Ecological Modernization as Global Industrial Revolution

Martin Jänicke*

Abstract: This article uses the concept of “Industrial Revolution” to underline the extraordinary speed and the global scale of ecological modernization (EM). The focus is on clean energy technologies, the core of this dynamic change. In several countries there is not only an unexpected speed of clean energy diffusion but also a policy feedback, indicated by more ambitious targets. The highest degree of change so far has been achieved by the power sector of the European Union. Beyond environment and climate related concerns there are two main explaining factors: first, the polycentric system of multi-level global governance as a “multi-impulse system” supporting a broad innovation and lesson-drawing; second, the lesson to be learned is about the co-benefits of EM which can be attractive for relevant actors. There are however clear limits of the current state of EM regarding its environmental effectiveness and its distributional equity. Ecological modernization needs to be completed by structural change away from resource-intensive and environmentally disruptive branches, infrastructures and life styles. This remains a big challenge.

Key Words: Ecological Modernization, Green Industrial Revolution, Structural Change, Co-Benefits

I. Introduction

In this article the concept of “Green Industrial Revolution” will be used to highlight phenomena of global change in terms of ecological modernization. Both are processes of dominant radical eco-innovation, characterized by a high speed and a global scale of diffusion. Low-carbon technologies for instance have extraordinarily high rates of diffusion. The scale of their diffusion is also remarkable. It is a global process, as have been the Industrial Revolutions of the 19th and 20th Century (Table 1). Environmental concerns and the

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environmental needs of the new global middle class are well known drivers of this global change. The article will in addition underline the role of the polycentric system of multi-level governance as opportunity structure for intensified global communication, innovation and lesson-drawing. The lesson to be learned is to address the co-benefits of EM to relevant interests and to transform environmental and climate policy objectives into business opportunities. This is what ecological modernization is about. It is a policy-driven market-based strategy of greening the economy beyond traditional clean-up technologies (“end-of-pipe treatment”). This strategy can be highly attractive for economic actors due to the implied economic co-benefits: innovation, new markets and jobs, or increased resource-productivity and competitiveness to mention only a few of them. The motors of the Green Industrial Revolution are essentially: (a) a global process of interactive learning in the polycentric “multi-impulse system” of multi-level governance, (b) the attractiveness of the economic lesson to be learned for relevant interests and (c) a new mode of governance. Reflexive governance – advanced “learning by doing” - can contribute to strategies which raise the ambition of green policy objectives. This is the strategic approach which has been adopted in the Paris Agreement. The dynamics of increased ambition can be explained by the interaction of policy, markets and innovation cycles. The special advantage of the new approach is its focus on voluntary action, based on real interests. Since energy is the core of any Industrial Revolution, the focus of this article will be on energy and climate-related technologies.

The author has used the concept of ecological modernization (EM) since 1982.\footnote{Contrary to the sociological theories on EM which have}
been published later (Hajer, 1995; Mol, Sonnenfeld and Spargaren, 2009), this concept was established in the tradition of policy analysis and policy advice. It has played a programmatic role in the German red-green government (1998-2005) and has been broadly adopted. Today they are synonymous with terms such as “green growth”, “green development”, or the creation of “green economy”. This article will extend the author’s concept of ecological modernization in the context of new research.

II. Dimensions of the Green Industrial Revolution

1. What is an Industrial Revolution?

There have been two Industrial Revolutions in the 19th and 20th century, both of which began late in the previous centuries (Table 1). As historical stages of development, they can be differentiated by dominant energies, dominant technology and materials, transport and communication system, basic socio-political structure, and leading countries.

1) The author has used the concept of “ecological modernization” first 1982 in a parliamentary speech and in a presentation on a conference on employment. 1984 it was the topic of a study of the Science Center of Berlin (Jänicke, 1985).
2) Today there is also the concept of a Fourth Industrial Revolution, mainly characterized by digitalization. However this was already included in the former concept of the Third Industrial Revolution. Therefore there is no need to introduce a new one, which could lead rather to confusion than to a systematic approach.
There are many definitions of Industrial Revolution (e.g. Rifkin, 2011), or Green Industrial Revolution (Fücks, 2013; Clark and Cooke, 2014; Sillíanpää and Ncibi, 2017). As a process of radical technical change, Industrial Revolutions can be characterized by the following criteria:

1. *dominance of radical innovation (vs. incremental innovation)*,
2. *high speed of technological change*,
3. *global scale of diffusion*,
4. *basic structural change* of the societal and political context
5. *long-term effects*.

The “*Green* Industrial Revolution” is characterized by additional factors:

It is caused by *the multiple crisis of the 20th century industrialism* and its basic technologies. This type of industrialism was based on cheap non-renewable resources. And it has caused environmental damages which finally undermined even the productive basis of the
ecology. Solving this crisis by clean and resource-efficient technologies offers a wide range of co-benefits. This is what EM is about.

