Globelics Seminar: Learning, Innovation and Low Carbon Development

Copenhagen, April 4-5, 2013

How do LCD innovation differ: specificities of low carbon technologies and energy systems

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1 Introduction

Innovations which foster both economic development in the South and a low carbon future have to account for the specificities of low carbon innovations. This paper addresses different specificities, which might have an impact on the pattern of the innovation system for low carbon innovation. Some of these features are very specific to low carbon development (LCD) and similar innovations, others can also be seen at other innovations, and it is the extent and combination with each other which make them a specific feature of LCD. Furthermore, low carbon innovations comprise very different technological fields, and some of the specificities are not valid for all of these technological fields, but only for the – however extremely important – part of electricity supply technologies.

The following aspects are covered:

- Techno-economic specificities of energy and low carbon technologies,
- aspects of Co-evolution,
- high importance of regulation
- structure of actors and ownership, and political economy
- The “energy efficiency paradox” and low speed of adapting routines.

The paper intends to give input into a lively discussion – thus it is not worded in a formal “journal ready” mode with fixed conclusions, but reassembles more my reflections about the experiences I have gained over more than 20 years in energy and sustainability research.

2 Techno-economic characteristics with regard to capital intensity and asset durability

Low carbon innovations comprise very different technological fields. Typically, energy efficiency technologies and low carbon energy supply technologies are distinguished.

Energy efficiency technologies comprise

- energy efficiency in housing (e.g. insulation)
- energy efficient appliances and lighting,
- cross cutting industrial technologies, such as electric motors, furnaces, boilers, compressors,
- sector specific industrial efficiency technologiesspecially at processes with high energy consumption (steel making).

Low carbon energy supply technologfies comprise different forms of renewable energy, but also carbon capture and storage.

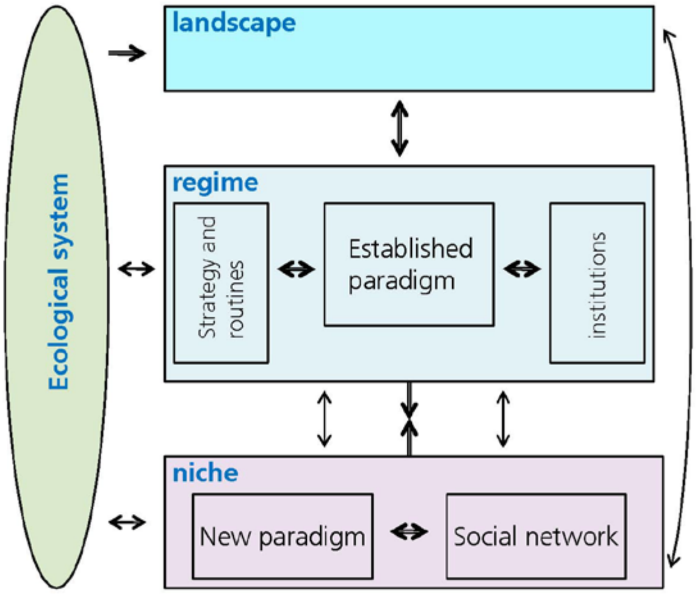
Markard (2010) emphasizes that a lot of these technologies are characterized by a very long lifetime. This holds for example for power stations, boilers, energy efficiency in buildings, but also for investments in related infrastructure. Thus, the high asset durability limits the opportunity for reinvestments. Furthermore, the investments in supply technologies tend to be very capital intensive. Thus, it would be very costly to substitute carbon intensive technologies before they have reached their end-of-life. Both factors support “technical path dependency”. Thus, large parts of the energy system are characterized by inertia and a technological carbon lock in.

3 Co-evolution

It is widely known that technical and institutional systems co-evolve. Thus, with evolutionary economics, this co-evolution takes place along a technological trajectory and makes changes from one technological paradigm towards another more difficult. The notion of path-dependency and co-evolution also shows up in the multi-level perspective, which is advocated by scholars such as Geels (2002). It distinguishes landscape, regime and niche. The landscape represents the broader picture of socioeconomic system, the regime consists of the established technological paradigm. A radical alternative has to grow in a niche together with a social network surrounding it, before it is able to compete with the established paradigm. Low carbon innovation can be interpreted as such a niche, which has to grow against the resistance of the established fossil fuel paradigm.

The notion of co-evolution in the tradition of evolutionary scholars shows up at various levels of the multi level perspective. It can be horizontal co-evolution within the regime between the established paradigm and institutions. Furthermore selection processes lead to an adaptation of strategies or routines of companies towards the paradigm. Co-evolution can also take place on vertical levels, e.g. between the paradigm and the regime. Another form of vertical interaction is the competition between new and established paradigm, with the latter using the surrounding institutions to fight the success of the new paradigm. However, it might also be that the landscape can benefit the growth of the niche.

Figure 1: Co-evolution in a multi-level perspective



Source: Walz 2012

This kind of co-evolution affects all different kinds of innovation, not only energy and low carbon innovations. However, if we look at ecological problems, we have also to consider that ecological systems and social systems also co-evolve (see Gual and Norgaard 2010). The state of the ecological system shows up in the landscape as environmental ethics and perceived importance of "nature" or "the environment". Thus, it is changes in these landscape factors which are important drivers of low-carbon innovations. However, there are also interlinkages on a more technical level, with the regime and niche both having an impact on the ecological systems via emissions.

