# Energy Transition: the Case Study of Germany and the Czech Republic

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I affirm that I have written the Habilitation “Energy Transition: the Case Study of Germany and the Czech Republic” on my own with the aid of the cited and mentioned sources and literature.

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**List of Abbreviations**

ACER – Agency for Cooperation of Energy Regulators

BNA – Bundesnetzagentur

BBPIG – Bundesbedarfsplangesetz

CACM – Capacity Allocation and Congestion Management

CCGT – Combined Cycle Gas Turbine

CCS – Carbon Capture and Storage

CEO – Chief Executive Officer

CHP – Combined Heat and Power

EEG - Erneuerbare-Energien-Gesetz

EBITDA - Earnings Before Interest, Taxes, Depreciation and Amortization

EnLAG – Energieleitungsgusbaugesetz

ENTSO-E - European Network of Transmission System Operators for Electricity

ERO – Energy Regulatory Office

EU – European Union

FSS MU – Faculty of Social Studies, Masaryk University

GW – Gigawatt

GWh – Gigawatthour

HDR – Hot Dry Rock (geothermal energy)

IEM – Internal Energy Market (of the EU)

kW – Kilowatt

kWh – Kilowatthour

kWp – Kilowatt-Peak

LCOE – Levelized Costs of Electricity

LF – Loop Flows

MFA CR – Ministry of Foreign Affairs of the Czech Republic

MLP – Multi-Level Perspective

MW – Megawatt

MWh – Megawatthour

NAP – National Action Plan (for the Development of the Nuclear Energy)

NC – Network Code

NTC – Net Transfer Capacity

NPP – Nuclear Power Plant

OCGT – Open Cycle Gas Turbine

PCR – Price Coupling of Regions

PST – Phase Shifting Transformer

PV - Photovoltaic

RES – Renewable Sources of Energy

SEPU 2015 - State Energy Policy Update of 2015

TSO – Transmission System Operator

TW – Terawatt

TWh – Terawatthour

UAF – Unscheduled Allocated Flows

UF – Unscheduled Flows

VAT – Value-added Tax

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## Abstract

With the global consensus on the urgent need for climate change mitigation and increasing investment into low-carbon technologies, social-science based research of energy transitions – dramatic and permanent changes in the way energy is produced and consumed in socio-technical systems – is on the rise. The goal of this paper is to contribute to this research with an analysis of how energy transitions may be affected by cross-border factors. For this purpose, this text looks at the case of Germany – Czech Republic, evaluating how the former country's energy transition (known as the *Energiewende*) affects the latter's system of electricity provision, which has its own transitional dynamics.

The research question is stated as follows: "How does Germany's *Energiewende* affect the transition of the system of electricity provision in the Czech Republic?" To answer this question, I employ a Multi-Level Perspective approach, which perceives any socio-technical system (the system of electricity provision in our case) as a dynamic network of infrastructure, institutions, and actors. The interaction of these constitutive elements ensures the functioning, reproduction, and gradual evolution of the system. Nevertheless, when the system is exposed to external pressure, and innovative technologies emerge on the micro level offering an answer to this pressure, MLP expects a system to undergo a transitional change.

This theoretical approach then is applied to the situation in Germany and the Czech Republic. Two major cross-border factors are discussed. First, Germany affects the Czech system of electricity provision via changes in the wholesale price of electricity. With the *Energiewende* adding a massive amount of subsidized renewable capacities to its system, Germany has been driving the average price of electricity down. This trend then spills over to the Czech Republic via the regional electricity market, affecting the behavior of energy stakeholders in the country. Second, the imbalance between rapid renewable construction and substantially less rapid grid investments and capacity allocation mechanisms has caused major unscheduled flows of electricity, compromising the stability of the Czech grid and its ability to carry out its commercial functions.

These two factors and the way they affect the transitional dynamics of the Czech system of electricity provision are then thoroughly analyzed. I show how the system has accepted some of the pressure and has adjusted to some of the characteristics of the *Energiewende*. However, since the transition of the Czech electricity sector is still immature, only general trends can be sketched, as accessible data about the transition progress does not yet point unequivocally in a single direction.

# 1. Introduction

No human activity is possible without a sufficient amount of energy, be it the production of food, defeating enemies, or building infrastructure. Over the course of multiple energy transitions in history, defined here briefly as the changes in the composition of primary energy supply and the technologies used, human society has succeeded in taking advantage of more complex energy flows and, consequently, has achieved a more prosperous and affluent existence.[1]

In the first energy era, time-limited by the emergence of *Homo sapiens* some 300,000 years ago on the one side and the beginning of the settled societies about 10,000 years ago on the other, human muscles and the occasional use of fire were the only sources of energy. In the process of the first energy transition, these primitive sources were supplemented by the power of domesticated draft animals and systemic usage of fire for the production of metals and glass. The second transition came a few millennia later, when waterwheels and windmills were mastered. The third one untapped the vast reservoir of energy hidden in fossil fuels (mainly coal), leading to the beginning of the Industrial Revolution in the 18th Century. The most recent one has been marked by the introduction of electricity and the dissemination of new energy resources; oil, natural gas, nuclear energy (Smil, 2004; Smill, 2016). These transitions constituted the significant steps in the development of human society, affecting dramatically every aspect of human existence.

Now, yet another transition seems to be on its way. This is driven by climate change concerns, and the primary goal of this transition is to decarbonize the world economy. Since fossil-fuel combustion is the source of about 68% of the world's emissions of greenhouse gases, there has been a growing consensus on the necessity to limit the energy usage of coal, oil, and natural gas to keep the world's average temperature increase below 2 degrees Celsius above pre-industrial levels – the threshold considered crucial for the stability of the global ecosystem (IEA, 2016b; United Nations Environment Programme, 2016).