It should be added that clean technologies today also include more and more nature-based technologies. The “greening” of the economy therefore includes the extension and improvement of the bio-sphere as a basis of life and production as well as a contribution to climate mitigation / sequestration and bio-diversity.

The Green Industrial Revolution is to a high degree “policy-driven” (Ernst and Young, 2006; OECD, 2011). It takes place under the condition of a new polycentric model of global multi-level governance (Ostrom, 2010; Sovacool, 2011). This provides an opportunity structure for intensified communication and “lesson-drawing” (Rose, 1993) from innovation and best practice (Jänicke, 2017). The mode of governance has also been innovated. Reflexive governance as interactive and adaptive policy of learning by doing has become more and more important. It includes the integration of a broad spectrum of actors and stakeholders.

The Green Industrial Revolution therefore means basically: radical technical innovation which is directed towards clean technology (vs. clean-up technology). This may be exemplified by the radical innovation of solar energy as opposed to the incremental innovation of increased efficiency of a coal power station. Radical eco-innovations contribute to an absolute de-coupling of economic growth from resource use and its negative environmental impacts. What makes it even more ideal is that they have no rebound effect, where growth effects and increased demand offsets the environmental improvement (Jänicke, 1985; Gillingham, Rapson and Wagner, 2014).
Radical innovations can also be the combined effect of several incremental innovations. There are typically also social innovations in the context of a radical innovation. Citizen-based decentralized green power supply in an example.

Green Industrial Revolution is the answer to the environmental and resource-related dilemmas of traditional 20th century industrialism. However, it is increasingly driven also by the multiple co-benefits of EM—from increased resource productivity, competitiveness and innovation to new markets, higher employment or reduced health expenditures. This can create a new interest base, which can lead to a policy feedback with increased ambition (Jänicke, 2012).

The Green Industrial Revolution also accelerates the processes of eco-innovation and their diffusion by new modes and institutions of global governance. The crucial social innovation in this regard is the polycentric system of multi-level governance dating back to the UN summit in Rio de Janeiro (1992). Today it is considered a “fast breeder” of innovation and peer-to-peer lesson-drawing. It is also a “multi-impulse system” where stimuli from different points of the system can have the same combined effect as a strong policy instrument (Jänicke, 2017). Each level of the global system has its own agenda, challenges and opportunities and its specific networks and modes of co-operation. There is for instance a climate-related cooperation and lesson-drawing at the continental level of the system, an example of which being the climate partnership between the European Union and the African Union, which influenced the (UNFCCC, 2015). There is, however, an even more intensive process of world-wide lesson-drawing at the national and sub-national levels of the global system of climate governance. The cooperation of cities
on low-carbon development is well-known (REN21, 2017). And there are vertical up-scaling processes of eco-innovation and best practice as well as top-down support for such processes. This mode of governance is highly attractive for relevant actors at different levels of governance. It is essentially a voluntary action – in times when legally binding solutions are increasingly unpopular.

The diffusion of clean technology is global because it addresses global problems and global environmental needs. This process can have long-term effects because it creates new vested interests in several sectors of the economy, from energy to construction.

These long-term effects will be explained in more detail in the following section.

2. Ecological Modernization (EM)

Industrial Revolutions are dramatic processes of modernization. The Green Industrial Revolution is basically ecological modernization (EM): the rapid, global diffusion of technical and social innovation, that has low impacts on the environment and save non-renewable resources.

When the author used the concept of “ecological modernization” first in Germany, it was to open a new field of innovation and employment trough an environmental policy strategy beyond the conventional “end-of-pipe treatment” (Jänicke, 1982). Instead of adding a pollution control technology to a “dirty” process or product, a basically cleaner technology would be introduced. Instead of an essentially unproductive additional investment in pollution control, an essentially low-impact technology would be preferred. It could be highly productive because it improves resource efficiency at the same
time. As a scientific concept “ecological modernization” was proposed in 1984 in a study for the Berlin Science Centre (Jänicke, 1985). It had broadly circulated within the so-called “Berlin School of Environmental Policy Research” before it became a political formula of the red–green federal Government in Germany (1998–2005). In the coalition treaty of this government, “ecological modernization” was characterized as: “…integration of labour and environment”, with the implication of “increased eco-efficiency, lower production costs and improved competitiveness” (Sozialdemokratische Partei Deutschlands, 2002). This description is relevant in the context of this article, because it already mentions several economic co-benefits of EM.