Furthermore, for important aspects of energy systems a third kind of co-evolution exists. Especially electricity related technologies phase a technical specificity, which can be called systemness: In most instances, they depend on a functioning grid. There are various problems arising which make it more difficult to change electricity systems:

- problems of frequency control of an existing grid; especially if the low carbon technologies cannot be modulated according to the demand (which is the case for wind and PV), either storage capacity is needed, or demand and supply must be modulated by a flexible power dispatch and a grid with high capacity.
- The systemness also leads to complicated pricing problems: the market value

of low carbon electricity depends also on the traditional technologies of the incumbents, which can lead to highly uncertain market prices and even to negative electricity prices.

- The dependency for a grid also leads to another kind of path dependency: The grid structure is optimized towards the existing carbon intensive power system. If the grid structure is not suited, even large investments in low carbon electricity supply do not necessarily increase the market share of low carbon alternatives, unless they are supported by vast investments into a new grid structure. This problem can already be seen in Germany, but also China. The problem is increased furthermore, if the grid operators and investors have specific interests in keeping the traditional structure intact.

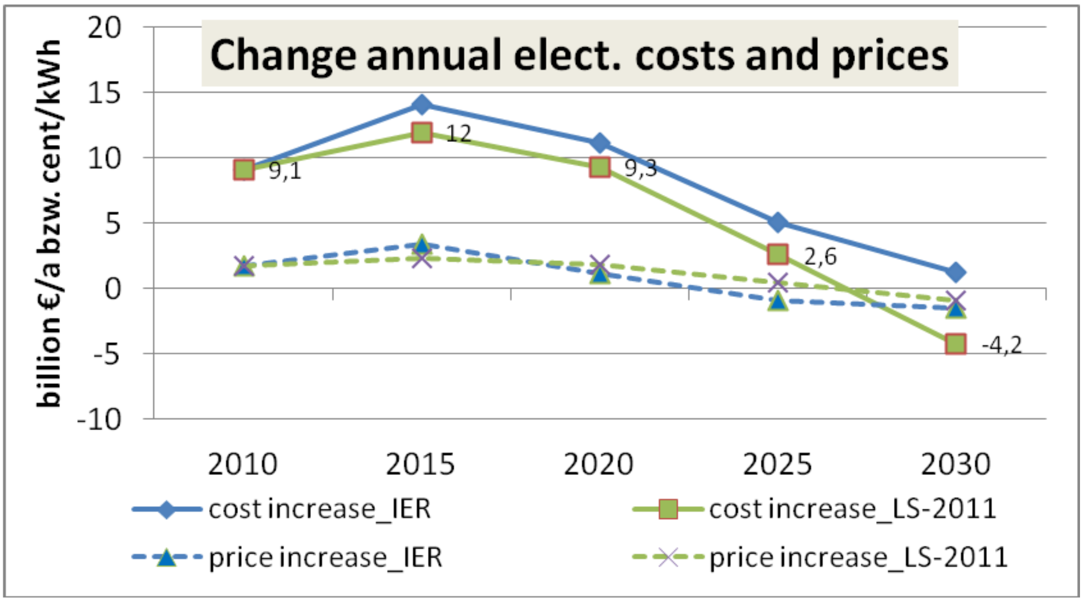
4 Importance of regulation

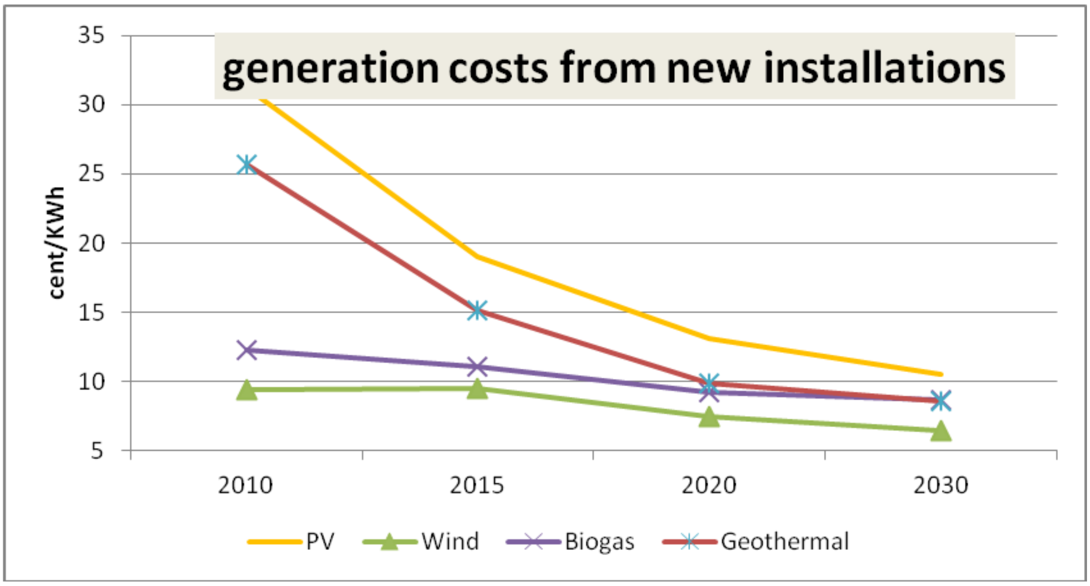
4.1 Environmental Regulation

Low carbon innovations possess one clear advantage over carbon-intensive technologies: They are more environmentally friendly. However, as long as environmental costs are externalized, this advantage does not show up in the economics of the technology choice. As perfect internalisation – the cornerstone of neoclassical environmental economics – can hardly be achieved in reality, there is a built-in need for environmental regulation. Thus, it is not only the externality of public research, but also the environmental externality which lead to a widely acknowledged double regulatory challenge (Rennings 2000) for low carbon innovation.

Indeed, many of the widely debated policies to foster low carbon innovations – e.g. emissions trading, feed-in-tariffs or quota systems for renewable - are necessary to achieve diffusion of low carbon technologies. Thus, there is a clear difference to other “normal” innovations: It is not (only) the lead users, which are important that new preferences are shaping a market, and which support innovations via user-producer interrelationship. The demand for low carbon innovations must be initiated by some form of environmental regulation. This does not necessarily involve public spending or public procurement. How long this market stimulation is necessary depends how quickly learning