Overcoming the Sociotechnical Barriers of Sustainable Renewable Energy Policies: Path Dependency and Technological Change

By

Vencel Gábor Bejczy

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Supervisor: Associate Professor Andreas Goldthau

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ABSTRACT

Facing climate change, depletion of non-renewable energy resources, energy security and energy independence, the current energy systems of most countries are unsustainable. However, the conventional, proven technologies of fossil fuels are so deeply embedded in contemporary societies that transitions to sustainable energy paths are very difficult, and juxtaposed in various complexities. 'Lock-in', and path dependency are phenomena that describe this situation well. Initiating change from all parts of society (including governments, civil society and business actors) by transitioning to a renewable energy future is challenging. This paper seeks to answer why this transition is so difficult by using the socio-technical systems approach in energy policy. Therefore, selected number of countries chosen and examined in this paper by using the holistic socio-technical systems approach as an analytical tool, describing how Germany and Iceland managed to tackle the various economical, political and behavioral barriers. The main finding of this research is that in order to make steps towards 'carbon lock-out', all parts of society has to work together and interact effectively through complex institutional, political, economical and behavioral settings.

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1. INTRODUCTION

1.1. Background and relevance

Currently the world is facing tremendous challenges in energy governance: climate change, energy poverty, depleting fossil fuel reserves, crisis of nuclear energy, problems of energy security, energy independence and so on. Tackling these issues should require a new, holistic approach (*e.g.* Tsoutsos and Stamboulis, 2005). Improving energy efficiency, promoting renewable energy or encouraging non-use are among the options to comply with sustainability. This paper will concentrate on renewable energy systems, and on the challenges it is facing in terms of a possibility of a transition to this kind of energy system.

Renewable energy is obtained from natural resources which are replenished within short time period of time (Nakata et al, 2011). Generating energy from these resources does not contribute to climate change, since it does not involve greenhouse gas (GHG) emissions to a scale which is harmful to the environment. Carbon emissions from these resources are negligible compared to fossil fuels and often labeled 'carbon neutral' (*ibid.*).

In 2008, 12.9 percent of global energy supply was provided by renewable sources (IEA, 2010a): mainly biomass and hydropower, and in a very small share, wind, solar, geothermal and ocean energy, which are the most promising technologies; these 'modern' or 'new' renewables are most likely representing the sustainable energy future. Yet coal, oil, gas (and controversial nuclear power) have an 85 percent share in total energy consumption (IEA, 2010a). Fossil fuels are responsible for nearly 60 percent of all global GHG emissions. Fossil fuel-based technologies are dominating the energy landscape, and this is unlikely to change in the near future, despite the urgent need and rhetoric for clean energy.

De-carbonization of society is high on agenda and 'renewable revolution' might happen in the near future. Despite subsidies, ever-increasing infrastructure investments, various policies, programs and initiatives to promote their use in the last decades, the global share of renewable energy is still tiny (Sovacool, 2009). Ambitious projections are prevailing too, such as it is feasible that by 2050, renewable energy will grow three to ten times, and 77% of the global energy needs could be provided by renewable sources (IPCC, 2011). These predictions have a resemblance to the ones that were made decades ago, for example in the US, where in the Carter-era such projections were envisaged that by 2010, solar panels would provide 38% of the country's electricity (Sovacool, 2009). In reality, today in the United States only 6% of electricity is generated from renewable sources, and a mere 0.0002% from solar energy (Sovacool, 2009 and IEA, 2010a).

In the EU, the gross final energy consumption of member states comes from 10.3% renewables, with the remaining 89.7% from conventional fuels in 2010 (Eurostat, 2011). The share of renewable electricity was 16.6% in the same year, slowly but steadily growing over the years. Wind power, as well as solar installations are the driving force behind the growth (*ibid.*). At EU level, the well-known goal is to increase the share of renewable energy from the current 8.5% to 20% by 2020. EU nations also adopted this goal, however, there is little consensus how to achieve this goal, different nations use different tools, including feed-in-tariffs (FIT), competitive bidding, or trading mechanisms, such as Tradable Green Certificates (GC) and Renewable Portfolio Standards (RPS). However, the effectiveness of these instruments is prone to debates: they are promoting long-term investments and innovation, or just an unnecessary burden on budgets?

Considering worrisome pollution statistics, and looking at the costs and benefits of various renewable technologies, it is easy to spot that there is a conundrum about why renewable technologies are still marginalized, and why their large-scale deployment is so difficult despite the enormous advantages they can offer at an increasingly affordable cost and efficiency level. It is not true anymore that renewable energy is prohibitively expensive, and it is also false that renewables do not make economic sense. Also, there is proof for climate change, and clearly there is a need to cut GHG emissions if we want to save our planet for future generations. Considering all of these factors, it is illogical not to use renewable technologies. Then why not we use them on a large scale? This question can be investigated by examining the interrelations of the various technological and social factors involved. The latter is vital, since we cannot make valid conclusions if we only consider the technologies itself.

1.2. Research aim and objectives

The aim of this paper is to conceptualize energy regimes as 'socio-technical systems' (STS) and look at selected countries which are best practices in terms of renewable energy utilization and policies from this perspective. Application of this framework helps to understand the dynamics of technological change in the energy sector. Therefore, the aim of this research is to present and apply this concept, and investigate these interrelated factors in the socio-technical regimes that could affect the deployment of new technologies with the hypothesis that there is a need for a holistic approach when we try to understand the complex factors involved in the process of technological change apart from the technology itself.

1.3. Methodology

The various methods used in the thesis include the analytical review of secondary data sources in scholarly literature regarding technological systems, technological change, path-dependence and carbon lock-in, as well as historical renewable energy policy development in selected case study countries. The detailed study of the relevant policies and regulations was crucial in order to understand the historical development of Germany's and Iceland's renewable energy approach, and understand how they managed to 'lock-out' (or at least not to be completely locked-in to) themselves from environmentally unsustainable carbon-based energy paths. A case study of Iceland included a field trip to the country where semi-structured interviews were conducted with energy experts and geothermal professionals at the

United Nations University Geothermal Training Programme (UNU-GTP), which is administered by the National Energy Authority of Iceland (Orkustofnun/NEA). There I attended lectures and conducted the interviews, most importantly, with the President of NEA about his vision of Iceland's special energy regime. Germany was selected in the basis of past and current trends and promising prospects in clean energy development. The empirical method applied in this study is qualitative research, which includes semi-structured interviews, case studies and various empirical observations as well as insights from energy professionals.

1.4. Thesis structure

The thesis will begin with a extensive literature review about the complex issue of technological systems and transition; lock-in, path dependency which are important to understand why renewable technologies are lagging behind fossil fuel-based systems despite the well-known benefits and availability. Then the analytical framework is described, which will explore the rich variety of intertwined technological, social, political and behavioral barriers which persist and interact with each other and which have to be surmounted in order to transition to a non-fossil based, sustainable energy system. According to this framework, two countries are analyzed, Germany and Iceland, the former representing a typical promising renewable society, and the latter as an outlier case to most typical countries, because of its unusually high level of renewable energy utilization. These countries are deemed good case studies to draw conclusions and identify best practices. Then these lessons and key findings are summarized, and we can see that whether it is feasible at all in developed countries which are currently locked-in to fossil fuel-based energy systems and also for developing countries, which might 'leapfrog' (Perkins, 2003) developed countries by choosing the right development path now.

1.5. Limitations of the research

The main limitation of the research was the information gathering for the Iceland case study. Although the study trip to Iceland was beneficial, I encountered with the same problem there what I experienced while researching for online resources: most of the research articles are outdated, and/or too narrow in perspective, *i.e.* concentrating on just one aspect of the development of Iceland's energy regime, most notably a technological/engineering approach. Clearly, there is a large opportunity to develop a more encompassing research, and try to investigate all the factors involved which made Iceland's renewable economy.