A variety of tools have been considered appropriate to achieve this goal. Fossil fuels are expected to be gradually replaced by low-carbon technologies, renewable sources of energy (RES, renewables), or nuclear power plants (NPP). In the meantime, greenhouse gases from fossil-fuel power plants could be prevented from entering the atmosphere using Carbon Capture and Storage (CCS) installations; this is technology that is able to sequester carbon dioxide and store it underground in significant amounts. Energy efficiency tools may also contribute, by decreasing the overall consumption of energy; these would consequently limit the combustion of carbon. However, from this spectrum only renewables seem to present a real alternative to existing patterns of the production and consumption of energy.

Nuclear sources are a low-carbon source, with only some limited amount of greenhouse gases being emitted during the production of fuel and the construction of plants. However, they face fierce public opposition, especially in the Western world, due to the increasing cost of

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[1] Proofreading of the study: Matthew C. Rees.

technology, concerns about security, problems with the permanent deposits of radioactive waste, and the inability of construction companies to build reactors on time and according to budget (Schneider & Froggatt, 2017; Bertélemy & Rangel, 2015). This situation became even worse after the Fukushima disaster in 2011 (Kim, Kim, & Kim, 2013). CCS technology is not economically viable, and without demand generated by substantial carbon prices, there is no market for it (Herzog, 2015). On the other hand, renewables are surging around the globe, with decreasing investment costs, increasing efficiency and predictability, and generally high public support. According to predictions by the International Energy Agency (IEA), production of energy from renewables is expected to reach 30% of global consumption by 2022, up from 24% in 2016 (IEA, 2017a, p. 7).

With the global consensus on the urgent need for climate change mitigation and increasing investments into low-carbon technologies (primarily renewables), social-science based research of the energy transition is on the rise (for a conceptual debate on social science research in this topic, see Stern, 2017; Castree & Waitt, 2017; Stephenson, 2017). Researchers gathering empirical data from different countries around the globe are transforming this data into theories of energy transition, with the aim of achieving a better understanding of transitional processes. The most prominent position in this research is occupied by the theoretical concepts associated with the Multi-Level Perspective (MLP), which also constitutes the theoretical foundation of this study.

In spite of the important contribution this growing body of academic literature has made (which I discuss more thoroughly in Chapter 2), it nevertheless focuses heavily on transitional processes defined by and confined by the borders of the nation-state. External (cross-border) influence is usually acknowledged, but rarely analyzed in detail, with the debate concentrating on intra-state actors, processes, and mechanisms. This gap has led to unsatisfactory analysis, since the ongoing transitional processes are clearly a result of a combination of both internal (domestic) and external (cross-border) pressures. Countries are affected by their commitments to global and regional climate regimes, such as the Kyoto and post-Kyoto framework. Moreover, due to cross-border flows of energy, finance mechanisms, technologies, know-how, and people, energy transitions and their processes spill over one country to another. No nation-state is insulated from these external forces; a proper understanding of the impact of these forces on domestic transitional processes is thus a critical goal of academic research.

I aim to contribute to this research with an analysis of the dynamics of the cross-border diffusion of an energy transition – i.e. the way the energy transition spreads from one country to another one, and the effects it creates. For this purpose, I have used the Germany – Czech Republic case study, evaluating how the former country's energy transition (known as the *Energiewende*) has affected – and continues to affect – the latter's system of electricity provision, which has its own transitional dynamics as well. The justification of this case study selection is based on the following reasons.

While the transition to low-carbon systems has been taking place in all different energy sectors, i.e. heat, transportation and electricity, the last of these is the most prone to change. For technical reasons, renewable sources are more suitable for electricity production than for other forms of energy. That means that we observe the most dynamic developments in the area of renewable electricity production; this, in turn, is the reason why the electricity sector is the most suitable for investigation, and this is the reason why we have chosen it for our case.

The German-Czech dyad was selected for a variety of favorable research characteristics (the data illustrating these characteristics are provided in Chapters 4 – 6). First, these countries are neighbors; this condition is essential for an intensive cross-border projection of influence. Second, their electricity markets are extremely closely connected, with robust cross-border transmission capacity, an intensive electricity trade, and a common regulatory framework. These characteristics are even more emphasized by their participation in the Internal Energy Market (IEM) initiative of the European Union, a project aimed at transforming national power markets to a pan-European one. Third, the degree of transition processes in these two countries is different: Germany's *Energiewende* is one of the most advanced in the world, while the Czech Republic's transition is in a rather early phase. This contrast helps to identify the vector of transitional cross-border pressure, where disruptive signals are expected to originate from Germany and affect the Czech Republic, and not vice versa. This is also supported by our last point, the significant imbalance of economic and political power between these two countries, with Germany being clearly dominant.

This imbalance in the relationship between both countries provides an essential analytical advantage. While an analysis of equally (transitionally) developed and powerful countries would require the researcher to work with a complex network of reciprocal signals, as well as their impacts, positive and negative feedback, and various reactions and counter-reactions, the German-Czech dyad requires a less complicated evaluation of the one-way flow of signals and the analysis of their impact on a single country.

Having defined the basic structure of the research case, it is now possible to define my research question: "How does Germany's *Energiewende* affect the transition of the system of electricity provision in the Czech Republic?" By answering this question, we will be able to get a better understanding of the interesting situation in Central Europe, where the economic, diplomatic, and environmental champion of the EU shares a border with its considerably smaller, environmentally moderate, coal-fired eastern neighbor.

This research idea is not a new one for me, as the author of this study. It reflects long-term research conducted at the Faculty of Social Studies of Masaryk University (FSS MU) over the last four years. Back in 2014, in an effort to cope with the increasing urgency of the *Energiewende* in Germany, the Ministry of Foreign Affairs of the Czech Republic turned to me (and my outstanding colleagues at FSS MU) to prepare an analysis of the possible impact of this transition on the Czech energy situation. Since then, multiple projects, papers, and grants have been conducted regarding this issue, helping me and my team to collect primary and secondary data; discuss this issue with numerous experts from academia, business, and government officials, in both the Czech Republic and Germany; and perfect the methods and theories to approach this issue. This work thus builds on all this existing research.