effects can drive down the costs of low carbon innovations. However, even though we have experienced quite impressive cost reductions recently, we must be aware that many low carbon technologies are still substantially more expensive than traditional technologies. In case of the energy transition in Germany, for example, cost projections come to the result that it will take at least another 15 years until system cost parity will be reached. Subsidies and setting revenues above fossil fuel generation costs are also necessary in China: According to the draft issued by the National Development and Reform Commission in China from March 2013, solar farms will receive subsidies of 0.35 yuan ($0.05) per kWh. Meanwhile, the country has set four rates from 0.75 yuan to 1 yuan per kWh for solar-power plants in different regions to sell electricity to grid operators, according to the draft.

Figure 2: German Energy Transition: Estimation of cost development for renewable electricity supply if scale effects and learning drive down costs





4.2 Public utility regulation

It has been mentioned above that important parts of the energy system need access to electricity grid. Despite the call for deregulation and liberalisation, it is still acknowledged also by neoclassical economists that monopolistic bottlenecks characterized by both sunk cost and natural monopoly cost functions should be regulated. Clearly, infrastructure systems based on physical networks such as electricity/gas, water supply and sewage treatment, or railways include such a monopolistic bottleneck. Even potentially competitive stages, in general, require access to the monopolistic bottlenecks. This also holds for power produced by independent power producers, e.g. the operators of renewable energy.

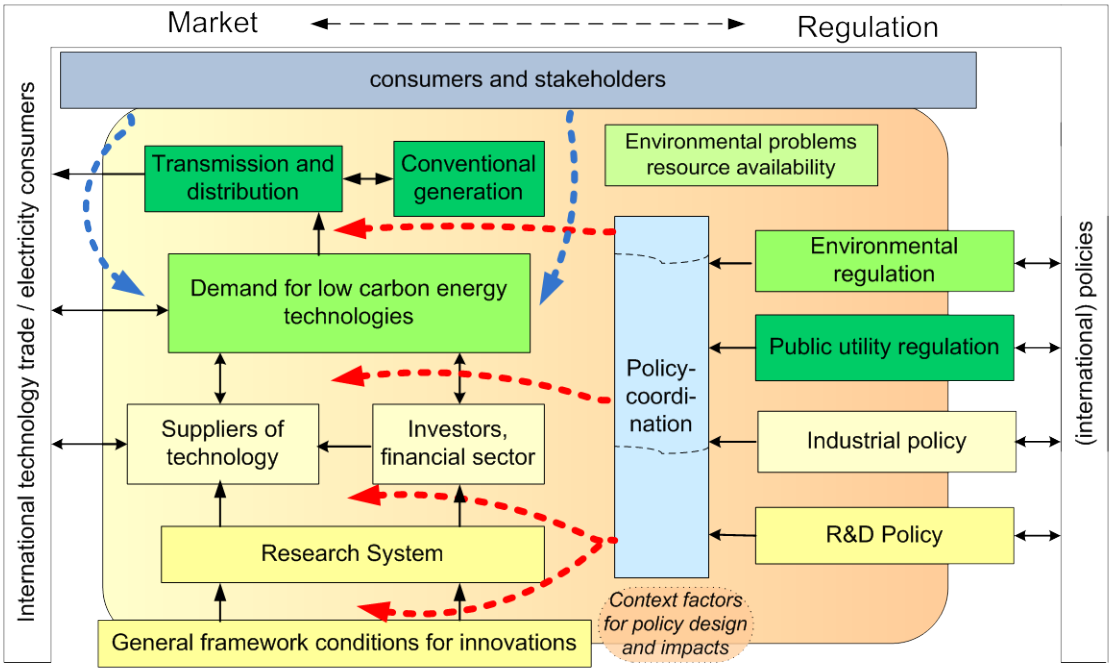
During the last two decades, regulatory economics started to emphasise the need to consider the incentive scheme within regulation. Based on the progress of the economics of information, the information asymmetries between regulators and regulated companies was addressed as a principal agent problem (e.g. Laffont/Tirole 1986), leading to the implementation of new regulatory schemes such as “price cap” or "incentive" regulation. There has not been much empirical work on the influence of different regulatory designs on technological innovation in the energy sector. However, the work of Walz (1995 and 2002) suggests that even minor details in the regulatory design may trigger important effects on innovation. Even details such as the provisions for allowing construction work in progress or overcapacity to be considered in the rate base has lead to substantial effects on electricity generation technology, by either hindering or favouring the development of capital intensive technologies, or by allowing the build-up of overcapacity which can be used as a strategy to deter newcomers with alternative technological solutions from entering the market.

