in the form of equipment and fissile materials. The cost of containing the ambitions of autocratic regimes, in some cases even 'rogue regimes', to avail themselves of nuclear explosive devices, is very high in terms of diplomatic effort, trade sanctions as well as overt and covert operations. While, in the past, nuclear technology spread mostly among state actors or state-controlled businesses, there are an increasing number of private businesses in the nuclear industry. This tends to accelerate proliferation and increase the risk that non-state actors, such as terrorists, obtain material to make nuclear bombs, including 'dirty bombs'.

The German *Energiewende* shows that nuclear power can be phased out without harming the economy or energy security. This is not surprising, with hindsight, given the dismal economics of nuclear power generation, a fact that is also revealed by the current negotiations for the construction of the new nuclear plant at Hinkley Point in the UK.[19] Absent any rational business case for nuclear power, only one or more of the following factors can explain the building of new plants: collective economic delusion; corruption, as large-scale investments make large kick-backs possible; or (unstated) military purpose and intent.

Germany's experience and the lessons that can be drawn from it, show that nuclear power and proliferation were costly mistakes.[20] Instead of continuing to promote the 'civilian' use of nuclear power, as Germany is still committed to do under the Euratom Treaty, research and development, policy design and investment should focus on renewable energies and smart grids. International frameworks that support or protect nuclear power should be abolished, or redirected to facilitate a speedy phase-out of nuclear power. A first step would be to initiate negotiations to amend the Nuclear Non-Proliferation Treaty (NPT) and the Statute of the International Atomic Energy Agency (IAEA), and thus, in the interest of reducing the high security policy price of nuclear power, change the context for dealing with governments with aggressive nuclear programmes.[21]

In addition, the various international agreements that limit cross-border liability for damages resulting from nuclear accidents should be annulled. They provide an unjustifiable privilege to the builders, owners, operators and insurers of nuclear power plants at the expense of the victims of any accidents.[22]

Finally, the *Energiewende* is also a response to the growing security threats that are caused or aggravated by climate change.[23] Germany has helped bring down the cost of energy efficiency, renewable energy and smart-grid technologies to the point that they are cost-competitive with new and in many cases even existing fossil and nuclear energy supply. As a consequence, the German energy system transformation is self-sustaining and self-accelerating by now, and government policy has shifted to slow it in order to protect incumbent interest groups that are important for electoral reasons.

Energy transformation, German style, is likely to be replicated all over the world, for economic reasons alone, albeit from different starting points.[24] Generally, the transformations in other countries are likely to be much faster, however, as the relative costs and risks of energy technologies are now very clearly in favour of renewable energy supply. Economic rationality indicates that, therefore, no new investment will go into fossil or nuclear energy, a development that will improve energy security and lower the security policy price of energy at the same time.

Conclusions and outlook

Germany coined a new word, which the world is adopting into many languages. It is a fascinating idea: a developed country known for incremental and not radical or disruptive innovation commits to transform its energy infrastructure. To that end, it realigns its resources to research, develop, deploy and commercialize clean energy technologies and thus changes the way it powers its homes, businesses, and automobiles. If Germany succeeds, and all the indications so far point to likely success, no one can deny any more that the world is in the Age of Energy Transformation, a term found in the language agreed to at the US-EU Summit held in April 2007.

The original word *Energiewende* was made popular as the book title for a blueprint, published in 1980, of how to move beyond oil and uranium. Experts working with the Oeko-Institut, the Institute for Applied Ecology, building on ideas first spelled out by Amory Lovins of the Rocky Mountain Institute, defined a policy vector for the country, first for West Germany and later for the larger unified Germany, on which large majorities across the political spectrum agreed ever since.

Viewed in its entirety and with its evolution spanning large geopolitical changes as well as technological developments, the true nature of the *Energiewende* becomes plain to see: a slow transformation over decades. It is reasonably well monitored and managed as an adaptive policy process. Overall, it is an economically sound, low-risk strategy. With the benefit of hindsight we can now say that it could have been accelerated. Even today, its ambition is held back by what might be called an overabundance of caution.