In December 2015, a classified paper with the title "Energiewende: current situation, future development, and impact on the Czech Republic" was prepared for the MFA CR; I served as lead researcher, and Jan Osička and Veronika Vaškebová were co-authors (Černoch, Osička, & Vaškebová, 2014). The findings from this analysis were discussed with representatives of the Committee for Sustainable Energy of the Government of the Czech Republic, of which I was (and still am) a member, in March 2015. A declassified, updated, and expanded version of the text was published in 2015, again under my supervision (Černoch, Osička, Ach-Hubner, & Dančák, 2015). In 2016, supported by the Czech-Polish Forum, related research was conducted dealing with the way Germany affects both the Czech Republic and Poland. Once released by the sponsor, it was published in an updated form (Černoch, Borshchevska, & Ach-Hübner, 2017). Another relevant book for this text was a detailed work on the Czech energy sector written in cooperation with Tomáš Vlček (Vlček & Černoch, 2013). Some of these sources are extensively used in this paper, and the descriptive parts summarizing the characteristics of the Czech and German energy sectors in particular have been essentially reproduced, albeit in an updated and upgraded form (I notify the reader of this occurrence in the corresponding sections of the text). In addition to this research, I also utilized my experiences and knowledge from a six-month residency at the *Deutsche Gesellschaft für Auswärtige Politik* in Berlin in 2014-2015.

To answer the research question, the paper tackles the following tasks, forming its structure.

In this introductory chapter (Chapter 1), I introduce and formulate the research problem, justifying its practical and theoretical relevance.

In Chapter 2, the concept of "transition" is discussed in detail. I look into the relationship between the more general "energy transition," a term describing any systemic change of how energy is used in a given system, and "decarbonization," which is the actual and deliberate process of switching from fossil fuels to low-carbon sources as a response to the climate change issue. The role of renewables in these transitional processes is also explained, revealing how their highly disruptive technical features are poorly compatible with conventional electricity systems based on traditional generation methods (coal-fired power plants, nuclear power plants and large hydropower plants).

Chapter 3 introduces the Multi-Level Perspective (MLP), providing us with the research tools to approach the empirical case. MLP perceives any socio-technical system (such as a system of energy provision) as a dynamic network of infrastructure, institutions, and actors. The interaction of these constitutive elements ensures the functioning, reproduction, and gradual evolution of the system. When the system is exposed to external pressure, and innovative technologies emerge on the micro level offering an answer on this pressure, MLP analysis should expect a system to undergo a transitional change. To understand this change, an MLP analysis allows scholars to offer a handful of the most probable transition pathways, based on previous empirical research. Building on this theoretical background, I have been able to construct a simple transitional model, which incorporates empirical data from the Czech Republic and Germany, and will be used to guide us through the research as a whole.

In Chapter 4, the Czech electricity sector is described in detail. Following the guidance of MLP, the text provides information about the state of the infrastructure, the institutions that govern their usage, and the actors that operate in the system. This dense and descriptive chapter is necessary to provide readers with some basic knowledge about the state of play regarding energy in both countries.

Chapter 5 examines the transition of the Czech electricity system. Building on the constitutive elements of the system, I illustrate how they are affected by the increasing dissemination of renewable generation facilities in the country. Later in the chapter, I discuss the overall dynamics of the system, trying to identify transitional pathways according to MLP. As will become obvious, this task is complicated by the fact that the energy transition in the Czech Republic is only in its infancy, revealing only a few traces of transitional trends.

The *Energiewende* and the way it might impact neighboring countries is depicted in Chapter 6. I identify two major factors enabling the transfer of the *Energiewende* to the Czech Republic: the price of electricity and the way it physically crosses the border. Detailed and updated data are provided to more deeply investigate these two factors.

These factors have the potential to change the Czech energy transition significantly, as illustrated in Chapter 7. Building on Chapter 5, I show how the Czech electricity sector interacts with the German one, accepting some of its pressure and adjusting to some features of the *Energiewende*'s transitional processes. Again, since the transition of the Czech electricity sector is still immature, only general trends can be sketched, as accessible data about the transition progress does not yet point unequivocally in a single direction.

In the last chapter, I utilize knowledge from the research to comment on the MLP approach and how it could and should be enriched. One of my claims is that the category of "external (landscape) pressures" needs to be more comprehensively developed and theoretically reinforced to represent the real situation of countries exposed to similar external pressures, as our case demonstrates.

# 2. The energy transition and the challenge of renewables

As indicated, this chapter defines and clarifies the term “transition,” with “energy transition” understood as a specific type of transition taking place in energy-related areas. “Decarbonization” is consequently understood as an even more specific sub-category of an energy transition, primarily describing current efforts to switch from fossil-fuel technologies to low-carbon ones. I also briefly comment on renewables as the primary tool of the current global energy transition/decarbonization and why they have such a disruptive impact on existing (conventional) systems of electricity provision.

## 2.1. What is an energy transition?

When scrutinizing transition as a general term, Philip Andrews-Speed ultimately defined it as “a gradual process of societal change, spanning the economy, technology, organizations, rules, systems, values and behaviors – essentially, a profound change in the way in which society operates” (Andrews-Speed, 2016, p. 217). Rotmans and his co-authors have offered the following characterization:

> Transitions inhibit development that takes place within economic, technological, political, environmental, social and other spheres that affect each other. They involve various actors from different groups. They are radical shifts from one configuration to another. Because of the multiple developments that are intertwined, the multi-actor nature, and the existence of radical shifts, transitions are complex processes with a high level of uncertainty. And finally, complexity and uncertainty add to the fact that transitions are long-term processes. (Rotmans, Kemp, & Asselt, 2001, cited in Lachman, 2013).

Building on these definitions, “transition” in this text is understood as a thorough, complex, and permanent shift from one status quo to another one, affecting all relevant segments of given system.