The situation is complicated further, if there are vertically integrated utilities which are active in both, the monopolistic bottlenecks and the potentially competitive stages. In this case, regulation has to deal with the problem that the market power within the monopolistic bottlenecks can be carried on to the potentially competitive stages either by excessive charges for access to the monopolistic bottlenecks, or by hindering or even foreclosing the downstream market to competitors (see Knieps 2001). As a result, there is no level playing field between incumbent utilities and newcomers using low carbon innovation.

To sum up this argument: Low carbon innovations depend crucially on regulation. This holds not only with regard to making new knowledge available (a regulatory challenge for all innovations), but also for a second regulatory challenge with regard to creation of demand (environmental regulation) and a third regulatory challenge with regard to low carbon innovation friendly economic regulation of monopolistic bottlenecks. Thus, one specificity of low carbon innovations is that they phase a triple regulatory challenge (Walz 2007).

The importance of regulation also affects the functioning of energy innovation systems. One key aspect is that the very different regulatory schemes must be integrated. The case studies on environmental innovations tell many instances in which different regulatory policies were put forward in an isolated, or even contradictory manner. Thus, the integration of innovation, environmental and sector regulation is a key prerequisite.

Figure 3: innovation system for low carbon innovation



5 Structure of actors

A lot of the actors of energy innovation systems have a similar structure as in other areas. However, there some differences: Public utilities are key actors in the low carbon innovation system. However, in many countries, they are not only regulated but publicly owned. The same holds in some countries for other major energy players in the gas and oil sector. Other energy supply companies belong to the core of companies for which the term multinationals was framed. Thus, the incumbents of a fossil fuel based energy system are typically very powerful and sometimes with extreme powerful links to government.

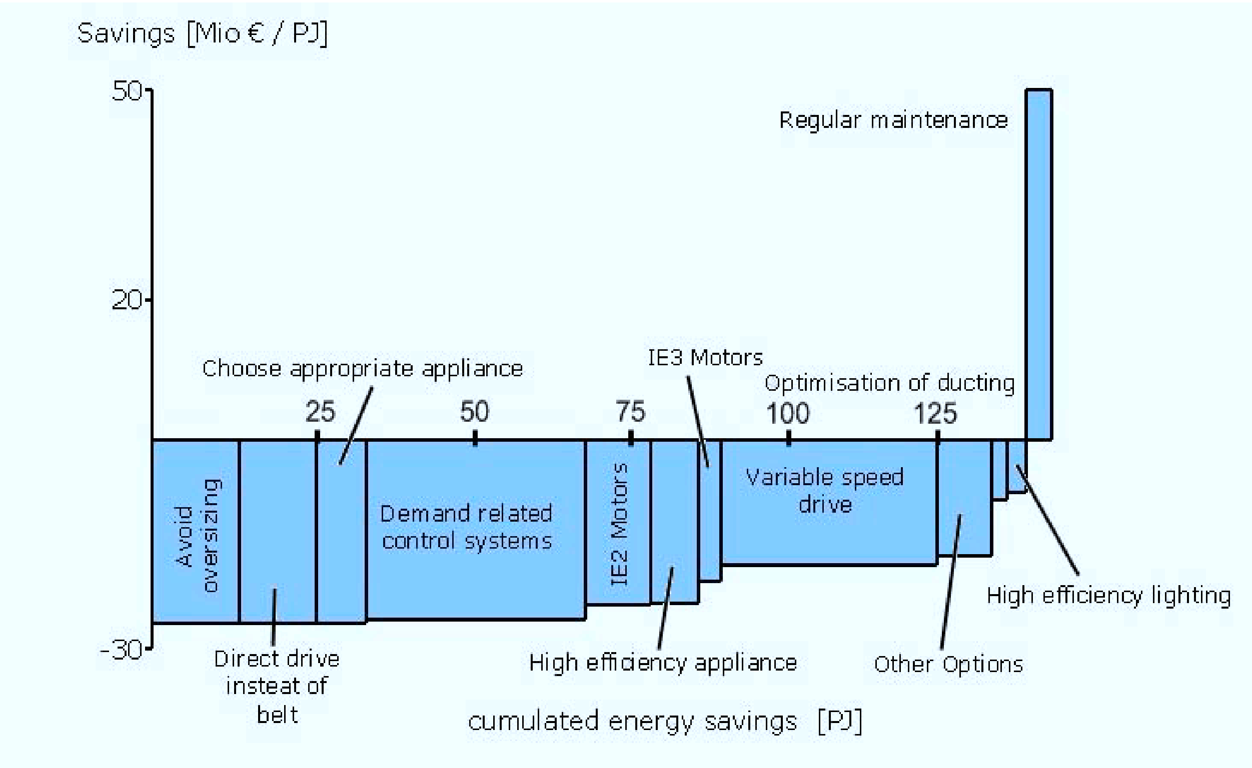
The actors for many low carbon innovations, especially renewable energy technologies, developed from newcomers. Some of them are small and medium enterprises, others are spin-offs from established companies (e.g. some of the big wind turbine producers in China). However, in addition to this actor constellation – which can also be found for other innovation systems – there are also community based groups and NGO-type actors, which are among the key proponents for LCD. This reflects the characteristic of energy as a basic need, which cannot put to individual market based decisions alone.