2. THEORETICAL FRAMEWORK

2.1. Literature review

2.1.1. Historical energy transitions

Development paths followed by industrialized countries in the last few centuries are closely linked to changes in the patterns of energy use. The relation between energy and economic development can be illustrated by the energy transitions which occurred in developed countries since the industrial revolution (Nakata et al, 2011). As technology improved, higher energy intensity was required to satisfy growing demands. This was facilitated by one of the hallmarks of industrialization: the transition from wood (traditional biomass) to coal. Then oil emerged, also as a transition first from coal to whale oil, than from whale oil to petroleum, which offered convenience and flexibility, and significantly increased the standard of living (Rhodes, 2007). Each of these steps of transitions has less carbon-content than the previous one (Science Alliance, 2011). Interestingly, the transition from wood to coal was the first step towards a 'low carbon economy', since the carbon content of coal is less than wood's (*ibid.*). These transitions made possible the transportation and electrification of modern society. By transition, we mean changes in the provision of primary energy supply; and obviously, a prime example for this is the transition from biomass to fossil fuels and to hydrocarbons.

The environmental impacts of energy use have been started to be acknowledged in the last few decades, and now they are considered being a major issue (Nakata et al, 2011). The rather vague and ambiguous idea of 'sustainable development' tries to deal with the issue of ensuring continued development in a way that environmental issues are considered. It is acknowledged that although we have reached a spectacular level of efficiency and technological sophistication, there is a need for a new transition in the energy system in order to preserve the planet and comply with sustainable development. But transitions are complicated and protracted, ridden with complex barriers and resistance from path-dependent and locked-in technological systems based on fossil fuels.

Geels (2011) points out that because sustainability is a collective good, it does not necessarily offer obvious user benefits. Without the extensive change in policies, taxes, support mechanisms, etc. it is unlikely that a transition would take place and dislodge existing systems. Therefore, the rhetoric of 'environmental sustainability' should be handled with care.

2.1.2. Technological systems and related concepts

Fossil fuel-based energy technologies can be better understood as part of a larger, complex technological system: various interrelated components connected in a network or infrastructure that includes physical, social and informational elements (Unruh, 2000). In a large technological system, such as electricity generation and distribution the whole is often greater than the sum of individual parts, or subsystems. This is based on Hughes (1983) observation that the electricity system goes well beyond technical or engineering issues; the generation, transmission and distribution of electricity is a combination of various 'artifacts' which are mutually adapted and aligned into one functioning whole. These include company structures, financial possibilities and obligations, negotiated government concessions, and consumer practices (Vleuten, 2009:219). Others note that radical change in the system is possible when 'bottlenecks' bring up critical internal contradictions that bring the system to an 'irresolvable state' (Tsoutsos and Stamboulis, 2005).

The 'dominant design' model is the basic theory behind the establishment of a technological system (Unruh, 2000). According to this, the first step is an invention, and then innovation follows, which creates several variants to meet changing consumer expectations. These variants then compete for performance and other improvements, which includes cost reductions and market share. The competition phase then ends when one of the technology variants reaches a critical mass and becomes the *de facto* standard of the technological system (*ibid.*). Once the dominant design is established, the shift from product innovation to incremental process improvement occurs. Technological development can be understood as an evolutionary process in which various technologies compete with each other to become the dominant design; thus winners and losers are selected, in the presence of considerable uncertainty about their merits (Könnölä et al, 2004).

Path dependence is a dynamic process whose evolution is governed by its own history (David, 2006). Thus its scope is very general, referring to developmental sequences and social dynamics which are characterized by self-reinforcing mechanisms and positive feedbacks (*ibid.*). Path dependence is induced by social and political arrangements that determine the formation of the system: management and power structures, technical disciplines and divisions, regulatory capture (Tsoutsos and Stamboulis, 2005). Lock-in is the result of path dependence: it is said to be responsible for the continued use of supposedly inferior technologies despite there are viable alternatives to replace them (Perkins, 2003).

'Momentum' is a concept which can relate to path dependency, but in a broader sense. It refers to the case of mature large technological systems which are resistant to change; more specifically, to the momentum when sufficient impetus is gained to spur change. Hughes (1983) noted that conservative innovations may help to initiate momentum, since radical innovations are difficult to implement because of the resistance of system operators (Sovacool, 2009). It is important to note that whether a system innovation is perceived conservative or radical is depends on the socio-technical system – in other words, it is socially constructed (*ibid.*).

Most analyses concentrate on the micro-level of decision making when considering why renewable technologies are not adopted in large scale and institutional/macro level elements are omitted (Könnölä et al, 2004). However, macro-level rules and norms are indeed having an effect and constrain micro-level decision making (*ibid.*, based on North (1981)).

A transition can be conceptualized as a non-linear process, where economic, social and technological subsystems interact with each other leading to irreversible patterns of change (Safarzynska and van der Bergh, 2010). It is non-linear in a sense that there is a need for interactive information exchange and negotiation (Tsoutsos and Stamboulis, 2005). Linearity of innovation means that investments are stimulated in the currently most cost-efficient technologies (Jacobsson and Bergek, 2011); therefore it is harmful for emergent, immature technologies and reinforcing lock-in. As Foxon and Pearson (2008) point out, the essence of non-linear innovation is that greater levels of support for R&D of new, cleaner technologies will automatically result in more of them reaching the market. All in all, transitional innovation is a systemic, non-linear process, involving significant uncertainties (*ibid.*). Also, because of the uncertainty about the pros and cons of technologies, it is crucial to engage in a 'social learning' process, which can either be a simple exchange of experiences, or imitation, during which actors imitate best practices from other actors in the sociotechnical regime (Geels, 2004).

The following diagram shows the elements of the technological system which interact with each other, dubbed 'holon' (Greek word for 'whole'). It can be seen that the interaction of these elements determines the technological systems' characteristics.

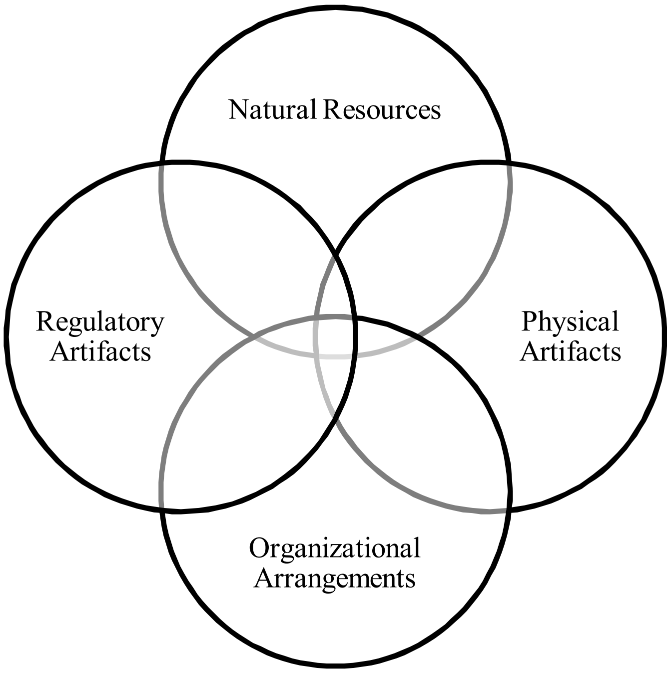

Figure 1: The holistic view of the elements of the technological system

Source: own graphic, based on Tsoutsos and Stamboulis (2005)

The winner technology in the battle of technologies is not necessarily the superior one: an inferior design can become locked-in as dominant design through a path-dependent process in which various factors' complex interrelations determine the winner. If this is the case, the winner inferior design will create unavoidable market failures (Perkins, 2003). Woolthuis et al. (2005) call these failures 'system failures' which include infrastructural (based on technology), institutional, interaction (based on networks) and capabilities (based on actors) failures, which classification better encompasses the phenomena than simply labeling them as market failures.

The role of networks in the diffusion of new technologies was described by Saxenian (1994), who argued that there might be institutional and organizational barriers which hinder the growth of the 'collective identity' by creating network failures, which can be either weak or strong. A weak network failure means that firms are not well connected among each other, with overlapping technological base (Jacobsson and Johnsson, 2000), while a strong network failure means when individual firms are guided by others in the wrong direction, or there are disruptions in knowledge sharing (*ibid*.).

Because of these factors, when dominant designs are locked-in, it is really difficult to come up with a completely new design, as companies tend to focus on polishing their established success factors: they will seek to improve existing products in order to preserve their core competencies (Unruh, 2000). This is the reason why the improvements of dominant designs of nuclear technologies, 'clean coal', carbon capture and storage and so on are more popular destination of R&D than completely new renewable technologies.

2.1.3. Innovation and change in the technological system

Unruh (2002) named several options to challenge the existing system: the least disruptive, *'end-of-pipe'* (EOP) approach means that there is no fundamental change in the system, but treat emissions instead by transforming or transferring pollution (Perkins, 2003) for example, by emissions-trading.