The original idea of EM was to use the inherent pressure for innovation in competitive capitalist market economies to transform the traditional resource-intensive and environmentally disruptive mode of industrialism. This was similar to the idea of “ecologizing the economy”, which was developed at the same time (Huber, 1982). In the environmental science debate, the concept of EM has been in widespread international use since the early 1990s (Weale, 1992; Hajer, 1995; Young, 2000; Mol, 2001; Mol, Sonnenfeld and Spargaren, 2009: Andersen, 2010). The author contributed again to this literature by describing EM as policy-driven processes of eco-innovation and its diffusion. Together with Klaus Jacob he underlined the multiple interactions between policy and technology, which could, for instance, be exemplified by policy-induced lead markets for clean technologies (Jänicke, 2000; Jänicke and Jacob, 2006).

Today we find several synonyms of ecological modernization, the most important being the creation of a green economy (OECD, 2011; UNEP, 2011). Now it includes not only all kinds of innovative
“nature-based solutions” (NBS) (Maes and Jacobs, 2017) and sustainable bio-economy (Sillanpää and Ncibi, 2017), but also preconditions such as afforestation. The EU aims to be the world leader of “nature-based solutions” (EU Commission, 2015). NBS is strongly connected to natural systems of agriculture, general natural solutions, eco-system-based approaches, green infrastructures or ecological engineering (Eggermont et al., 2015). It can be regarded as an extension of the traditional concept of EM in the direction of nature-based innovations.

<table>
<thead>
<tr>
<th>Curative Approaches</th>
<th>Preventive Approaches</th>
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<tr>
<td><strong>Repair</strong></td>
<td><strong>End-of-Pipe</strong></td>
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<tr>
<td>Adaptation,</td>
<td>Pollution Control</td>
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<tr>
<td>Compensation</td>
<td><strong>Ecological</strong></td>
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<td></td>
<td>Modernization</td>
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<td>Eco-efficient innovation</td>
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<td><strong>Ecological Structural Change</strong></td>
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<td>Transition Management</td>
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<tr>
<th>Repair</th>
<th>Preventive Approaches</th>
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<tr>
<td>Adaptation to climate change</td>
<td>Resource productivity</td>
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<tr>
<td>Soil sanitation</td>
<td>Renewable Resources</td>
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<tr>
<td>Re-cultivation</td>
<td>Substitution of materials</td>
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<tr>
<td>Repair of environmental damage</td>
<td>Recycling</td>
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<tr>
<td>−Desulphurisation</td>
<td>Change of:</td>
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<td>−Catalytic converters</td>
<td>−Branch structures</td>
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<td>−Carbon Capture &amp; Storage</td>
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<td>−Passive Noise Protection</td>
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EM can lead to a structural change, which reduces the share of environment and resource-intensive sectors. But there are several cases where eco-innovation takes place without any change in structure. In some countries we find for instance a parallel increase of renewable energy and coal power. In consideration of this, a green structural change policy is the necessary second step of EM. (Table 2).
3. The Co-Benefits of EM

“Co-benefits” have first been discussed in the context of climate change mitigation (Mayrhofer and Gupta, 2016). In this article, the concept will be extended to the green economy in general. Early on, co-benefits became a “no-regret” argument, according to which the positive economic side-effects should suffice for legitimizing the respective climate change mitigation measure (Adler, 2000). Over time, in addition to positive side-effects, *multiple* benefits were increasingly addressed. In 2014, the International Energy Agency (IEA) published a list of 15 such co-benefits, which can occur through greater energy efficiency alone (IEA, 2014). The Fifth Assessment Report issued by the Intergovernmental Panel on Climate Change (IPCC, 2014) arrived at 18 potential economic, ecological, and social co-benefits of climate change mitigation. The World Bank calculated positive co-benefits in the areas of health, energy savings, and agriculture (The World Bank, 2014).

The Japanese Ministry of the Environment has used the following definition of co-benefits (Ministry of the Environment, Japan, 2009):

“Co-benefits refer to multiple benefits in different fields resulting from one policy, strategy, or action plan. Co-beneficial approaches to climate change mitigation are those that also promote positive outcomes in other areas such as concerns relating to the environment (e.g., air quality management, health, agriculture, forestry, and biodiversity), energy (e.g., renewable energy, alternative fuels, and energy efficiency) and economics (e.g., long-term economic sustainability, industrial competitiveness, income distribution).”

The global co-benefits of renewable energy have been reported by the International Renewable Energy Agency (IRENA). The 2017 Report
gives the figure of 9.8 million jobs in the main countries included in the study (IRENA, 2017) and 3.955 million jobs in China alone. The World Bank has calculated the health and energy benefits from climate change mitigation in China, India, USA, EU, Brazil and Mexico for 2030. The figure was 1.23 trillion dollars (The World Bank, 2014).

It is not easy to explain why the “multiple benefit approach” has been restricted to climate protection while EM may have even more co-benefits. Like the low-carbon economy, it is characterized by a double advantage of higher resource-efficiency and lower environmental damage, both offering a broad spectrum of innovation, lower costs, new markets and jobs. Co-benefits therefore are an important argument for EM in general. Together with environmental and resource-related concerns, they are an important explanation for the Green Industrial Revolution.