To sum up the argument, important actors in energy innovation systems are different from the typical actors in other innovation systems. Thus, it can be expected that their behaviour also differs. Furthermore, low carbon innovation can be characterised as an arena with a very uneven power structure: Large companies, which profit from existing fossil fuel lock in, sometimes directly linked to government, versus drivers of low carbon innovation, which very often are not part of the established innovation system, and do neither possess capital reserves nor experience in bringing forward innovation.

6 The energy efficiency paradox

The previous sections make a strong case that more radical energy innovations, such as renewable energy, face a strong challenge in overcoming path dependency. Following the previous line of argument, it should be expected that more incremental innovations such as improving energy efficiency of technologies, which do not require such fundamental changes in the set-up of the energy innovation systems, should move on much easier. Furthermore, compared to a lot of renewable energy technologies, energy efficiency measures very often are a low cost option. The cost-effective no-regret potential, that is the amount of energy which can be conserved without incurring additional costs under given framework conditions, has been estimated by the IPCC at 10-30 %. Even rather conservative, pro business consultants argue that there are energy efficiency opportunities with negative costs. However, looking at the dynamics of energy innovations, it is surprising to see that there is a lot of dynamics in renewable energy, despite their higher costs. On the other hand, energy efficiency seems to be much less reluctantly pursued, despite lower costs and higher compatibility with the existing energy system. In the literature, Canio (1998) used the term efficiency paradox – indeed, this result looks paradox from the perspective of innovation research, too.

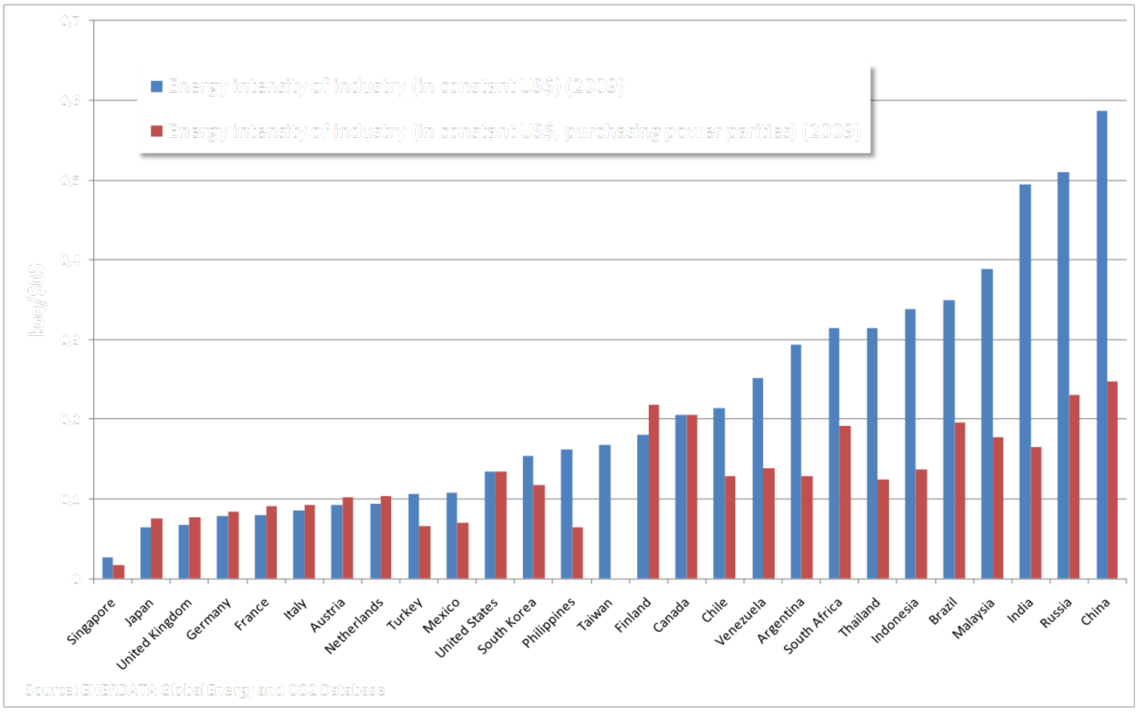
Figure 4: Example of negative costs energy efficiency potential for industrial cross cutting technologies



The potential for cost efficient energy efficiency is also very important for newly industrializing and developing countries. In NICs, the immediate impact of industrial energy efficiency on the competitiveness of the country is much larger than for traditional industrialized countries: Taking the period from 2000 – 2008, the share of the industrial sector in final energy consumption has been increasing in NICs from 34 to nearly 40 % (with highest shares in countries like China close to 50 %) while its share has decreased from 25 % to 23 % in the same period in traditional OECD countries (ENERDATA 2010). This implies that the weight of industrial sector in energy terms is nearly twice as high in NICs as in traditional OECD countries.