These characteristics are universally applicable to a variety of socio-technical transitions, including energy ones. While there is no single definition of energy transition, the existing and commonly used ones correspond to the idea of systemic change introduced above: “a change in fuels and their associated technologies,” “a shift in the fuel source for energy production and the technologies used to exploit that fuel,” “a particularly significant set of changes to the patterns of energy use in a society, potentially affecting resources, carriers, converters, and services,” “the switch from an economic system dependent on one or a series of energy resources and technologies to another,” “the time that elapses between the introduction of a new primary energy sources or prime mover, and its rise to claiming a substantial share of the overall market” (Hirsh & Jones, 2014; Miller, Richter, & O’Leary, 2015; O’Connor, 2010; Fouquet & Pearson, 2012; all cited in Sovacool, 2016). Augmenting primitive prehistorical sources of energy (human muscles and fire) with the power of draft animals, as well as wind and water mills; energizing economies with coal during the Industrial Revolution; mastering electricity and spreading it to all areas of human activity in the last century – all these transitions dramatically and permanently changed the way energy was produced and consumed and, more generally, how society developed afterwards.

"Decarbonization" is commonly understood as a complex, long-term, and fundamental shift from a fossil-fuels-based system to a system based on low-carbon technologies. Like all transitions, this shift in technical and economic sectors has been interwoven with changes in societal structures, routines, and cultures. As such, it obviously represents a discrete case as an energy transition (Binder, Mühlemeier, & Wyss, 2017; Grin, Rotmans, & Schot, 2010). At the same time, moreover, it exhibits some features never seen in an energy transition before. The most important one is its normative and intentional motivation: while previous historical transitions were driven by evolutionary technological inventions and its goals were neither known nor specified, in the case of decarbonization, the target has been politically set, guiding the strategies and actions in a pre-defined way. Decarbonization is not a consequence of superior low-carbon technologies surpassing existing technologies; it has been a targeted effort to replace fossil fuels with technologies that yet need be developed for this purpose. Moreover, in comparison with previous transitions in history, private actors have only limited motivation to genuinely address this issue, since its goal is focused on the collective good of sustainability, not primarily on immediate benefits for these private actors as such (Geels, 2011).

Acknowledging these terminological differences, the case that this work addresses is that of decarbonization. And the term "decarbonization" shows up extensively in this study. However, since current decarbonization processes are analyzed with the theoretical and methodological tools developed for energy transitions generally, and since I intend to use these tools as well, this work inevitably uses the term "energy transition" to describe the very same process. This should not cause any misunderstanding, as these two terms practically overlap in this case.

## 2.2. The role of renewables in decarbonization

As indicated, the aim of decarbonization is to decrease the amount of greenhouse gases emitted by conventional fuels in national energy systems. The emissions of different technologies are compared in Table 1.

*Table 1: Life cycle of $CO_2$-equivalent selected electricity supply technologies. Arranged by decreasing median values. In $gCO_2eq/kWh$*

| **Technology** | **Median** |
|---|---|
| Coal | 820 |
| Biomass co-fired with coal | 740 |
| Gas – combined cycle | 490 |
| Biomass – dedicated | 230 |
| Solar PV – utility scale | 48 |
| Solar PV – rooftop | 41 |
| Geothermal | 38 |
| Concentrated solar power | 27 |
| Hydropower | 24 |
| Wind offshore | 12 |
| Nuclear | 12 |
| Wind onshore | 11 |

*Source: Schlömer et al., 2014, p. 1333.*

The table clearly shows some ways how to proceed with decarbonization; this would primarily be by switching from coal and natural gas to renewable sources of energy and nuclear power plants. Other frequently discussed tools have included energy efficiency and energy savings, and sequestering greenhouse gases and burying them underground using CCS technology. However, considering the current situation in the countries in this study as well as in the EU more generally, the only viable decarbonization option seems to be the use of renewable sources.

At this moment, there are no CCS installations in either Germany or the Czech Republic, and none are planned. Moreover, Europe's regulatory and investment environment is not conducive to the development of CCS (Herzog, 2015). Energy efficiency and energy savings are strongly supported on the EU level, and they are also embraced on the national level in both case countries analyzed here. However, their impact is limited by definition, since any economic activity requires at least some energy. In Germany, net electricity consumption decreased from 340 TWh in 2007 to 325 TWh in 2015; in the Czech Republic it decreased from 60 TWh to 59 TWh over the same period (ERO, 2017c, p. 7; Appunn, Bieler, & Wettengel, 2017). Considering the continuous economic growth of these countries, this is a respectable achievement, and energy efficiency and savings tools certainly play some role in checking greenhouse emissions in these countries, but only partially. Moreover, these tools do not contribute to energy transitions in terms of changing the system – they only put some limits on already existing technologies and how much fuel they need to consume.

The decarbonization potential of nuclear energy is also limited. Germany is heading toward a full phasing out of its nuclear capacity (*Atomausstieg*), to be completed in 2022. In the Czech Republic, status quo actors, mainly the Ministry of Industry and Trade (*Ministerstvo průmyslu a obchodu*, MPO) and, with some hesitation, the ČEZ Company as well, have called for new nuclear investments. However, financial constraints have so far prevented any new construction; any development has only been limited to increasing the efficiency of existing reactors. By upgrading them, ČEZ (the sole nuclear operator in the country), increased their installed capacity from 3760 MW in 2007 to 4290 MW in 2016 (ERO, 2017c, p. 25). Irrespective of how impressive this achievement is, it is not a challenge for the existing system in terms of an energy transition.

Renewables are thus the only decarbonization tool with noticeable dynamics. Their production has increased dramatically in the last decade – whether globally, EU-wide, in Germany, or in the Czech Republic – and this trend has continued (more in Chapters 5 and 6).

At this point, however, some clarifications need to be made. "Renewables" are not a homogeneous group of technologies with similar characteristics, treated equally at the level of the system. Hydropower sources are considered a status quo technology, with a decent level of dispatchability, predictability and reliability, excellent economics, and, in the case of smaller installations, also with an acceptable environmental impact. However, due to a long tradition of the water-management industry, its potential is almost exhausted, with no significant untapped water capacities to be exploited in the Czech Republic or Germany. Regarding short-term and mid-term expectations, geothermal energy is in the very same position as a source with an insignificant potential (OTE, 2016).