This can be exemplified by the flow of material resources along the value chain. At each stage of the production process, we have a large variety of resource uses, the reduction of which can lead to economic, ecological and social co-benefits (Table 3).

<table>
<thead>
<tr>
<th>Reduced Material Flows</th>
<th>Economic Co-Benefits</th>
<th>Environmental Co-Benefits</th>
<th>Social Co-Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>Lower Cost of</td>
<td>Reduced</td>
<td>Improved</td>
</tr>
<tr>
<td>Basic Industries</td>
<td>-Materials</td>
<td>-Emission</td>
<td>-Health</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>-Energy</td>
<td>-Dissipative losses</td>
<td>-Employment</td>
</tr>
<tr>
<td>Retail trade</td>
<td>-Water</td>
<td>-Waste</td>
<td>-Taxes</td>
</tr>
<tr>
<td>Final consumption</td>
<td>-Transportation</td>
<td>-Loss of living space</td>
<td></td>
</tr>
<tr>
<td>Waste management</td>
<td>-Land use</td>
<td>-Loss of species and functions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Pollution control</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Competitiveness</td>
<td></td>
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<tr>
<td></td>
<td>Innovation</td>
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<tr>
<td></td>
<td>New materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Income</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Balance of Trade</td>
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</table>
When it comes to the first stage of mining, we can draw the conclusion that if this stage could be avoided by using recycled materials, the use of energy, water, land, and transport or the deposition of overburden can be reduced. A co-benefit would also be to reduce the necessary environmental protection or restoration measures. Recycling, in addition, means less final disposal of waste. All this can reduce costs, improve competitiveness, or induce innovation. The national economy will benefit from this in terms of additional income, which implies further benefits to follow, such as tax income. The ex-ante design of products, for instance, can also have many co-benefits: Should products be decreased in scale or have a longer life cycle, a huge amount of resources of all kinds – from raw materials to energy – and water used for transportation or land use will be saved. Such co-benefits have, of course, to be balanced with negative impacts such as loss of jobs in the mining sector.

The importance of co-benefits of EM may be illustrated by the example of the German Chemical Industry (Table 4):

<table>
<thead>
<tr>
<th>(Table 4) Indicators of the German chemical industry 2000–2013 (VCI, 2015)</th>
<th>2000</th>
<th>2013</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnover (billion euros)</td>
<td>135</td>
<td>190.6</td>
<td>+41.2</td>
</tr>
<tr>
<td>Value added (billion euros)</td>
<td>40.1</td>
<td>51.8</td>
<td>+20</td>
</tr>
<tr>
<td>Energy consumption (TJ)</td>
<td>727,089</td>
<td>645,470</td>
<td>−12.6</td>
</tr>
<tr>
<td>Greenhouse Gas Emissions (Mt.)</td>
<td>50.7</td>
<td>45.1</td>
<td>−11</td>
</tr>
<tr>
<td>Water use (billion cbm)</td>
<td>3.31</td>
<td>2.62</td>
<td>−20.8</td>
</tr>
<tr>
<td>Waste disposal (Mt.)</td>
<td>2.31</td>
<td>0.88</td>
<td>−61.9</td>
</tr>
</tbody>
</table>

The increased added value between 2000 and 2013 could be achieved with lower absolute resource consumption and pollution.
Although ambitious environmental and climate policy measures were taken at this time (which often faced heavy resistance), the German Chemical Industry remained highly competitive. Seen from today, this was also due to various means of cost reduction, from energy and materials to water, waste or land use. It can also be attributed to a pressure for innovation, which has been exerted after 1998 by a government with an explicit orientation towards “ecological modernization” (see sect. 3).

4. A high Speed of Change and a Global Scale of Diffusion

As mentioned above, Industrial Revolutions are not only characterized by the high impact of their innovations, but also by the speed of technical change and its global diffusion. Roland Berger has found out, that the global diffusion of selected clean technologies (resource efficiency, clean energy, sustainable mobility or water management) had a real growth rate of 6.5% and could achieve a volume of 5,385 trillion € in the world market by 2025 (BMU, 2014). Energy is the dynamic core of this systemic change (with 7.4% global growth of renewable energy). Therefore, low-carbon technologies will provide a good example in this respect. It should, however, be mentioned that other clean technologies have similar global growth rates (sustainable mobility: 9.6%; resource efficiency: 8.1%; sustainable water management: 5.7%; BMU, 2014). Hence, the development in the energy sector is not an isolated process and a high speed of EM can be observed in other sectors as well.