At the same time there seems to be a substantial gap in the level of energy efficiency between NICs and traditional OECD countries. If energy efficiency is measured through industrial energy intensity (energy consumed per unit of industrial value added), the energy intensity of the least efficient country is 30 times higher than that of the most efficient country with an average factor of 4 between the energy intensities of traditional OECD countries and NICs (Figure 10). This average distance shrinks to a factor of 1.6 if purchasing power parities are used which take into account the different living standard. However, this does not consider that for imported energy carriers exchange rates are the most relevant because the energy imports need to be paid in US$. There are certainly also factors such as the industrial structure that explains some of these high values. Nevertheless, the conclusion that the industrial sectors in developing countries are on average 2 - 4 times less energy efficient remains certainly valid.

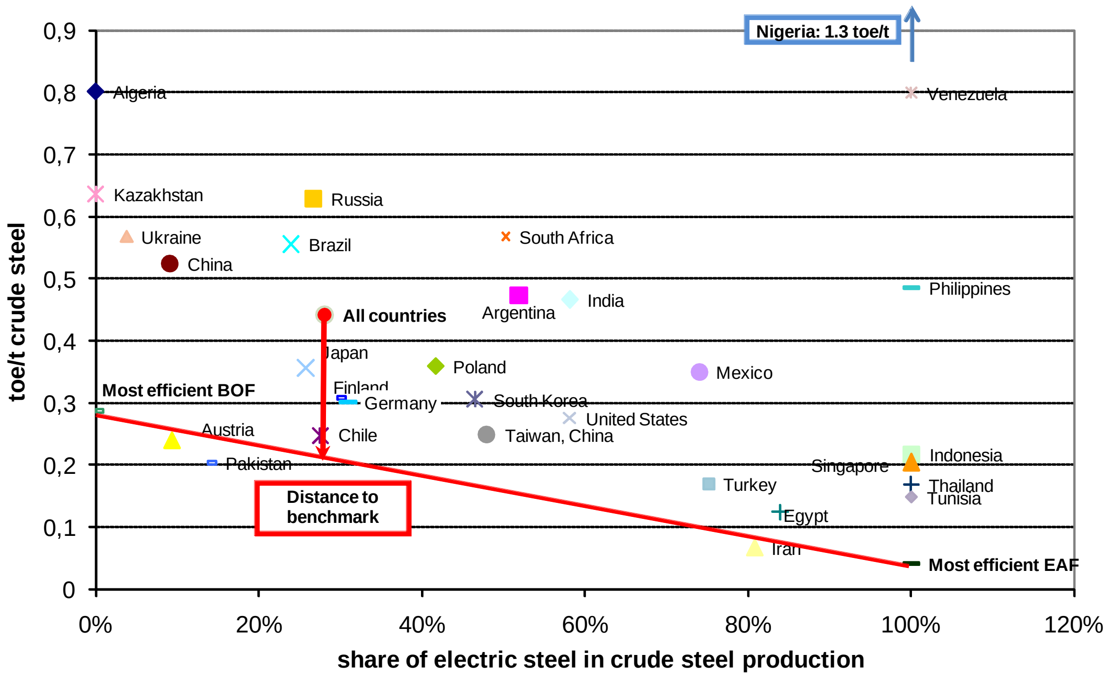
Figure 5: Spread in industrial energy intensities



Source: Walz and Eichhammer 2012, based on ENERDATA Global Energy & CO_2 Data

The gap in energy efficiency is also confirmed when looking at specific products such as steel, cement or paper production, using physical activity indicators. In Figure 6 showing the specific example of steel the position of the countries is partly influenced by the share of electric steel production which uses less energy than the blast furnace route. The vertical distance from the red line which represents a mix of the most efficient blast furnace process (BOF, based mainly on iron ore) and electric arc process (EAF, based on scrap) shows the distance of a given country with the same process mix to the benchmark set by the most efficient processes. With a comparable process share a factor 2 - 4 with respect to the benchmark can also be observed here. However, moving from the left-hand side of the diagram to larger share of EAF steel may also present an improvement in energy efficiency but this is more difficult to realize in some countries. Many NICs tend to have a stronger focus on electric steel processes because they represent smaller units which can be more easily managed and financed. On the other hand scrap, which is necessary as input for EAF steelmaking, is less easily available. This explains the position of countries such as China or Brazil more to the left-hand side. Differences between countries may be explained by lack in investments such as in Algeria or by the introduction of modern energy efficient processes such as the MIDREX process in Iran which is mainly based on natural gas[1]; hence the low energy consumption of the country for steel production in Figure 11.