Continuity approach is more radical, it seeks the modification of selected components but maintaining the overall system architecture. A good example for this is the carbon capture and storage (CCS) or 'clean coal' technologies, or new generations of nuclear reactors. As Unruh (2004) points out, this is the interest of fossil fuel energy companies, because by this technology they would preserve their existing investments, know-how and durable capital. Also, continuity technologies, more specifically CCS can be a 'bridge-technology' until more fundamental innovations can happen (Vergragt el al, 2011). At the same time fossil-based CCS eventually should give way to renewable technologies – but the concern is that this bridging technology could be locked-in, and it will be very difficult to lock-out and this will hurt renewable technologies' advancement; this can be termed 'fossil fuel reinforced lock-in' (Vergragt el al, 2011).

The most disruptive is the *discontinuity* approach, which requires the replacement of entire systems with an alternative climate friendly alternative. It entails path breaking or radical innovations, which would make current fossil fuel-based systems obsolete. To break the path dependency, or to 'lock-out' from a large technological system which created an internal stability in the system over time, there is a need for 'exogenous shocks', or extraordinary events (Könnölä et al, 2004): this can be a technological breakthrough, social movements, changes in tastes, or an oil shock. The discontinuity approach means a transformational change, where new ideas are combined with entrepreneurship to depart from the familiar economic equilibrium (Wilbanks, 2011). As Wilbanks (2011) estimate, it is inevitable that in the next 30 to 40 years there will be a transformational change in the energy system, and that radically new alternatives will contribute to the mitigation of carbon emissions.

2.1.4. Approaches to describe technological change

In the innovation literature, there are two streams of approaches which analyze technological change: the innovation systems approach and the technological transition (or multi-layer) approach (Markard and Truffer, 2008). The main feature of the former is that it composed of networks, actors and institutions which interplay with each other, and develop, diffuse and use innovations and mainly exploring the role of emerging technologies (*ibid.*). The technological transition approach is a rather new concept, which deals with socio-technical regimes, studies the transformation of technological regimes (Rip and Kemp, 1998). Both concepts are interdisciplinary, based on evolutionary economics and they are helpful for policy makers dealing with innovation decision-making. They emphasize the crucial role of actors, networks, learning processes and especially institutions, in which actors and networks are embedded, and also acknowledging such phenomena as path dependency and lock-in

(Markard and Truffer, 2008). Due to much similarities and blurry definitions, it is not easy to clearly separate or distinguish these approaches from each other.

2.1.5. The multi-layer approach of technological transitions

The technological transition, or 'multi-layer approach', which explains transitions with the interplay of processes at three different levels (Geels, 2004).

The **socio-technical regime** is the key element of this system, representing the 'meso-level' with previously established rules, norms, etc, acting as a vast barrier for disruptive innovations. This kind of regime is for example the current system of fossil fuel-based electricity generation with the entire infrastructure; or the gas pipeline systems. The socio-technical regime is generally very stable and path-dependent. It includes all the stakeholders, including business, civil society, rules, norms and expectations (Rip and Kemp, 1998). In this system, technologies embody the rules, and actors perform the routines that make up the regime (Markard and Truffer, 2008). While Geels (2002) distinguished socio-technical regimes from socio-technical systems, according to other scholars the distinction is problematic. According to Geels (2011) 'system' refers to tangible and measurable elements (artefacts, market shares, infrastructure, regulations, consumption patterns, public opinion), whereas 'regime' refers to intangible and underlying deep structures (engineering beliefs, heuristics, rules of thumb, routines, standardized ways of doing things, policy paradigms, visions, promises, social expectations and norms). For the sake of parsimony, in this paper socio-technical regimes and socio-technical systems are used interchangeably.

Niches are the micro-level of the framework, representing a space for new innovations, where they can develop somewhat decoupled from the existing technological regime. They can either be market- or technological niche. The example for the former are customers who are willing to pay the extra price for installing a novel equipment, and the latter are the various mechanisms by which institutions support these initiatives (*e.g.* feed-in tariffs for solar PV) (Markard and Truffer, 2008). Radical innovations rarely go beyond niche level, but when the regime is weak, there may be possibilities: this is when system transitions or even dramatic regime shifts occurs (*ibid.*).

Geels (2004) note that because of path dependence, the incrementalism of innovations and the stability of sociotechnical systems, it is difficult to create disruptive innovation in the system. However, in 'niches' radical innovations eventually might arise and challenge the existing regime. These emerge in 'protected spaces', where they are supported by subsidies, and even by investments from visionary companies, therefore niches can act as an 'incubation room' for radical innovations – they are the 'seeds for technological change' (Geels 2011). It is vital to support these niches in order to encourage innovations and early adoption of new niche technologies too. The following diagram shows the stages of technology development and the corresponding policies to help the diffusion. It can be seen that niche markets can progress further with the help of support and the removal of barriers accelerates adoption:

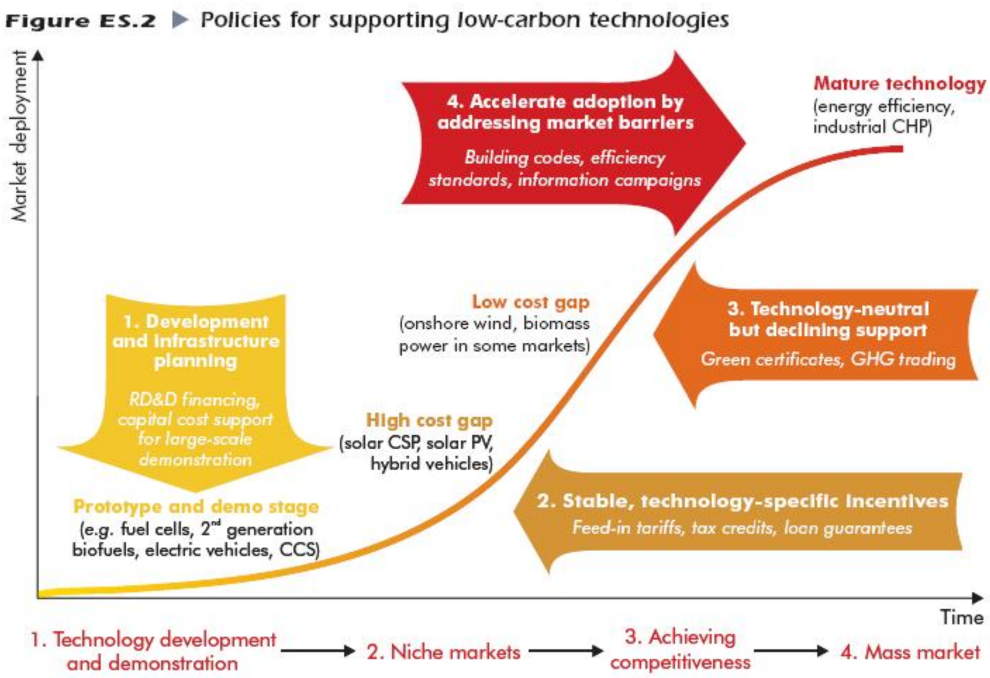

Figure 2: The dynamics of technology diffusion and policies

Source: IEA (2010b)

The macro-level is called the '**landscape'**, which encompasses all factors in the external environment. The factors in the landscape (for example wars, oil price, etc) can exert pressure on the socio-technical regime, by disturbing the coherence of its elements, or destabilizing it (Geels, 2004). Changes in cultures, values, and ideologies, as well as in macroeconomic and political factors can have significant influence on the landscape (*ibid*.). Strategic behavior of actors could open up the sociotechnical regime: despite the fact that most R&D expenditures are going to incremental innovations, there are always some bolder actors who are willing to explore radical innovation paths: this could lead to 'domino' or 'bandwagon' effects among favorable circumstances and can initiate Schumpeterian 'creative destruction' (Geels, 2004). The following diagram shows the graphical representation of the multi-layer approach (Geels, 2002, 2004):