In several countries, an unexpected speed of diffusion of renewable energy technologies, particularly technologies of wind and solar
power, has been observed. The fact that the share of new added green power capacity increased from 20% (2012) to 62% (2016) world-wide provides a piece of proof to this astonishing speed. In the EU, it increased from 57 (2008) to 86% (2016) (REN21, 2017). This profound transformation process of the European power sector was policy-driven. And in many countries, heightened ambition as a form of policy feedback was observed: the unexpected speed of diffusion of wind or solar power installations often resulted in stricter targets. Germany has increased its 2020 green power target several times, from 20% eventually to 35%. China was more radical, increasing the wind power target for 2020 step by step from 20 GW to more than 210 GW (with the real grid connection being lower). Other examples can be found in Portugal, or India, at the sub-national level in Scotland or Texas (Jänicke, 2012, 2017).

The examples belong to the well-known success of renewable energies. There has also been, however, occasions where the unexpected reduction of greenhouse gases stimulated a similar feedback. The UK, for instance, increased its greenhouse gas emission (GHGE) reduction target for 2020/25 several times, from 12.5% to 50%. This was a reaction to the fact that the GHGE had been reduced by 36.6% already by 2015 (compared to the 1990 level). Sweden and Denmark, together with Germany, increased their 2020 greenhouse gas target to 40% (Jänicke and Quitzow, 2017).

The rapid diffusion of renewable energy technology was paralleled by a diffusion of supporting policies and instruments. Political clean-energy targets had an extremely high speed of global diffusion. The number of countries with such targets increased from 55 (2005) to 176 (2016), which more than doubled within a few years (REN 21,
Energy-efficiency targets exhibited nearly the same dynamics (2016: 128 countries), although this approach is often more difficult to implement. A similar speed of diffusion was characteristic for energy-efficiency standards (e.g. for cars or buildings). For a long time, this dynamic process of policy diffusion had been distinctive only to the OECD and some emerging countries like China and India. Meanwhile, the developing countries are rapidly catching up, at least regarding policy support for renewable energy. The share of developing countries with such policies increased from nearly zero to 62% (early 2015) (REN21, 2016). A clear global scale of diffusion and lesson-drawing regarding renewable energy has been achieved. The number of climate related regulations in general have increased from about 60 (1997) to more than 1,200 (2016), and two thirds of the total increase took place since 2008 (Nachmany, Frankhauser, Setzer and Archenkova, 2017). Most remarkable is that this dynamic process of global policy diffusion was nearly completely voluntary and not the result of legally binding international treaties.

5. Structural Change and Long-term Effects

The long-term effects of global socio-technical change – or its final stability – refer to the “creative destruction” of the pre-existing interest base (Schumpeter, 1942; Patashnik, 2008). This holds immense importance because, as mentioned above, EM needs to be supported by structural change. Modern capitalism is able to integrate many innovations that seem to be “alternatives”. Clean technologies seem to be an alternative to “dirty industries”. However, in reality, they often co-exist and one’s growth can go in parallel with the other’s. Therefore, the structural change from the existing interest
base of the dominant technology to a new one is a critical aspect of EM.

Phasing out fossil fuels could be the test case for the energetic core of the Green Industrial Revolution. Again, the European Union and particularly its power sector is a pioneer. While the power sector is changing rapidly with green power accounting for 86% of the newly added capacity, its interest organization EURELECTRIC also decided to put an end to new coal power plants by 2020. Only two national members voted against (Greece and Poland). There are also several EU member states who decided to phase out energy-related coal consumption by 2022 (France), 2025 (UK) or 2030 (Finland, Austria, Portugal, Italy and The Netherlands).

Coal-fired power collapses not only in Europe and Canada (aiming for complete phase-out by 2030), but also in the U.S., irrespective of the actions taken by the Trump government. Coal consumption has also been restricted in China and India. Bloomberg New Energy Finance expects 369 new coal power plant plans to be canceled globally. This is indeed a “creative destruction”, although there are still strong counter-tendencies in the coal sector. The stability of the traditional fossil-fuel system is even stronger as long as oil and gas are concerned. Structural change has, however, began to emerge in this sector as well. Irrespective of the continued increase of global oil consumption, there has been a reduction in capital expenditures of the oil and gas sector (Carbon Tracker / PRI, 2017). It could rebound again. In the long run, nevertheless, it may be stabilized by changes in the transport and heating sector.

The stability of energy transition has also been increased by institutional change as has been described in section 5 (see also
The institutionalization of climate policy has reached a remarkable degree at the global level (UNFCCC, IPCC) as well as at the regional (continental), national and sub-national level, where climate-related sub-systems have been created. It has to be underlined anew that the transition of the global energy sector has been the core of the Green Industrial Revolution, which is still on-going. Energy has also been at the center of the other two Industrial Revolutions in the 19th and 20th century.

The broader institutionalization of EM or the green economy in general is less impressive than the institutional architecture of climate policy and the low-carbon economy. However, with the SDGs, a global strategy with targets and time-frames, based on a global consent, has been established (Kanie and Biermann, 2017). Institutional arrangements include strong economic institutions as the World Bank and the OECD. The Council of the EU has called on the EU Commission to set out an implementation strategy with timelines, objectives and concrete measures to have all EU policies reflect the 2030 Agenda by mid-2018 (Council of the EU, 2017).