Only three sources are thus considered viable renewable alternatives for decarbonization: biomass and biogas; wind power; and solar sources. In terms of technical characteristics, biomass and biogas are traditional sources, possessing a reasonable level of reliability and predictability and the possibility to be utilized in existing infrastructure. Co-firing of biomass with coal is an example of this. These fuels *do* challenge existing systems; since they are built in the form of relatively small units, they contribute to the decentralization of production. However, this disruptive potential is limited by the physical limits of biomass and biogas. The spatial constraints, high costs of transportation, and demand of biomass for other industries limits this source significantly.

The two remaining renewable sources, wind and solar, are different for multiple reasons. Most importantly, their growth potential considerably exceeds that of hydro or biomass/biogas, both in terms of increasing efficiency of the technology and spatial capacities to increase their overall capacity. They have also significant decentralization potential, being smaller than conventional generators. For example, a typical rooftop photovoltaic power station features a capacity of only 5-20 kW (Power-technology.com, undated). This allows for the decentralization of production, with the number of generators mushrooming across the country and with the involvement of new actors in production – medium and small businesses, municipalities, companies producing electricity as a side business, and households. This contradicts the traditional system based on centralized production by a limited number of core generators (IEA, 2017b; IEA, 2014; Bertsch, Growitsch, Lorenczik, & Nagl, 2014; Vlček & Černoch, 2013). Their fuel costs are zero; once built, these sources are very competitive, driving the overall price of electricity down and other (more expensive) sources out of the market.

Lastly, they are non-dispatchable, dependent on the (current) weather: the intensity of the sun radiation or wind speed. This characteristic and the way it affects the existing energy systems, however, needs to be explained in detail.

The traditional model of the electricity sector is based on the combination of base and peak load generators. The first one provides the elemental load of the power system, uninterrupted daily electricity consumption. These sources have usually high investment costs and low operation costs. This category is typified by nuclear and steam power plants, and the ability to regulate the output of these plants is limited. Peak load is load on the power system exceeding the standard level, supplying consumers in times of high demand. This category consists of sources with a more even distribution of investment and operation costs – sources that are able to ramp up and ramp down their production quickly. Pumped-storage hydroelectricity, gas, combined cycle, and some steam power plants are representatives of these category (Vlček & Černoch, 2013, p. 170).

Production of non-dispatchable solar and wind sources correlates with local weather. There is thus some element of uncertainty regarding their output following from the uncertainties of long-term and short-term weather forecasting. Due to these characteristics, the energy system needs to be ready to back up their production with sources of flexibility – batteries, demand management tools, or conventional flexible power plants that are able to ramp up and ramp down supply on short notice.

By having all these characteristics, non-dispatchable renewables cannot easily be integrated into the system as “just another source of electricity.” At some point, they start to have the potential to disrupt the system, changing it dramatically.

Acknowledging the combination of these two issues – the growth potential of wind and solar sources and their incompatibility with the existing patterns of production of electricity – this study focuses primarily on these sources as drivers of change (transition), because I assume that their massive dissemination will inevitably result in a dramatic change in how the electricity system works.

## 3. The analytical framework

In an attempt to explain the phenomenon of an energy transition, multiple distinctive but at least partially overlapping approaches have emerged in the last three decades (Lachman, 2013). These have included, for example, the "Strategic Niche Management" approach, which tries to explain transitional shifts by focusing on the development of experimental technologies on the level of "niches," or spaces of primarily technical innovative activity. In the process of learning-by-doing and doing-by-learning, some momentum is gained in niches, which helps new technologies to break into the mainstream system (Kemp, Schot, & Hoogma, 1998). The "Transition Management" approach focuses on the way a transition policy is (or should be) conducted on a practical level, combining activities on different levels of analysis (strategic, tactical, and operational). It assumes gradual and sustainable development through a combination of short-term targets and long-term thinking. Yet another approach, the "Innovation System," tries to combine both institutional and economic structures as they affect the direction and the speed of technological change in society. This concept's ambition is to break down a system into its constituents and discover which system elements do not fulfill their intended purpose. Due to this practical focus, this approach is attractive for decision-makers, helping them to pinpoint development bottlenecks (Jacobsson & Bergek, 2011). The "Techno-Economic Paradigm" focuses on long-wave cyclical developments on the macro-level that span multiple generations. This cyclic movement is one result of the emergence and diffusion of clusters of new technologies that replace existing paradigms (Lachman, 2013). Another one, the "Socio-Metabolic Transitions Approach," focuses on the interaction of a society (understood as a "socio-metabolic system") with other systems in the surrounding environment.

For the purpose of this study, however, I decided to use the "Multi-Level Perspective" approach, which focuses on socio-technical regimes and analyzes long-term developments in and between three defined operational levels ("macro," "meso," and "micro"). According to this approach, transition occurs as a result of dynamics at these levels which challenge each other, creating a window of opportunity for a systemic change. The next pages provide a more detailed description of this approach.

This choice was driven both by theoretical and practical reasons. After more than a decade of intensive work, authors using the MLP approach have turned it into a credible, coherent, and reliable tool to deal with socio-technical transitions in all their complexity. While the other aforementioned concepts usually approach only some segments or analytical levels of an ongoing transition, MLP tries to provide a comprehensive picture, offering some level of generalizability.