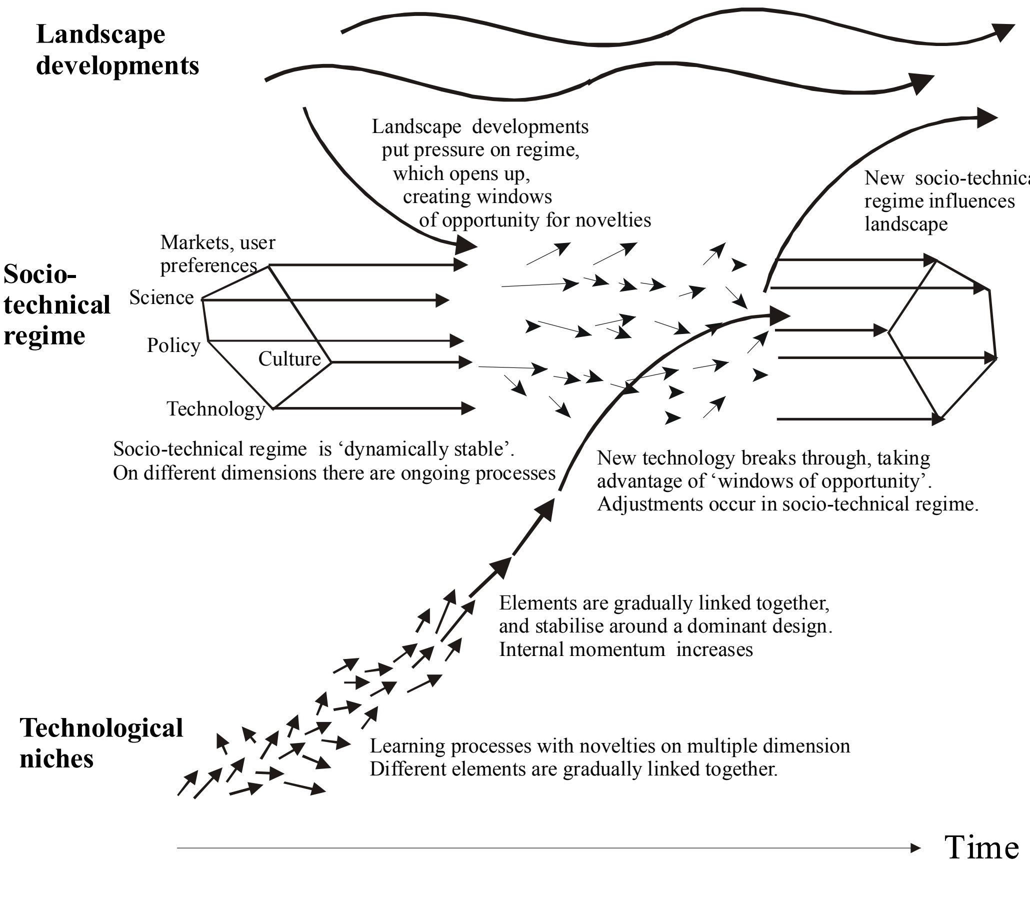

Figure 3: The multi-layer approach of system innovations

Source: Geels (2002,2004)

David (2006) argued that in order for a new system to formulate, increasing diversity is crucial in a situation where path-dependent development of the networks, actors and institutions exists. Geels (2004) says that transitions came about when dynamics at these three levels link up and reinforce each other.

2.2. Analytical framework: Sociotechnical systems

Socio-technical systems (STS) can be defined as constellations of technologies, social networks, actors, institutions, and rules (Markard and Truffer, 2008). They are 'hybrid' systems: they involve components and elements, such as individual people, business actors, governmental actors, and more abstract components, such as institutions, laws, regulations and rules (Franssen and Kroes, 2009). In the socio-technical system, electricity network operators always prefer a less radical approach, since disruptive technologies, and large scale renewable deployment would challenge many of the assumptions of the system (Sovacool, 2009). Since renewable technologies are challenging the existing large technological system of electricity generation, it faces many challenges which can be grouped into several clusters (*ibid.*). The STS perspective identifies the barriers to fundamental system transformations. In this framework, markets are understood as only one institution among many others artifacts. Such institutions are embedded in a framework of co-evolving elements, such as technology, the environment, organizations, knowledge and values; where at any point any of these elements could prevail more dominantly than the other (Scrase and MacKerron, 2009). The socio-technical energy regime consists of a set of technologies deeply embedded in a social, political, and institutional context, with regime specific rules, procedures, habits and practices (*ibid.*). According to the framework there are various impediments which explain why renewables are lagging behind traditional, carbon intensive technologies (Sovacool, 2009). These include economic, political, and behavioral barriers, encompassing various technological, social, political/regulatory, cultural, and educational factors.

2.2.1. Economic barriers

Financial impediments, market failures and market barriers can be classified as economic barriers for renewable energy. The full social costs of electricity are not reflected in the highly subsidized prices of fossil fuels. Subsidies tend to favor traditional and polluting technologies indeed, and the implementation of G20's commitment to phase-out fossil subsidies is going at a snail's pace. As a result, the consumption of these fossil fuels is greater than desirable, moreover, this phenomenon suppresses the desire to develop technological substitutes for fossil fuel-based technologies (Mowery et al, 2009). As the IEA (2010a) argues, eradicating subsidies to fossil fuels would mean a 'triple-win solution' by enhancing energy security, reducing GHG emissions, and bringing economic benefits. The negative externalities of coal, gas and oil energy generation, and the related social costs are not yet internalized by taxes or fees; these costs are 'hidden' in the prices, but on the other hand, the positive externalities of renewables are not reflected in the prices of renewable electricity.

Also, for traditional power plant operators, it is really easy to externalize social and environmental costs to consumers directly; this can be explained by Hardin's 'tragedy of the commons' theory (Sovacool, 2008). So the prices of electricity are so skewed that this makes it virtually impossible for renewable technologies to expand and to compete with conventional technologies. Also, the lion's share of subsidies is given to mature technologies; in 2004 in the US, 94% of subsidies were given to fossil and nuclear; and this ratio is true for the whole twentieth century (Sovacool, 2008). The three implications for renewable technologies are the following: first, artificially low cost of innovation in mature industries, second, increased barriers to entry for cleaner technologies, third, obscured costs and risks of conventional fuel cycles (*ibid.*).

Another factor is the expected return on investments, and investment risks: rational and profit-maximizing, often risk-averse investors are used to minimize payback periods, and this is not compatible with renewable energy projects, which are more risky and with longer payback periods. Bürer and Wüstenhagen (2009) researched whether FITs or trading schemes (GC, RPS) are more effective from the investor point of view. They concluded that FITs are superior since they reduce investment risks by providing stable stream of cash flows.

However, economic barriers are only one kind of barrier to surmount; political and behavioral barriers should also be considered. Another problem is a short-sighted, myopic view which hinders the large-scale diffusion of renewables.

After market restructuring (privatization, deregulation and market liberalization), powerful energy companies, which are 'invested in' or 'locked in' (Scrase and MacKerron, 2009) to old systems are more concerned about competition and keeping costs low, therefore investing and putting sufficient amount of money to renewable R&D is unlikely. The side-effect of market restructuring is that *'energy policy is concerned with the least cost energy production, supplied from centralized, large scale power stations to meet predicted growth in demand'* (Scrase and MacKerron, 2009). Clearly, energy policy today is mainly based on market mechanisms despite its apparent failures and barriers. As Brown (2001) argues, by failing to account for market imperfections, the assessment of climate change mitigation options and clean energy policies based on neoclassical economic models are failing to show the full benefits of clean energy policies. The concept of 'increasing returns' is important - there are four major classes of it (Arthur, 1989):

1. **economies of scale**, where unit production costs decline as fixed costs are spread over increasing production volume
2. **learning economies,** where cost reductions and performance improvements achieved by the accumulation of specialized skills and knowledge through production- and market experience

3. **adaptive expectations** arise as increasing adoption of a technology reduces uncertainty and both users and producers become increasingly confident about quality, performance, and permanence
4. **network externalities** emerge due to the interrelations among technological systems and users: physical and informational networks can become more valuable as they grow in size. This is the most common type associated with technological lock-in (Perkins, 2003).

Under increasing returns conditions, if one technology does not succeed in early adoption, then it will be locked-out from the market, and find itself in a difficult setting to compete with the winner technology (Perkins, 2003). A technology which did not manage to capture these elements of increasing returns, will face high cost and low utility, and the new technology may never has the chance to rectify these initial disadvantages (Jacobsson and Johnsson, 1998). David (2006) also specified increasing returns as a condition which makes a technological path dependent, along with other two factors: the technical interrelatedness of the system and the quasi-irreversibility of the investment. Also, switching costs further complicate system transitions: not only huge sunk costs which would make existing infrastructure obsolete, but technological discontinuity and dynamic transaction costs which means that the new system would have to catch up with the new technological and organizational arrangements (Langlois, 1992).