The global diffusion of standards and targets contribute to a certain global “governance by diffusion” (Jörgens, 2004). Here the demonstration effect and the competitive pressure of countries like Germany or China can be regarded as a substitute of global governance for EM. In many countries, the environmental policy is also conceived as industrial policy (Hallegatte et al., 2013). This has also indirectly stabilised the institutional basis of EM. The EU is generally a strong player in this regard (Walz, 2015). Climate policy was called explicitly a reason to revitalize its industrial policy (EU Commission, 2007; Jänicke and Quitzow, 2017).
6. Governance

How can the remarkably high speed of global socio-technical change be explained? As had been already mentioned above, global EM is a market and innovation process which is essentially policy-driven (Jänicke and Jacob, 2006; OECD, 2011; REN21, 2017). The policy was first motivated primarily by the ecological crisis. Later on, it was progressively influenced by new opportunities and co-benefits of this process. While the ecological crisis had to be solved at first by expensive end-of-pipe technology (the high costs often causing resistance), the innovative approach of EM was often more profitable, more interest-based and voluntary. It provided often new opportunities and co-benefits. Accordingly, it also resulted in reduced resistance. In Germany, for instance, illegal reaction increased along with the rising costs of add-on pollution control (until the late 1990s). As more and more of this type of forced investment in expensive (and unproductive) add-on technology have been substituted by investment into clean(er) technology, mainly after 1998, the illegal pollution (e.g. illegal waste disposal) has declined. The stark contrast of strong resistance against expensive pollution control and increased acceptance of eco-innovative approaches is highly important but often ignored. It means a completely different situation for governance: Governments are not acting alone, but together with a broad spectrum of actors and stakeholders. Now it is mainly governance with a strong role of collective learning by doing. “Reflexive governance” has become the most adequate approach.

The success of this governance approach, however, can only be fully understood in the institutional context of multi-level governance. This is a polycentric system providing the opportunity structure for
intensive communication and interaction – a system supporting accelerated lesson-drawing from best practice of ecological modernization. The lessons to be learned are essentially the economic co-benefits of this process.

1) Innovation and Lesson-Drawing in the Polycentric System of Multi-Level Governance

The multi-level system of environmental and sustainability governance dates back to the UN summit in Rio de Janeiro (1992). This conference tried to give an answer to the following question: how could billions of global citizens be mobilized for the strategic objective of sustainable development? One important answer was to translate the global strategy into the language of national and local policies. In 2002 at the UN Johannesburg summit the provincial level was also included. In the last years, the “continental” level (with global players such as the EU or the African Union) became part of the multi-level approach as well. Climate governance with its strong implications for rural communities has stimulated a new interest even at the lowest level: the villages. Meanwhile, it has become clear that each level of global governance has its own agenda, its own challenges, opportunities, institutions and networks. And it has its own distinctive mechanism of peer-to-peer lesson-drawing from innovative solutions for given environmental and resource problems. The system has a global goal structure. In addition, it has a global knowledge base provided by institutions such as the IPCC or the Intergovernmental Panel of Biodiversity, the UNEP or the World Bank. And it has a global policy arena including not only the UN-System, the G7, or G20, but also a broad range of global policy networks
(Biermann, 2014; Jänicke, 2017). This system of multi-level governance is the main condition for the explosion of learning and the global scale of the Green Industrial Revolution.

This system of governance has been developing since 1992. Today we find an advanced system of multi-level governance in the EU with institutional arrangements at all levels (Jordan, v. Asselt, Berkhout, Huijtema and Rayner, 2012; Schreurs and Tiberghien, 2007, Geels, 2011; Stephenson, 2013). There are also multi-level green economy approaches in the U.S., China, or India.

Multi-level governance has been used first for implementing the UN sustainable development strategy, from global to local. However, it has proven to be far more successful in global climate governance. It furthermore seems to be highly relevant to EM as an opportunity structure for innovation and lesson-drawing. This process is essentially interest-based and driven by interactive learning from best practice. In the literature it has been described as a “polycentric system” (Ostrom, 2010; Sovacool, 2011). In this article the concept of a “multi-impulse system” is preferred. It does not refer to the structure of the system but to its impacts. The original idea here was that multiple impulses from different points of the systems can have a strong effect on innovation and best practice. And the sum of such impulses – mainly incentives to learn – could have the same innovative effect as a strong policy instrument, which is often not feasible (Klemmer et al., 1999). In the multi-impulse system of EM, the impulse can be an economic stimulus provided by a higher level of the governance system. It can be competitive pressure. It can be transferred by co-operation within networks, or be a new socio-technical solution in another country or city. The impulses can
come along levels and across levels of governance. The system of multi-level governance is a kind of “fast breeder” of lesson-drawing from innovation and best practice because it is a system of intensified horizontal and vertical communication.