Today, Germany has two issues that strengthen its soft power around the world: the 'Dual System' of vocational training in the arts and crafts, of technicians and managers, and the *Energiewende*. Both play well towards other perceived strengths of Germany and the Germans: technological prowess built on research as well as practical education, economic and fiscal solidity, and continuity in realizing long-term projects. It is not surprising, therefore, that a new 'Energy Foreign Policy' (*Energieaussenpolitik*) is emerging, coupled with the external climate policy developed over the past 20 to 25 years.[25] Both are strong on public diplomacy as a complement to more traditional foreign policy instruments.

The most important contribution Germany may be able to make for the success of international climate negotiations, and the regular revisions agreed to at the Climate Summit in Paris at the end of 2015, is to show that transforming the energy system, once begun in earnest, is much easier than it first appears. Many decision-makers around the world still cling to the belief that protecting the climate involves sacrifice today for the benefit of future generations. The example of Germany's *Energiewende* shows that the energy transformation produces short-term benefits that outweigh its costs, that those costs are not higher than maintaining the old, non-sustainable energy system, and that the costs are coming down as experience accumulates. Saving the planet is getting cheaper by the day.

In countries that are rich in fossil resources, the 'resource curse' tends to result in centralization, increasing corruption of elites and, ultimately, the emergence of autocratic, repressive government.[26] The experience with nuclear technology is no better, and the security policy price paid for the proliferation of nuclear technology through the energy sector, is high and rising. This is in stark contrast to the German experience, where the *Energiewende* is a contagious democratic happening driven by citizens across the country. People all around the world are fascinated by the readiness of Germans to engage and invest in the *Energiewende*, and their ability to do so as a consequence of changes in policy and regulation.

Notes

1 Carlowitz, Hans-Carl von; Joachim Hamberger (ed.), 2013 [1713], 'Sylvicultura oeconomica oder Haußwirthliche Nachricht und Naturmäßige Anweisung zur Wilden Baum-Zucht' (Sylvicultura oeconomica or economic information and natural-science-based instruction on the care of trees in the wild). München: Oekom, ISBN-13: 978-3-86581-411-1 (annotated re-edition of the historic book establishing sustainability as a principle).

2 This chapter is based on reflections begun in 2015 as Visiting Scholar at the Center for Energy and Environmental Policy (CEEPR) of the Massachusetts Institute of Technology (MIT). I am grateful to Michael Mehling, MIT CEEPR's Executive Director, and colleagues for probing and stimulating discussions. The main writing was part of a research fellowship at the Institute for Advanced Sustainability Studies (IASS) in Potsdam, building on earlier work at Ecologic Institute, Berlin, Germany. Jane A. Johnston helped with many comments and edits on drafts.

3 Germany still has a small number (of around one dozen) nuclear warheads provided by the USA with dual key controls, legally making Germany a nuclear weapons state. This is symbolic and of no practical or political relevance.

4 See Chapter 6 in this volume.

5 Kraemer, R. Andreas, 'Security Through Energy Policy: Germany at the Crossroads'. *eJournal USA* 14, no. 9 (2009): 19–21, http://ecologie.ev/2984.

6 Soft, brown coal, or lignite, is relatively heavy for the energy it contains and is best used close to the mine. Industrial development based on lignite would have been very different to what has been.

7 See Kraemer, R. Andreas, 'Dissolving the "Westphalian System": Transnationalism in transboundary water management', in *Strategic Review* 2, no. 4 (2012): 43–47. http://ecologic.eu/7434.

8 For an interesting contemporary assessment see Director of Central Intelligence (1982), 'The Soviet Gas Pipeline in Perspective'. CIA document SNIE 3–11/2–82 of 21 September 1982. URL: www.foia.cia.gov/sites/default/files/document_conversions/89801/DOC_0000273322.pdf. For a thorough treatise of the shift from oil to gas in Germany, see Duffield, John S. (2014), 'Germany: From Dependence on Persian Gulf Oil to Russian Gas', in John S. Duffield, *Fuels Paradise – Seeking Energy Security in Europe, Japan, and the United States* (Baltimore, MD: Johns Hopkins University Press), 151–194.