2.2.2. Political barriers

In terms of political barriers, weak and inconsistent incentives, varying standards, underfunded research and development, as well as competition among utilities can be described, among others. Also, the powerful lobby groups' leverage should not be underestimated.

In the US in the ’70s there have been increased rhetoric for renewable technologies, but after fossil fuel prices fell, efficiency increased, a U-turn occurred and this created such an uncertainty that deterred both public and private investment, and this factor constitute as ‘inconsistency’ (Sovacool, 2009). In the US, during the Carter-era was the time when such unrealistic projections have been made as by 2010, solar panels would provide 38% of the country’s electricity (Sovacool, 2009). Then, the Reagan administration’s U-turn energy policy (spurred by enhanced productivity in the energy sector) destroyed this optimism, and this is where the path-dependency and ’lock-in’ is probably established what we are facing today.

The intermittency and variability of policy support is a serious political impediment for renewable energy, since investors cannot be sure that the government support is continuous or intermittent. Agnolucci (2008) note that policy stability is crucial in promoting renewable energy policies by persuading financial actors and utilities to invest. In economics parlance, ‘hold-up problem’ might arise when because of uncertainty, investors may forego positive-NPV projects because of the fear that if they invest, then policy suddenly changes they would lose bargaining power since capital goods would not be possible to use for other purposes (Agnolucci, 2008).

2.2.3. Behavioral barriers

Simon’s bounded rationality refers to the idea that human beings in principle cannot be rational. It is physically impossible that somebody possess all the available information when make decisions (Sovacool, 2009). According to this theory, apart from logical and objective factors, there is a whole deal of other factors affecting the decision making process of an actor making decisions about investments in renewable energy.

The perception of risk is also another factor. Some investors and decision makers are more risk averse than others, who are risk-loving, and willing to explore new territories with higher uncertainties.

Masini and Menichetti (2010) argued that policy makers should understand how investors behave and make decisions, the understanding of underlying psychological factors are important. They propose and approach which based on the concept of behavioral finance, take into account these factors in energy policy.

The behavioral barriers include cultural and social dimensions; such as public apathy towards energy affairs, misunderstandings, psychological resistance towards new technologies. Public apathy towards energy affairs is widespread: people assume they are entitled to unlimited supply of energy resources. People generally do not care and/or do not interested where electricity comes from. Also, people view energy differently; these value system differences can be seen as consumers view energy either in a scientific, economic, ecological, social, or energy security sense (Sovacool, 2009).

In relation to path-dependency, there is the phenomenon of ‘path-dependency of the third kind’ (Buzar, 2007). According to this concept, agents make inefficient choices about energy due to various cultural, ideological, and/or opportunistic reasons, even though they are fully aware of other alternatives; in this case, people might be fully aware of the advantages of renewable energy, but they simply do not care, or not motivated enough to act.

3. CASE STUDIES

3.1. Germany

Germany, the fifth largest economy in the world (by PPP terms), and the largest economy in Europe is the home for 81.5 million people on a 357 000 km^2 area (CIA World Factbook, 2011).

The country can be an exemplary case in its history and attitude towards green energy, and can be considered as a success story in terms of a leader in transition from fossil fuel-based energy regime into an increasingly sustainable, renewable-based one. The basic enabler technologies for the spectacular growth are wind turbines and solar cells. In 2010, the share of wind in Germany's 603 TWh electricity generation was 6.2%, while solar PV 2% and their share is growing steadily (especially the latter – it was only 0.8% in 2008) (AEE, 2011). Only in 2010, quarter of a million solar PV units installed adding a capacity of 7 400 MW to the grid (Gipe, 2011). The final goal is to boost renewable electricity to reach 40% share by 2020 (*ibid*.).

In the following, I will review the historical roots and development of the country's renewable energy policy, and in the process, identify the key factors relevant to the sociotechnical systems framework.

The **'Electricity Feed-In Law' (StrEG)** was enacted in 1991 with wide political consensus. Since then, a fixed feed-in tariff (FIT) system has been in place which was the main factor in the country's renewable energy development and support, and as Bechberger and Reiche (2004) note, led to the market breakthrough of wind energy.

The StrEG required utilities to connect generators of electricity from renewable energy technology to the grid and to buy the electricity at a rate which for wind and solar cells amounted to 90% of the average tariff for final customers (and 80% for other renewables), significantly exceeding the costs of conventional power generation (Jacobsson and Lauber, 2006, Frondel et al, 2010). It gave considerable financial incentives to investors, although less for solar power since its costs were still prohibitively high. One of the purposes of the law was to establish a 'level the playing field' for renewable electricity by setting feed-in rates at levels that internalized the external, social costs of conventional power generation (Jacobsson and Lauber, 2006). After the market liberalization in 1998, the level of FIT was decreased in tandem with the decreasing costs of electricity (Frondel et al, 2010).

In 2000, the **'Renewable Energy Sources Act' (EEG**) substituted this act, and set a target of 12.5% of electricity generation from renewables until 2010 (by 2008 this goal was already exceeded). The change compared to the Feed-In Law was that it decoupled the tariff level from the electricity retail price, and set the new tariffs based on the real costs of electricity generation (Haas et al, 2011). The basic principles were a fixed payment for new installations to encourage technology learning and a long period of regressive reimbursement (Costa et al, 2008). The EEG made possible for other technologies, most notably to solar PV and biomass to repeat the success of wind power promotion.

As a consequence, Germany more than doubled its renewable energy production since 2000. Frondel et al (2010) argues that the differentiated subsidy system actually stifles innovation, and creates an 'unlevel playing field', and they advocating for a uniform subsidy level for all renewables thus enabling to market to decide which technology is the best, thus advocating for less government intervention and letting the market to pick the winners. They even go that far that '*rather than promoting energy security, the need for backup power from fossil fuels means that renewables increase Germany's dependence on gas imports…[a]nd* *the system of feed-in tariffs stifles competition among renewable energy producers and creates perverse incentives to lock into existing technologies'.* These authors seem fail to realize that without strong government intervention, it is not possible to effectively promote renewables if they have to 'fight' with conventional technologies and vested interests of large, incumbent utilities. The embededdness of conventional technologies skew the 'free market' landscape and this clearly requires government intervention. As a matter of fact, as several authors point out, e.g. Scrase and MacKerron (2009:142) that FITs are not only design to mitigate carbon emissions, but it is intended to encourage innovation, and niche magagement, in order to pass from one level (niche) to the another (sociotechnical regime).

After serious of criticisms and controversies, the EEG was amended in 2004, and a 20% renewable goal was set by 2020 as well, in harmony with EU laws. Also, they increased the FIT for emergent, niche technologies, such as geothermal electricity and solar PV. Additional bonuses were granted for innovative technologies too. Investment security for green energy generators was provided up to 20 years, as a fixed period, and not dependent on market prices. EEG was so successful that a handful of countries emulated Europe-wide.

Onshore wind is the main element in the increase of renewable electricity in Germany: more than 60% of new installations were this type since the early nineties (Haas et al, 2011). In 2000, when the EEG was enacted, the total installations of onshore wind reached all previous records, and this led to 11% renewable electricity in 2005, compared to 4% in 1997.

According to Jacobsson and Lauber (2006) there were three distinct phases in the diffusion of these green technologies in Germany. From 1974 until 1988, the 'formative phase' can be described. After the oil shocks, all the countries, thus Germany too rethought their energy policy and priorities. This period can be characterized by initial experimentation, or 'baby steps' towards renewable development.

This was the time when a dilemma was persistent whether nuclear power should be prioritized, or energy efficiency and renewables. Increased funding for clean technology R&D, strong public involvement spurred development of the latter, while opposition from large utilities was apparent too. Harnessing the niches and in the initial formation of niche markets, R&D funding was crucial. During this time, several new institutions were formed which were vital in forming advocacy coalitions later (Jacobsson and Lauber, 2006). These institutions were industry actors, but environmental actors as well, and included the Institute of Ecology (1977), the German Solar Energy Industries Association (1978), and Eurosolar (1988).