2) “Progression over Time” and “Reflexive Governance”

The extraordinary speed and scale of technical and political change towards a greener economy is based, to a high degree, on interactive learning (Grin and Loeber, 2007). Again, climate governance is the most advanced field of EM. And “progression over time” is the most exciting example. It refers to the mechanism of the Paris Agreement (Art. 3, 4) that the Parties of this agreement are expected to increase their climate change mitigation ambition through repeated rounds of strengthening their Nationally Determined Contributions (NDCs). The indicators for this are the climate policy targets. This is a policy innovation which is based on empirical best practices in different countries. It refers to a process, where political actors start with (a) an ambitious target-based policy (e.g. support for renewable energy), which induces (b) a market cycle which leads (c) to product and/or process innovation. This tripled cycle of innovation typically brings about not only technical improvements and lower production costs. Often times this also creates a new interest base (Jänicke, 2017). And this, in turn, can lead to a “policy feedback” (Pierson, 1993) of increased ambition, based on the new interests and perceived opportunities arising from the process (IPCC, 2014; Umweltbundesamt, 2016). A practical description of this feedback process of interactive learning has been provided by the Indian government in its “Solar Mission”: 
“The immediate aim of the Mission is to focus on setting up an enabling environment for solar technology penetration in the country both at a centralized and decentralized level. The first phase (…) will focus on capturing of the low-hanging options…In the second phase, after taking into account the experience of the initial years, capacity will be aggressively ramped up to create conditions for up scaled and competitive solar energy penetration in the country” (Government of India, 2010). India has meanwhile increased its target for implementing solar by 2022 from 20 GW to 100GW.

This is also an example of “reflexive governance”. The concept has been first used by Voß and Kemp in the context of sustainable development (2005). It defines a mode of governance by which experiences on the level of implementation are transferred to the level of governance. This feedback mechanism allows the steady reformulation and adaption of strategies (Brousseau, Dedeurwaerdere and Siebenhünner, 2012; Voß and Bornemann, 2011). It also allows “progression over time” based on learning by doing and increased capacities resulting from the process. Learning is also the effect of a broad interaction with stakeholders. Our own research has applied the concept of reflexive governance to explain reinforcement effects in multilevel governance systems (Jänicke and Quitzow, 2017).

7. Evaluation: The Strengths and the Limits of EM

A long time has already passed since the Green Industrial Revolution has started at the end of the last century in European countries like Germany or Denmark, but also in California or Japan and Korea. Therefore, a short evaluation of the results, which so far
have been achieved, seems probable. Especially with regard to the criticism on EM that has arisen in the meantime, an evaluation seems highly asked for.

Using the four broadly accepted criteria of policy evaluation (e.g. Wollman, 2007; IPCC 2014) – *environmental effectiveness, economic efficiency, distributional equity and political feasibility* – the following general assessment could be reached: EM has achieved a high speed of change and a global scale of diffusion because it is an economic approach to environmental policy that is relatively easy to realize; that is, EM has a *high feasibility*. One reason for this is the high *efficiency* of the approach which tends to save resources and, in turn, often leads to lower production costs, particularly when compared to the high and unproductive investment in end-of-pipe technologies. This is part of the potential economic co-benefits of EM, from increased competitiveness to innovation and employment. EM has a high feasibility because its co-benefits can be addressed to relevant interests of the society. Hence, it is essentially an approach which is more interest-based than norm-based (van Schaik and Schunz, 2012), more voluntary than “legally binding” and more an opportunity than a burden. The strength of EM and its global dynamics as Industrial Revolution are efficiency and feasibility.

However, there also are weaknesses, which have been criticized in recent times. This critique relates mainly to two of the aforementioned evaluation criteria *effectiveness* and *equity*. The effectiveness (the degree of achievement of the intended goal) of EM has been disputed by several authors (e.g. York and Rosa, 2003; Ewing, 2017). And indeed, many environmental problems have not been solved; sometimes they have been even exacerbated. Soil
pollution, loss of species and, of course, climate change are problems which are far from being solved. Not all environmental problems can find a technical solution. In the first publication on EM already, the environmental impact had been regarded to be potentially subject to reduction by growth effects (Jänicke, 1985). Other authors stress the rebound effect, where increased resource efficiency becomes offset by higher use of resource due to the saved money (Gillingham, Rapson and Wagner, 2014). Henceforth, the dominance of radical innovations (e.g. PV, plus-energy houses, or electric vehicles), which cannot be easily neutralized by higher consumption, holds great importance. Other options are dynamic targets and standards, or a clear cap.