Figure 6: Unit consumption per ton of steel as a function of the share of electric arc furnace (EAF) steel in total crude steel production (2007)

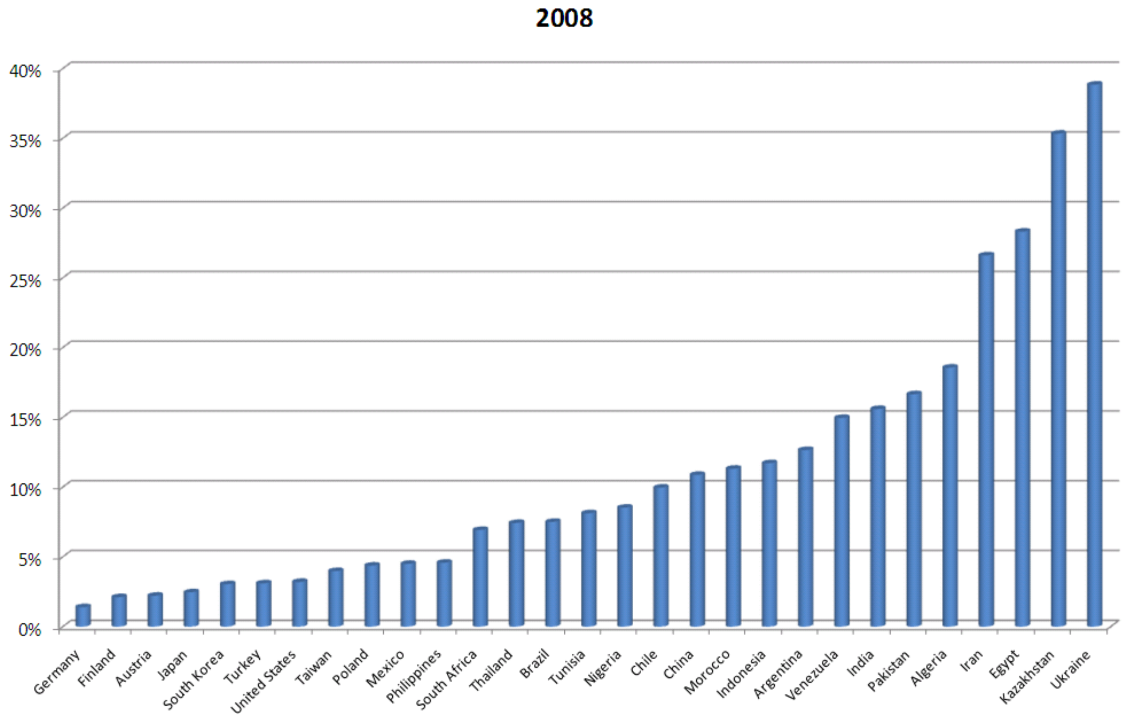


Source: Walz and Eichhammer 2012, based on Data from ENERDATA Global Energy & CO_2 Data (2010) and Worldsteel (2010)

The consequence of this gap is that the more wasteful a country uses energy in its own industry, the higher is the fraction of manufacturing value added which has to be spent on energy. This is illustrated by Figure 7: While the countries on the left-hand side are only spending 1 - 2 % of manufacturing value added on energy, countries on the right side spend de facto - if implicit and explicit subsidies are not considered - nearly 40 %. If the oil price is rising to levels beyond those of 2008 (around 95 US$/barrel on average), the share increases further.

1 http://steelmaking.wordpress.com/2010/01/28/iran-steel-industry-overview/

Figure 7: Cost share of industrial energy consumption in value added of the manufacturing industry (at an oil price of around 95 US$/barrel on average in 2008)



Source: Walz and Eichhammer 2012, based on ENERDATA Global Energy & CO_2 Data (2010)

There are various reasons for this unused energy efficiency gap. Lack of capital has been already mentioned. Another one might be lack of capabilities to plan and operate installations. Both reasons, however, are not specific for energy innovation systems in developing countries and NICs.

There are other reasons which are brought forward and are more specific for energy technologies. One is related especially to energy efficiency for households: It is argued that consumers put more emphasis on the amount of the purchase price, and less on total cost of ownership. Such behaviour is supported by information asymmetries. The demand for energy is derived from the operation of the consumption good, which needs energy as an input to fulfil its functions. Thus, consumers are aware of the functions of the product (e.g. size or speed of a car), but do not put that much emphasis on the (hidden) input required to fulfil this function. This contrasts with technologies of renewable energy, which main product feature is that they do not use fossil fuel. Furthermore, it can be argued that some renewable energy technologies can also fulfil the function of a positional good in the sense of Veblen.

Numerous publications also question the assumption of the utility maximising, rational behaviour of people and are emphasising – in addition to information and knowledge deficiencies – the competence and motivations of actors. Instead, they are putting forward the concept of *bounded rationality*. It is pointed out that decisions within companies are the result of a complex process, which is characterised by multifunctional network structures with differing objective functions, spillovers between the individual sectors and limited information processing abilities so that, at any time, there is the possibility to bring about substantial efficiency improvements (Nelson 1995). This argument is applied to energy and climate policy in the work of DeCanio et al. (2000 and 2001).