From 1988 until 1998, in the second phase, **wind power** took off. With the falling oil price, the gap between the costs of renewable versus conventional energy generation grew further. In 1989, the '100MW' then two years later the enlarged '250 MW' project was launched with the aim of installing this amount of wind power. This was an ambitious goal, since the then current capacity was a mere 20 MW. It also served as a field of experimentation and learning about the technology, and first started in state level (REN Program in Northern Rheine Westphalia) before federal level deployment. In the period between 1990 and 1998, wind power grew from 48 MW to 4 443 MW (Bechberger and Reiche, 2004). By 2008, Germany became the second largest wind power leader in the world (after US), with 24 000 MW installed capacity. Apart from subsidies, soft loans played a vital role as well, provided by the state-owned *Deutsche Ausgleichsbank* (*ibid.*). Apart from unprecedented market expansion, other benefits included the emergence of learning networks and the related spill-over effect for new entrants (Jacobsson and Lauber, 2006).

With the success of wind power, large utilities were increasingly furious and they tried to crumble the success story. They filed a complaint to EU's DG Competition and the EU concluded that FITs should decrease. Finally, this battle led to stagnation of wind market between 1996 and 1998 due to uncertainty and investor insecurity. Finally, FITs were not reduced due to unprecedented agreement even between political sides. After this clear signal, uncertainty disappeared and the wind power industry has been revitalized.

In the third phase, after 1998, the **solar industry** reached significant success as well. By 1999, the '100 000 roofs' programme took off, as a more ambitious successor for the '1000 roofs' program which ran from the early nineties. However, incentives (including soft loans) were not enough to encourage large-scale deployment; everybody was clearly waiting for the revision of the FIT law while the industry was in the 'age of darkness' as the German government effectively stopped subsidizing solar PV when the '1000 roofs' program concluded (Mallon, 2006).

After new impetus and policy change in 1999, the 'age of enlightenment' (Mallon, 2006) came, and the solar industry took off. By mid-2003, the '100 000 roofs' goal reached (*i.e.* 350 MW_p capacity in total). Other goals were also reached, namely raising awareness of the public, with the usual cost reductions and system performance improvements which are the features as niche technologies moving up the innovation curve.

Solar PV is by far the most privileged technology in terms of FIT funding: while in 2009, the mean tariff was 13.6 euro cents per kWh, solar PV FIT was 43€c/KWh, this equals to almost one-fourth of overall (€9 bn) FITs (Frondel et al, 2010). Currently, more than 40% of global solar PV business is located in Germany (*ibid*.). However, the inconsistency of political support should be noted in case of solar PV: after the so-called '1000 roofs programme' between 1991 and 1995 there was a strong support for solar PV, then after the program concluded with '2000 roofs' actual installation (fairly successful), suddenly all the support were gone – and according to experts this led to the migration of solar PV investors to other countries with actual support mechanisms (Bechberger and Reiche, 2004). This period of turbulence was until 1999, when the abovementioned '100 000 roofs programme' took off. Around the millennium, several other programs took off, such as the ETR (Ecological Tax Reform, 1999), and the Market Incentive Programme (MIP, 1999).

As of the most recent development, political will for renewable energy is stronger than ever, thanks to the crisis and possible demise of the nuclear power industry. In a recent policy document (SRU, 2011) policy makers are acknowledging that if they do not manage to break the fossil fuel path dependency, which would be the 'death knoll' for the achievement of climate policy. They also acknowledge that a '*new balance between market forces, government planning and public participation'* is necessary for meaningful achievements. Most importantly, they can also see that market forces in themselves are not sufficient for transition, and more bottom-up approaches should be promoted involving the public. As for the future of EEG, the same policy document mentions that however it is basically very successful, it is ripe for renewal. The long-term cost efficiency of support schemes, and portfolio optimization approach are the cornerstones of 'future EEG'. Interestingly, they admit that solar PV has been over-subsidized, and this led to a cost-inefficient renewable energy portfolio, and further technological advancements are needed before large-scale solar PV expansion (SRU, 2011). Also, another policy document declared that the future EEG will be more market oriented (BMU, 2010).

Finally, the following diagram demonstrates the former predictions and the current reality about German renewable development, which is the proof for the shining success by the reality exceeding all expectations:

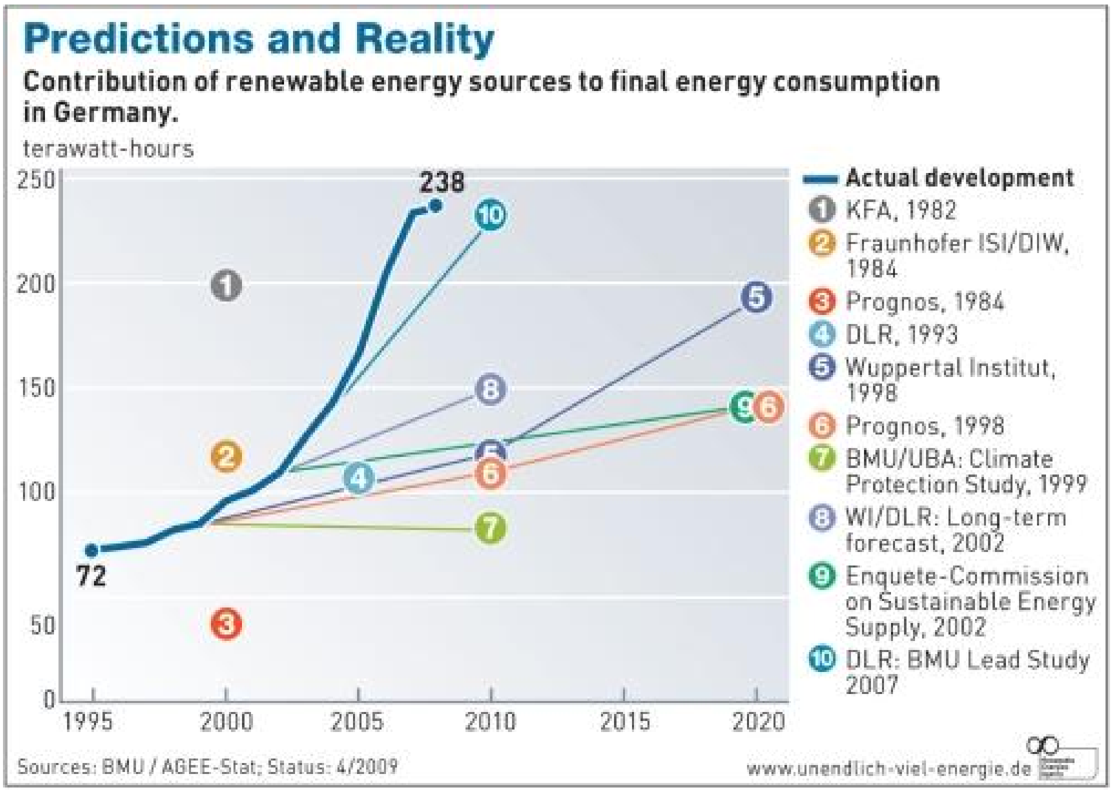

Figure 4: The development of German renewable energy sources

Source: AEE (2009)

What can de deduced from the German case is that there was a very strong government intervention favoring renewable energy sources, and putting a pressure on large utilities. Coal lobby and large utilities did everything to sabotage the policy and this was definitely a strong barrier; the battle between decision makers and the 'conventional' energy industry was not helpful in the large scale deployment of renewables. However, the results are still impressive, and make Germany an interesting case study how to promote renewables. In this, the role of the active and informed public is tantamount, and without the pressure of the public, probably there would have not been this scale of success. When wind power was a niche technology in the eighties, it was crucial that ambitious programs and determined efforts were put forward to elevate the technology into the sociotechnical regime and make the wind industry of the flagship technology of Germany. Solar PV is in its nascent state as of now, but if we look at the statistics, we can see that there is a bright prospect for this technology as well to emerge in the sociotechnical regime.

Economic barriers were surmounted by ensuring that investors are getting a remuneration which are stable and calculable which ensured investment security. It was really helpful that remuneration was set as technology specific, and this lead to specific technology development with the case of wind and solar. In political terms, the 2002 decision about phase-out of nuclear power was certainly served as an impetus for renewable energy development. The political support to end high import dependence was also crucial element of the policy of supporting renewables. In terms of behavioral barriers, since there was no significant opposition among the public to the deployment of (sometimes controversial) wind turbines, this was not a significant barrier. Also, an enabler can be identified: the well-informed and conscious German people.