Second, MLP has been thoroughly utilized in energy-related research, which means that it is possible to take advantage of experiences from a variety of countries and their correspondingly varied energy systems. A quick preview of MLP literature serve to illustrate this point. Historically, the approach has built on early works of Kemp (1994), Schot, Hoogma, & Elzen (1994), or van den Endea & Kemp (1999). These (and indeed other) authors helped the most productive researcher in this field, Frank W. Geels, to contribute continuously to the development of the whole concept. This is true for his contributions for the concept's justification at the outset (Geels, 2002; Geels 2005); his illustrations of case studies of different sectors (e.g. the hygienic transition from cesspools to systems of sewers or waste management in the Netherlands – see Geels, 2007, 2006; Geels & Kemp, 2007; Geels et al., 2016); his refining of the concept (Geels, 2004; Geels & Schot, 2007); or his defense of the approach against academic criticism (Geels, 2011). Other authors also joined the debate, providing detailed and informative MLP driven case studies: Dzebo and Nykvist (2017) analyzed Swedish heat energy systems; Foxon, Hammond, and Pearson (2010) did the same with the electricity system in the UK; Hermwille (2015) contributed an analysis of the impact of the Fukushima accident on the energy sectors of Japan, Germany, and the United Kingdom; de Haan and Rotmans (2011) developed an evaluation of the Dutch health system; Markard, Suter, and Ingold (2014) made an analysis of Swiss energy policy; Tenggren, Wangel, Nilsson, and Nykvis (2016) examined Nordic transmission grid development; Correljé and Verbong (2004) put out a study of the transition from coal to gas in the Dutch gas system; Belz (2004) contributed a study on the transition towards sustainability in the Swiss agro-food chain; Raven (2004), as well as Verbong and Geels (2007), contributed analyses of the Dutch system of energy provision; Raven (2006; Raven 2007) also compared waste and electricity regimes in the Netherlands; Nykvist and Whitmarsh (2008) compared transitions in transportation in the UK and Sweden; Köhler et al. (2009) analyzed sustainable transportation; Bree, Berbong, and Kramer (2010) focused on the introduction of hydrogen and battery-electric vehicles, etc.

This body of work has provided scholars with some confidence about the validity of the MLP approach for the purposes of my research. On the next pages, therefore, I introduce MLP in detail.

## 3.1. Components of energy systems

The Multi-Level Perspective builds on a variety of theoretical approaches, with some prominence given to the sociology of technology and evolutionary economics. The first component – the sociology of technology – provides an understanding of how the various sectors of an economy (energy, transportation, housing, agriculture, or any other sector) are constructed, what elements a sector consists of and what the relations between these elements are. The latter approach – evolutionary economics – tries to offer an explanation for how the system changes; what drives the change, what resists these changes and what form these changes may take (Geels, 2002). In this subchapter, we start with the first issue, answering the question of what the socio-technical system is according to MLP and what elements it consists of.

Within the MLP framework, socio-technical systems are understood as “linkages between elements necessary to fulfill societal functions”; they “encompass production, diffusion, and use of technology” (Geels, 2004, p. 900). However, MLP disassociates itself from thinking about systems in purely technical terms, as a cluster(s) of tangible artifacts (power plants, grids). Employing the sociology of technology approach, it points out that technology needs to be considered in association with human agency, social structures and organizations, since technology co-evolves with society.

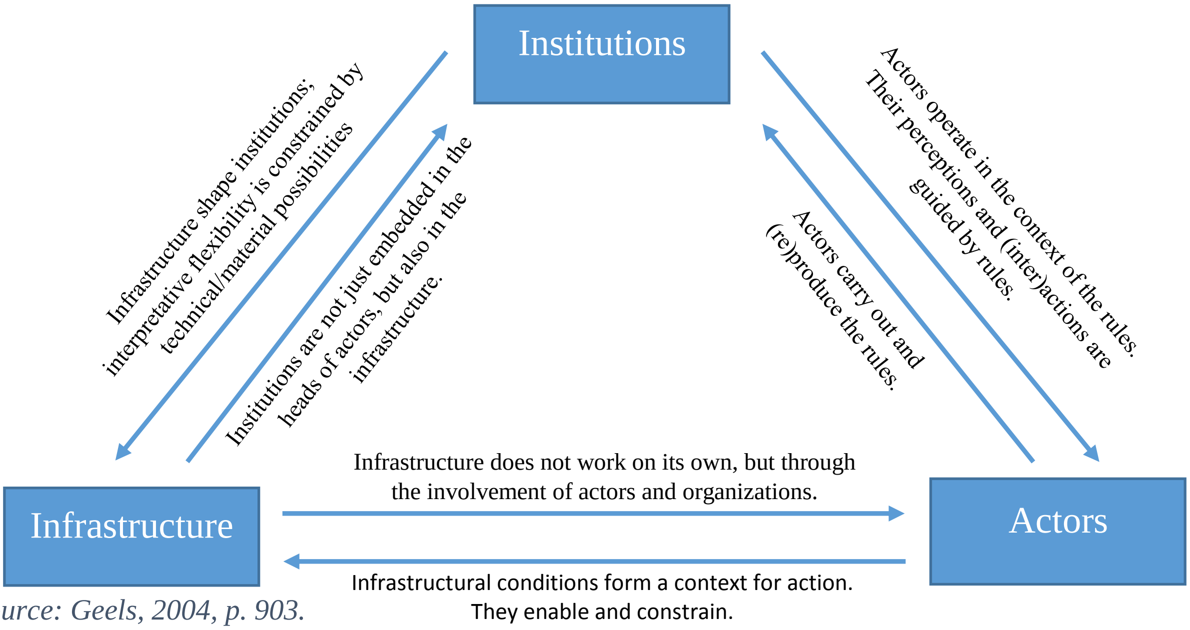
> “Actors in social groups do not act autonomously, but in the context of social structures and regulative, normative and cognitive rules. Companies react to problems posed by

> existing technology based on engineering insights and managerial lessons. Products are embedded in consumption patterns, through routines and cultural meanings. Infrastructures very much determine the economics of use. Practices are reproduced because of economics and rules. The rules consist of search heuristics and may include problem agendas, guiding principles, standards, government regulations, and a sense of identity for companies and the persons in it. Consumers have developed certain ways of life, routines and understanding that may be viewed as rules too. The rules do not coexist individually, but are linked together in semi-coherent sets of rules…" (Geels & Kemp, 2007, pp. 442-443).

Only in this combination is any development possible; the technology by itself does nothing (Geels, 2002, p. 1257). This network of physical infrastructure, organizations, resources, legislation, science, and other elements thus creates a specific configuration; knowledge, skills, patterns and routines are embedded with the technical infrastructure, linking the elements together and enabling the whole sector to deliver its societal function. The stable flow of electricity in the case of the power sector or the efficient movement of goods and people in the case of the transportation sector could serve as examples.