9 For the history of the nuclear industry in Germany see Radkau, Joachim, and Lothar Hahn, *Aufstieg und Fall der deutschen Atomwirtschaft* (The Rise and Fall of the German Atomic Industry) (München: Oekom Verlag, 2013).

10 See www.oeko.de/en.

11 The eight leading institutes form the Ecornet Ecological Research Network, see www.ecornet.eu.

12 Krause, Florentin, Hartmut Bossel, and Karl-Friedrich Müller-Reißmann, *Energiewende – Wachstum und Wohlstand ohne Erdöl und Uran* (Frankfurt am Main: S. Fischer, 1980).

13 Lovins, Amory (1976), 'Energy Strategy: The Road Not Taken', *Foreign Affairs*, October. www.foreignaffairs.com/articles/united-states/1976-10-01/energy-strategy-road-not-taken. Also available as a reprint (with an introduction) at www.rmi.org/Knowledge-Center/Library/E77–01_EnergyStrategyRoadNotTaken.

14 For his contribution to the *Energiewende*, Amory Lovins was awarded the Officer's Cross of the Order of Merit of the Federal Republic of Germany on 17 March 2016.

15 Stefes, Christoph H., 'Bypassing Germany's Reformstau: The Remarkable Rise of Renewable Energy', *German Politics* 19, no. 2 (2010): 148–163. http://dx.doi.org/10.1080/09644001003793222.

16 See www.kombikraftwerk.de/100-prozent-szenario/power-flow-animation.html.

17 Morris, Craig (2015), 'Germany's cheap, green energy keeps aluminium sector healthy', *Renewables International*, 30 March. http://reneweconomy.com.au/2015/germanys-cheap-green-energy-keeps-aluminium-sector-healthy-58772.

18 Frank-Walter Steinmeier, the German Foreign Minister, identified domestic renewable energy as being 'non-deniable' by enemy action (short of invading the territory of Germany), in his speech on

26 March 2015 at the Berlin Energy Transition Dialogue (BETD). www.energiewende2015.com/wp-content/uploads/2015/03/150326-Berlin-Energy-Transition-Dialogue-Rede-BM-Steinmeier.pdf (in German).

19 See Chapter 15 in this volume.

20 'We will look back and think that nuclear was an expensive mistake', Paul Massara, chief executive of RWE NPower, one of the UK's big power generators, as quoted in Pratley, Nils, and Sean Farrell (2015), 'Planned Hinkley Point nuclear power station under fire from energy industry', in *The Guardian*, 9 August 2015. www.theguardian.com/environment/2015/aug/09/planned-hinkley-point-nuclear-power-station-energy-industry. (The original article was published in the *Sunday Times*.)

21 See Kraemer, R. Andreas (2010), 'A Transatlantic Agenda for Global Nuclear Governance', summary of the 7th Transatlantic Energy Governance Dialogue convened by the Global Public Policy Institute (GPPI) and the Brookings Institution, Potsdam, Germany, 4–5 March. http://ecologic.eu/3303.

22 See Kraemer, R. Andreas, 'Germany, Fukushima and global nuclear governance', *Strategic Review* 2, no. 4, (2012): 143–152. http://ecologic.eu/7436.

23 See Chapters 3 and 4 in this volume.

24 Kraemer, R. Andreas, and Christoph H. Stefes, 'The changing energy landscape in the Atlantic Space', in Jordi Bacaria and Laia Tarragona (eds), *Atlantic Future. Shaping a New Hemisphere for the 21st century: Africa, Europe and the Americas* (Barcelona: CIDOB, 2016), 87–102.

25 See, for instance, Müller-Kraenner, Sascha, *Energy Security* (London; Sterling, VA: Earthscan, 2008), 141–156.

26 See Chapters 8 and 10 in this volume.