It can be concluded that the feed-in tariff system without a sound, stable and supportive public policy framework would have most likely been ineffective.

3.2. Iceland

Iceland, - a prime example for a sustainable energy regime -, is located on the Mid-Atlantic Ridge, with 311 000 people living in a 103 000 km^2 area (CIA World Factbook, 2011). The economy heavily relies on the fishing industry, as well as heavy industries (*e.g.* aluminum).

The country is being lucky to be endowed with vast geothermal and hydro resources due to its unique geographical location. The country's geothermal reserves are said to be equivalent to one-third of currently known global oil reserves (Mackay and Probert, 1996). High and low temperature geothermal areas are abundant, available for generating electricity (indirect use), and other purposes, including space heating, bathing, agriculture (direct use). Among the 24 countries around the world currently generating electricity from geothermal energy with a total capacity of 10 GW, only Iceland and Italy are doing this to any appreciable extent (Thórhallsdóttir, 2007a), while direct use available in 72 countries (*ibid*.). Iceland's per capita electricity consumption is among the highest in the world (0.0544 MWh in 2009). This is because the heavy industries which were lured into the country with extremely cheap electricity prices. Only 20% of the 16.5 TWh electricity consumption is consumed by the population (Landshagir, 2010), and Iceland produces five times more electricity than it needs (President of NEA interview, 2011).

The economically exploitable hydropower resources of the country are estimated to be around 30 GWh/year, and geothermal is also about the same magnitude, although difficult to measure (Thórhallsdóttir, 2007b). Number of hydropower plants had been constructed by the mid-nineties, but after controversial projects, public opposition grew which led to abandonment of several projects (Thórhallsdóttir, 2007b). These debates shed light to the shortcomings of Icelandic decision making process in energy issues.

Government policies for energy are rather unique because of Iceland's special geological features, but it can provide a valuable insight how to build up a sustainable society based on renewable energy.

As part of the country's sustainability approach (every policy document is revolving around this concept), a 1997 white paper had been published, in which the government pledged to the long-term development of energy resources by considering economic, social, environmental and regional aspects (Thórhallsdóttir, 2007b). In 1999, this evolved into a framework called 'Framework for utilization for geothermal energy and hydropower'. As a part of this framework a public consultation started, with an aim to develop a 'Master Plan' by setting up several working groups and mutual learning. They emphasized that this is 'scientifically based' and 'open to public opinion' (Landvernd, 2010). Landvernd, an environmental NGO was asked to establish an open forum for discussion, which involved workshops, open meetings, cooperation with the media, as well as an interactive homepage with 100 000 visitors yearly (*ibid.*). This number demonstrates that the public is pretty much interested in the issue, since more than one-third of the population visited the webpage in a year. The first phase of the Master Plan was completed by 2003 with the all-encompassing evaluation of 22 geothermal and 19 hydropower development projects (Thórhallsdóttir, 2007a). Currently the second phase is set to conclude.

The current legal framework has two cornerstones: the 57/1998 'Act on Survey and Utilisation of Ground Resources' and 65/2003 'Electricity Act'. According to NEA lawyers, linking more closely these two legislations to each other is the future challenge for policy.

These documents determine the ownership, licensing and other related issues concerning the exploitation and use of energy resources.

Speaking about key institutions, the 'Welfare for the Future' is Iceland's national strategy for sustainable development, outlining a roadmap for the 2002-2020 period. In this document, the negative effects of hydro- and geothermal energy are also acknowledged (for example a concern about the slow renewability of geothermal reservoirs, or the effects on ecosystem and wildlife) (WF, 2002:18).

The Icelandic Energy Marketing Unit (MIL) was set up in 1988 with the aim of attracting investors in energy intensive industries, and foster the direct export of power (Mackay and Probert, 1996). The National Energy Company, Landsvirkjun was founded in 1965, and currently this company supplies 74% of the country's electricity, and recently set a goal to double its power capacity by 2025 (IPS, 2011). The company also participates in projects investigating the possibility to harness wind- and tidal energy. For the former, participation in the ICEWIND Nordic research project is on way, and a 50 metre high mast has been set up for experimentation and depending on the results, wind power might play a role in Iceland's future energy portfolio (IPS, 2011).

The ICI (Innovation Centre Iceland) is conducting research in the West Fjords about the possibilities of tidal energy utilization. Landsvirkjun also adopted a very flexible policy in the early nineties to attract power-intensive industries (Mackay and Probert, 1996), that is how Iceland became the world largest aluminum producer (IPS, 2011). The attractiveness was understandable: for instance in 1993, the electricity unit price for large industries was 2.33 US cents, while in Germany for instance, it was 9.25 US cents at the same time Mackay and Probert, 1996). As foreign investment has been poured into the aluminum sector, IT companies are also interested in moving their server parks to the country (*e.g.* Google, Microsoft). However, the financial crisis severely affected Iceland and the signs clearly are visible as of today (empty office buildings, delayed constructions, *etc.*) (CIA World Factbook, 2011).

In 1976, NEA had been founded and got its first mission to manage the 'Icelandic Energy Fund'. The fund, established by the government, gave out loans for geothermal exploration and drilling (the costliest parts of the development), and if projects were turned out to be unsuccessful, the loans were converted into grants (Thorsteinsson, 2005). Until a geothermal source is successfully proven, there is generally no way to get external funding: the investor has to borne the costs of drilling by himself, which can exceed two-thirds of total project expenditures. This is a special circumstance, and significantly deters risk-averse investors whose main concern is a stable cash-flow stream.

As the president of NEA pointed out during the personal interview, various mechanisms were supposed to distribute and mitigate risks to spur investments (budget money, guaranteed loans, drilling fund). This was the way to overcome the economic barrier of transition to indigenous resources. Direct subsidies were not given to investors, only in remote, very cold areas, where geothermal was not available for exploitation.

With the explosive growth of the industry however, these loans became unnecessary, and utilities took the leadership in geothermal exploration and development soon after, and there were no need for the financial support from the government (Thorsteinsson, 2005).

As energy experts emphasized during personal interviews in Iceland, it was crucial to convince people that the transition will be beneficial for them: renewable energy is for the benefit of the people, as they frequently emphasized. And this benefit should be economical too: this 'beneficial transition' indeed happened: heat and electricity is so cheap, that the price of these services is not on their mind at all (personal interview with Páll Valdimarsson, R&D director of Enex).

In terms of political barriers, it was obvious for the political elite that dependence on oil was dangerous, and this was the main driver to overcome political uncertainties. Also, it was a concern that with the goal of attracting energy intensive industries, it would have been very controversial to invest in conventional, fossil fuel-based power plants, so this was out of the question (Interview president of NEA, 2011).

The main behavioral barrier was people's reluctance to change. However, because of the rather small population and 'cosy' atmosphere of Iceland, people were easily convinced about the benefits of geothermal utilization (Interview president of NEA, 2011). As of today, the main barrier is the growing opposition of people because of visual concerns, or environmental degradation. Once there was a case when people opposed a geothermal development because of the 'ugly pink colour' of the pipelines going long way through the countryside (UNU-GTP director interview).

Today, more than 80% of total energy consumption comes from renewables, and 100% of electricity generation and heating provision are renewable-based. The share of geothermal in electricity generation is 20% with 422 MW_e installed capacity, and in district heating, 90%. Only 20% of geothermal potential is used and there are ambitious (but realistic) plans to harness this unique opportunity further. Iceland's geothermal energy is used 54% space heating, 28% electricity generation, and the other uses include fish farming, snow melting, swimming pools, etc. (Thorsteinsson, 2005). About the costs savings, the president of NEA remarked during the personal interview that because of the geothermal district heating system, '*we live for free every tenth year'*.

One might think that Iceland has always been a clean, renewable country. But this is not true: until the 1970s, the country was similar to any other nations in terms of energy usage patterns: fossil fuels dominated. For instance, after World War II, space heating was almost entirely fossil fuel-based. By 1970, 43% of the country's space heating was provided by direct-use geothermal energy (Thorsteinsson, 2005). The oil crises spurred the large-scale development of indigenous resources, and this was the 'extraordinary event' or 'extrenal shock' (described in the literature review) needed to complete transition.