Still, the main problem remains: as the author pointed out earlier, structural change is a necessary complement to EM (Jänicke, 1985). As far as the energetic core of the “Green Industrial Revolution” is concerned, some of the first steps towards coal phase-out can be observed: nevertheless, the main task of structural change or the transition of the energy sector is yet to be done. The same is true regarding the volume of transported goods, air traffic, or industrialized agriculture. It is important to underline that in such sectors, the feasibility of structural change is significantly lower than in the market-based innovation process with various co-benefits that accompanies EM. Structural change is immediately confronted with the losers of the process. This is different from the booming markets of renewable energies.

The author has also identified the selectivity of EM as a weakness. What this indicates is that the focus on technical solutions tends to ignore non-technical solutions. And the emphasis on profitability may
lead to an underestimation of solutions that are not profitable (e.g. increased biodiversity). Policy intervention is often necessary to prevent environmental disruption. The loss of productive soil is an example. And of course, the “greening of the economy” must progressively include the real green and nature-based solutions. In many parts of the world - particularly in poor rural villages - this kind of green and nature-based development has become a great opportunity. It is, of course, EM.

There is another weakness of EM which has been recently been under criticism: the dimension of equity, or the fairness of the process with regard to its global impacts (Bonds and Downey, 2012; Ewing, 2017). In many industrialized countries (even including in China) we find a de-location of “dirty industries” into less advanced countries. The final production in developed countries may be relatively “clean”; however, the consumption or the early stages of the production line can be based on heavy industries in developing countries. This needs structural change of the global economy, which has been taking place only slowly so far.

There are however spill-over effects of EM into the developing world, caused by imported cleaner technologies, by the diffusion of advanced standards and increasingly also by domestic innovations. The regulatory dominance of the EU and other industrialized countries (e.g. in energy efficiency of cars) has clearly contributed to EM also in emerging and developing countries. The global diffusion of more ambitious standards and targets in industrialized pioneer countries (see section 4) is an important advantage which, to a certain degree, can compensate for the above mentioned negative distributional effects. It should also be acknowledged that, as a rule, the lead markets of
industrialized countries (e.g. for PV or Wind power) repay the learning costs of many clean technologies until they have become cheap and efficient enough to diffuse through developing countries. Germany, for instance, still pays a high price for electricity to compensate for the high feed-in tariffs that massively stimulated clean power markets in earlier times.

Nevertheless, the global distributional fairness of EM and the environmental effectiveness remain important challenges both to the environmental science and policy.

III. Conclusion

It makes sense to describe the high speed and the global scale of innovation and socio-technical change of the present in terms of an Industrial Revolution. It is a radical, long-lasting change not only of the energy basis but also of a broad spectrum of other clean technologies. It includes also a broad range of social and institutional innovations. The Green Industrial Revolution includes innovations of governance and its global architecture. It is essentially an EM driven by both, the pressure of the environmental and climatic crisis and the co-benefits of resource efficiency. These co-benefits can be attractive for relevant actors: that is, if the lesson has been learned. In the EU, this lesson has been learned since 80% of the population have agreed that fighting climate change and using energy more efficiently can boost the economy and jobs (EU Commission, 2014). The learning process is being supported by the polycentric framework of multi-level governance as a multi-impulse-system of interactive
learning.

The evaluation of this global dynamics shows that we need a differentiated approach. EM and the transition to a green economy take place with an unexpected speed of change and a surprising scale of diffusion. However, the environmental effectiveness and the distributional equity and fairness are still causing disputes. The environmental improvements of the EM have been often neutralized by growth and rebound effects. And the various co-benefits of increased resource efficiency in rich countries have often had negative impacts in countries where the resource-intensive input in the value chain is being produced. Cleaner production in industrialized countries has to be regarded in the context of a consumption pattern where the “dirty” input comes from abroad. This critical view of EM, however, should be more differentiated. There are, for instance, several spill-over effects of EM into developing countries. And the stricter standards of the OECD world have often been adopted by other countries, particularly those who export to OECD markets.

There is no alternative to EM and the greening of economy. At the same time, there is also no other alternative but a steady improvement.

References


Ernst and Young, 2006, *Eco-industry, its size, employment, perspectives and barriers to growth in an enlarged EU*, Commissioned by the Commission, DG Environment, Brussels.


__________, 2014.3.3., Press Release.


for the Futures.


revolution – Aufbruch in ein ökologisches Jahrhundert, Berlin: BMU.


Pierson, P., 1993, “When effects become causes – Policy feedback and political
Ecological Modernization as Global Industrial Revolution

change,” World Politics, 45, pp.595-628.
Umweltbundesamt, 2016, Instruments to increase climate policy ambition before 2020 – Economic and political implications in selected industry and emerging countries, Dessau: Umweltbundesamt.
UNEP, 2011, Towards a green economy – Pathways to sustainable development and poverty eradication, Geneva: UNEP.
UNFCCC, 2015, Adoption of the Paris Agreement (FCCC/CP/2015/L.9).


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