In other words, the MLP approach breaks down any system into three elements: a) Infrastructure, the tangible artefacts needed to fulfill societal functions; b) Social groups (actors) who maintain and refine the elements of socio-technical systems; and c) Institutions that guide and orient the activities of social groups.

*Figure 1: Three interrelated elements of the system*



*Source: Geels, 2004, p. 903.*

However elaborate the MLP approach is, it is nevertheless necessary to engage it now and make some adjustments. What complicates the work with the MLP literature is its terminological ambiguity. In different articles, the term "system" has been used for both the infrastructural element, when infrastructure is being referred to as "socio-technical system," and the functionally interconnected structure, consisting of infrastructure, actors, and institutions (an energy system, a transportation system). For institutions, the terms “institutions, “rules,” and “socio-technical regime” are used interchangeably. For actors, the terms “actors,” “organizations,” “social groups” are used in the same overlapping way. It is necessary to simplify and clarify this terminological confusion. That is why the following terminology will be used in the rest of this study. “Infrastructure” covers the tangible objects that create the physical part of energy systems, such as generation plants, the grid, etc. “Actors” constitute the individual or collective stakeholders, such as ministries, energy regulators, companies. “Institutions” include the rules, norms, and principles that guide and restrict the decision-making of actors and define the way the infrastructure is used (again, see Figure 1). The functionally interconnected network of these three elements will be referred to as the “system,” in our case, the system of energy provision.

## 3.2. The dynamics of energy systems

Having the understanding of what elements socio-technical systems consist of, it is now time to turn to the issue of system dynamics: how the elements of the system interact with each other and how the system develops.

This discussion can be opened with the simple case of the historical development of automobile transportation in the U.S. Expansion of the road network (infrastructure) financed by the government (actors) incentivized both consumers (actors) to buy more cars and producers (actors) to invest more in their improvement and production. Driving developed from a fashion to a necessity (institutions, in terms of social pressure), with society (actors) calling for more roads, parking spaces, fuel stations, and repair workshops (infrastructure) to be built. Government regulated the whole sector with safety rules (institutions), and collected taxes and fees to build even more roads.

Apart from depicting the role of elements of the system and their interaction, this illustration also emphasizes the issue of the stability of the system. Once any development path is set, (in this case, a preference for internal combustion engine automobiles over carriages, bicycles, trains, or any other form of transportation), it generates a cycle of positive feedback. Money and effort are invested in infrastructure, services, rules, and institutions with actors trying to protect these sunk costs. (Economically successful) inventions are restricted to the settled technology trajectory, and vested interests prevent any significant change. The whole system gets locked in. New ideas, such as replacing individual car transportation with public transit or bicycling, face significant opposition, either from actors benefiting from the status quo or previous infrastructural commitments – it’s difficult to build a bike path where there’s an eight-lane highway (Unruh, 2000). This intuitive understanding of system inertia is theoretically depicted in the concepts of path dependence and lock-in (see Unruh, 2000; Jacobsson & Johnson, 2000; Walker, 2000).

Moving on to the three constitutive elements of the system, it becomes possible to identify a few basic mechanisms that contribute to the preservation of the status quo. Institutions guide the perceptions and actions of actors on the cognitive level, making engineers and designers to look in one particular direction and not the other. As a result, they may ignore relevant developments in areas outside of their focus. Normative rules drive behavior in ways that have widespread acceptance, and formal rules and regulations stabilize the situation in the form of legally binding contracts, legislation, and agreements (Geels, 2004, p. 910). Actors are embedded in stable and interlinked networks with a high level of organizational capital, with systemic resistance to change (Geels, 2004, p. 911). Infrastructure costs money and time to be built, and any change threatens the sunk costs and consequently the interests of investors.

Yet no matter how stable and how resilient systems are, they are still far from unchangeable. The history of humankind provides a wealth of empirical evidence of how seemingly indestructible systems were replaced by more progressive ones, with the switch from sail-powered ships to steam ones in naval transportation being a classical example. This means that change may happen – but how?

MLP's explanation builds on the subversive power of small but radical technology innovations that, being deliberately protected from the market selection of the competitive environment, may take advantage of general trends in the system and offer a more appealing alternative to it. Continuing in the automobile sector analogy, internal combustion engines (ICEs) were originally developed among circles of car-racing fans. At that time, no obvious winner of the competition between carriages, steam, electricity, or ICE transportation was on the table. But due to the increasing demand for commuting and the availability of cheap gasoline as a byproduct of kerosene refining, the ICE started to gain momentum, gradually replacing existing transportation technology.

To capture these dynamics, three analytical dimensions are introduced in the MLP. The meso-level of the (socio-technical) system itself, the meta-level of "the landscape," and the micro-level of "niches." This division provides us with tools to map the dynamics of the evolution of any given system, enabling us to capture different components of the system as their role and importance of their activities vary over time.

Having already introduced the meso-level (the socio-technical system itself), we may move to the other analytical dimensions.