For the assessment of specificities of low carbon innovation, the inefficiencies in energy efficiency have to be particularly pronounced. Thus, arguments are necessary which support the supposition that inefficiencies exist, particularly with regard to decisions about energy saving investments. Alongside the already mentioned traditional reasons for market failure, a justification may exist in a form of bounded rationality which does not adapt fast enough to the changed frame conditions and therefore forfeits its efficiency, which may well have been present under the original conditions. The following aspects must be considered here [2]:

- The company's energy supply is not at the centre of the corporate performance processes. In the sense of satisficing, the aspiration level consists mainly in securing supply at reasonable costs.
- During times of sinking energy costs, routines developed stating that a costly search for energy saving possibilities does not pay off anyway. This decision routine is plausible for the large number of companies in which energy consumption mainly occurs in ancillary services such as the supply of process heat or compressed air production and only constitutes a small share of the total costs.
- This tendency is reinforced even more by the fact that energy-relevant investment decisions are often reinvestments, in which the decision is not made independently of decisions taken at earlier points in time. Thus, inefficient decisions in the past influence future decisions (good money is thrown after bad).
- Energy-relevant investments do not have to be made continuously, but often have a rather ad hoc nature. At the same time, these investments also often have a disproportionately long lifespan. On top of this are the complex environment and uncertainties with regard to future developments. Under these condi-

2 The following arguments are based on Walz and Schleich 2009

tions it is especially plausible to have an orientation along decision routines which are difficult to dismantle, even more so since the drop in energy prices after the oil price crises seems to reinforce these kinds of decision routines.

- Policy measures which draw attention to the necessity to reduce CO2 emissions in the future could help to change these decision routines independently of whether they alter relative prices or have a different leverage. The altered decision routines establish themselves through social interaction. For measures to accelerate the diffusion of these routines, it is of considerable significance to select the respective multipliers and opinion leaders as the target group. This type of group-specific design can simultaneously limit the costs of the policy.

To sum up, the arguments presented in this chapter are directed at explaining why the inefficiencies are particularly relevant for energy efficiency.

7 Summary

Energy is a basic need which has to be fulfilled not so much for its own sake, but because it enables many functions which are necessary for survival and development. Thus, it is not possible to postpone decisions into energy investments. However, the solutions introduced have a high path dependency. The techno-economic features (high capital intensity, asset durability), and specific features of co-evolution (systemness) lead to a comparatively high level of path dependency, which can be described with the term carbon lock-in.

Regulation is a second key component of these innovation systems. Innovations for a low carbon development must be driven by environmental regulation on the one hand. On the other hand, economic sector regulation of monopolistic bottlenecks influences the speed and direction of innovations as well. Thus push for low carbon innovations, however, need a long-term perspective. In order to change the path of innovation, new technological paradigms need time to develop and to experience enough learning to become competitive with regard to private costs. Given the importance of regulation, this translates into stability of policy actions towards such a transformation.

Energy and low carbon innovation systems are characterized by a specific structure of actors. On the one hand, the established incumbents are either closely aligned to government, or powerful multinational companies. Thus there is something like an “energy-industrial complex”. This holds not only for traditional OECD-countries, but also for many NICs. On the other hand, community based groups and newcomers are actors driving radical low carbon initiatives. However, their power depends on how quickly landscape factors such as new forms of an environmental ethic are gaining hold in society.

The high path dependency poses especially a problem for more radical innovations such as renewable electricity supply. However, the untapped potential of energy efficiency is also very high, without many of the carbon-lock-in problems being as prominent as in the case of renewable energy. Thus, there must be other reasons beside the ones discussed. Energy being a derived demand, which is hidden behind the functionality of product features, might be one of them. Others are that the routines for energy decisions is only slowly changing, and that many decisions with regard to energy still reflect the framework conditions of the 1990’s. Furthermore, the effects of climate change still seem to be too uncertain to be taken seriously into account in (political) decision making, either because of the time lag between cause (emissions) and effect (impact), or the uncertainty of the magnitude of impacts, or the uncertainty which region might be effected. Thus, the distributions of the benefits of the innovations (the avoided climate change) looks uncertain and for the time frame of political economy to be lying to far in the future.

The taxonomy of specificities of low carbon economy also calls for a specific policy approach. Mowery et al. (2010) have pointed out that such an approach cannot rely on the traditional form of a mission approach: It is not only a single technology or one technological breakthrough that has to be achieved, but a whole range of radical and incremental innovations and a new mode of how to deal with energy issues. Many more actors must be involved, and the need to initiate demand goes beyond anything that can be achieved with public procurement. However, on the other hand, there has been a wide range of environmental policy instruments being developed. Even though not intended by the environmental policy makers, these instruments can also serve as initiating the demand necessary for innovation. However, this requires a new form of integration between environmental and innovation policy making.

The political economy of low carbon innovations tends to be skewed in favour of the traditional fossil fuels based actors. The function of legitimization, which has been introduced in the context of the technological innovation system analysis, seems to be crucial. There is a need to bring together new advocacy coalitions: potential winners of energy transitions, which might be small and not part of the established lobbying process, must be linked to advocacy groups from environmental and community based NGOs. Thus for both, traditional OECD countries and NICs and developing countries, the link between industrial policy and energy and low carbon policy becomes crucial.

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