The following diagram shows coal's spectacular disappearance from the Icelandic energy regime between 1930 and 1970, first replaced by oil, then after the oil crises, by indigenous resources:

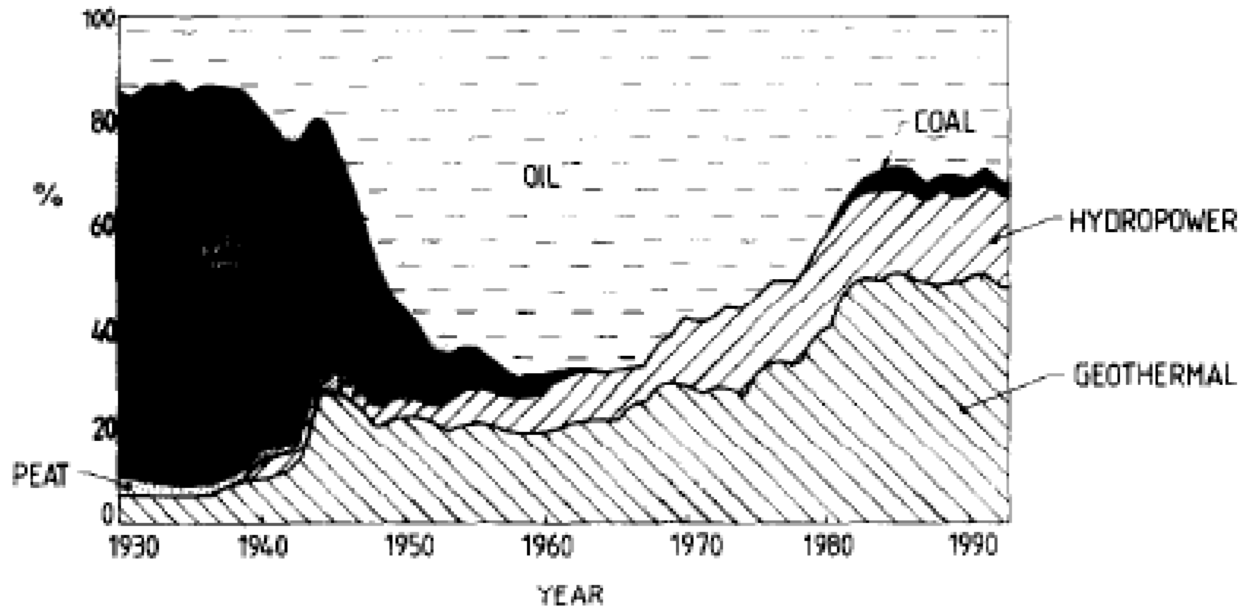

Figure 5: Iceland's percentage use of imported oil and coal, and indigenous-energy consumption as percentages of total energy consumption

(Source: Mackay and Probert, 1996)

The measures taken by the Icelandic government in the 1970s included giving grants and aid for enhancing the insulation of all existing buildings, as well as issued more and more strict building regulations on insulation. Also it gave aids and grants to communities for new investigations for geothermal usage in space heating applications (Erlingsson, 2008). While house heating in the seventies was provided by oil in a 50% share, in 2007, the share of oil contracted to a mere 1%. It is estimated that about 100 million tons of CO_2 emissions have been avoided because of the geothermal district heating system since the first house has been connected to the system in 1943 (Axelsson et al, 2010).

Currently, the Iceland Deep Drilling Project (IDDP) is an ambitious plan to harness the not yet developed geothermal potential of Iceland, the so-called 'supercritical geothermal systems', which would produce up to ten times more electricity than existing technologies. The real challenge for Iceland now is that how to enhance its 'clean economy' by tackling the challenges of transportation, since pollution levels are increasing as cars are still running on conventional fuels.

In terms of how Iceland can serve as a best practice for propagation of clean energy and renewable energy utilization, it would be important to boost the profile of this field: for example, more research activities (not only technical), more broader scope (not only supporting developing countries with the UNU-GTP training programme). Iceland could easily take a leadership approach instead of 'quietly' staying in the background. For what it's worth, they are leader in engineering and expertise, but in terms of 'soft skills' dissemination, there would be more possibilities to promote sustainability around the globe based on their experience.

4. CONCLUSION

The key issue around the world recently is a renewed debate about the market-based approach towards renewable energy development, and the question about government intervention in order to correct the market failures of energy policy (Scarse et al, 2009). From the German case study it can be seen that this is a real challenge now, as previously they preferred strong government support, but now they seem to be ready to cut the umbilical cord from the renewable industry. Whether this comes together with the internalization of fossil fuel externality costs is an open question. However, it still remains true that the 'neoliberal consensus' model, *i.e.* the market-based approach with emphasis on low-cost, short-term investments with quick return on investments is not sufficient to tackle the problem of ensuring long-term sustainability in the energy system (Scarse et al, 2009).

The investment decisions made today will determine whether the world can be put on a sustainable energy pathway. The decisions made 20 or so years ago will still determine the energy regime for the next 10 to 20 years (Scarse et al, 2009). Therefore it is critical to think about how to ensure the transition, if it is possible at all.

As Scrase and MacKerron (2009) argue, in lieu of seeing change as a function of supply and demand as well as individual responses to market incentives, analysis should concentrate on the socio-technical systems approach instead in order to understand the dynamics, mechanisms and patterns through which transitions from one energy system to another happen. This paper tried to apply this approach and argued for its application in policy making.

Reframing energy policy is an essential element of the transition to low-carbon energy system: this includes reframing and rethinking problems and solutions (Scrase and Ockwell, 2010). Climate change is an issue which is framed as a problem which can be solved with existing technologies and practices, and there is no need for forward-looking, visionary mindset (Lovell et al, 2009). As it was described in the literature review, this is connected to firm's propensity not to innovate radically and preferring continuity approaches which are improving the existing technologies rather than large-scale new innovations and renewable deployment. However, if full-fledged transition is necessary, this approach is clearly insufficient.

In developing nations, traditional biomass still plays a big role. This makes energy transitions in the developing and the developed world different, raising important questions, such as whether it is possible that developing countries 'jump' straight ahead and follow a renewable energy pathway instead of locked-in into hydrocarbon intensive technologies and infrastructures which would constrain their choices later; this phenomenon termed 'leapfrogging' (Perkins, 2003). By learning by the 'mistakes' of now-developed countries, developing countries could invest heavily in clean technology, since now they are in their early stage of their industrialization path which has already happened in the developed world long ago. This would effectively mean the decoupling of developing and the developed world in terms of future energy systems. As an IPCC (2011) report shows, currently 53% of electricity generation is in developing countries, and as these countries are shifting from using traditional biomass (*i.e.* burning wood), to modern technologies, there is a viable possibility that these technologies will be clean ones.

The capacity of the atmosphere to handle carbon emissions is limited. Nobody knows the exact dates when a saturation point will come, but there is a consensus that when this point reached, there is a real possibility to system transformation, and inevitable technological transition to renewable technologies, since a current technological system always prone to be displaced if there is an 'extraordinary' event or external shock (Unruh, 2004). This 'shock' is a kind of event like currently the turmoil in the Middle East (oil), possible growing political problems involving Russia (gas), or the Japanese nuclear disaster, and so on.

The future of energy governance is not about classic concerns of energy resources, infrastructure and markets: it should extend beyond these and encompass the technologies and behaviors (*i.e.* social factors) throughout the society and economy Scrase and MacKerron (2009). Widespread renewable energy systems pose tremendous challenges to policy making; and mean significant pressure on existing institutional structures and routines of planning authorities – who are rarely visionary and innovative.

This paper has argued that in order to transition to a low-carbon future, it is essential to think in broader terms, and include all political, social and economic factors into our decision making. However, the paper also pointed out that because of bounded rationality, it is not an easy task to include all available information into decision making. Policy makers are busy with political struggles, and other actors may not care about energy policy, or they have different viewpoints about it, more conservative, traditional, or more visionary. To level all these different considerations with carefully planned and implemented policies and decision making is challenging, but if we manage to do so, it can help to overcome the various barriers to transition.

Helping technological change is a very complex matter, and rarely understood by political, economic or 'ordinary' actors. However, it is possible that incremental changes in policies can initiate a change and break path dependency. The case studies in this paper demonstrated two different situations in terms of transition. Iceland is an extreme case, and one can say that their nearly 100% renewable situation is only luck, but of course it is far more complicated than that. Germany is a rather typical country in terms of energy usages, but also a very good example how iron-fisted and coordinated government policies and strong public awareness can help putting a fossil fuel locked-in country into a renewable future track.

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