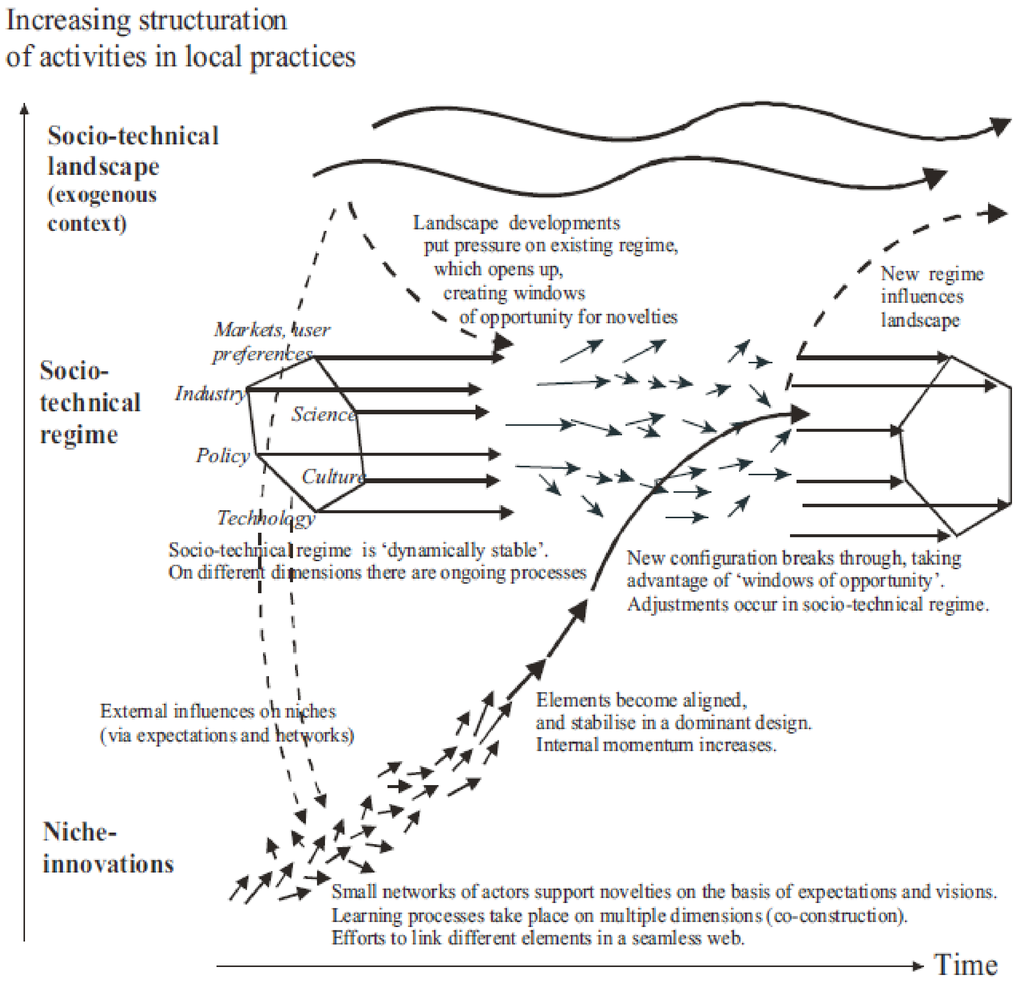
The socio-technical landscape (the meta-level) consists of external factors, such as economic growth, globalization, wars, global or regional normative and cultural values, systemic environmental changes, etc. They are beyond the control of actors of the system, are of a heterogeneous character, and usually change rather slowly, but their impact on the meso-level can be significant, opening the windows of opportunity for regime change (Geels, 2005a).

The micro-level (the creation of niches) serves as an incubator for radical technology development. In niches, technical advances are protected from market forces, and are able to develop to a competitive state. A typical example would be a military, which is able to cultivate some initially prohibitively expensive and seemingly ridiculous innovations, but ultimately successful ones (radar, jet engines). Niches also enable the formation of the social networks that facilitate innovations (Geels, 2005b; Geels, 2002). Importantly, selection procedures are different in niches, enabling survival and learning at the level of non-profitable prototypes of prospective technologies.

These three levels are interconnected: socio-technical systems as a whole provide stability and basic guidance for incremental development; the landscape level provides external factors incentivizing change on the meso-level, creating the window of opportunity; and niche level is responsible for the production of fundamental innovations. MLP uses the term “nested hierarchy,” emphasizing the idea that regimes are embedded within landscapes and niches within regimes.

The detailed theoretical explanation of the dynamic in the system is thus as follows. All three levels demonstrate some internal tensions and misalignment, since no system is totally static. These tensions are transferred to other levels; for example, a change in global oil prices (an external factor on the landscape level) may call into question the traditional way oil is consumed in the transportation sector (meso-level); the window of opportunity that new, efficient, electric cars developed on the niche level may put traditional cars (with internal combustion engines) under pressure. Systemic changes then occur as a build-up of multiple factors, usually when niche developments coincide with the window of opportunity created by the dynamics on the regime and landscape level (see Figure 2). As we shall see, climate change, mentioned in the introductory chapter of this work, is a typical landscape factor, with significant disruptive potential for energy systems.

*Figure 2: A dynamic multi-level perspective on technological transition*



*Source: Geels, 2011, p. 28.*

### 3.3. Pathways of system change

The previous chapters have depicted MLP's understanding of socio-technical transitions. New technologies emerge at the niche (micro) level; nevertheless, they are invented and developed in an existing regime and landscape. These technologies compete with each other, sheltered from the competition of dominant and established technologies. Gradually, society acknowledges some of these advancements, creating an environment for them (rules, legislation). Consequently, the new technology breaks through into the system, potentially outcompeting the dominant technology due to the effects of the learning curve, economies of scale, and diminishing production costs; this leads to increasing financial returns and changing preferences of customers. Status quo structures and actors resist, trying to protect their sunk investment and vested interest; their position might, however, be weakened due to various internal problems or landscape pressure. An example of this may be an inability of existing infrastructure to deal with new environmental problems. As a result of this combined interaction of different levels, the technology may eventually get through, replace the existing technical configuration, and introduce systemic change to the regime. Status quo actors may be forced to exit and new ones may enter in this period of flux and restructuring. The new regime may also influence landscape development (Geels, 2004; Geels, 2005b). Nevertheless, due to the lock-in of different subsystems, the change is neither easy nor fast.

In a real-life situation, this scenario may have some variations resulting from varying local conditions. In an effort to catalogue these different transition pathways, to define the most frequent, archetypal ones, Geels and Schot (2007) combined two formative criteria; the timing of the interaction of the meta, meso, and micro levels, and the nature of their interaction.

The former criterion elaborates on the previous idea of simultaneous alignments of development between different levels in the MLP. The different timing of these interactions is added, assuming different results in different configurations. For example, the interaction of landscape pressure with a fully developed or, conversely, an immature niche innovation could be entirely different. While currently developing countries pursuing climate goals may utilize reasonably efficient renewable sources developed difficultly in the last decade in the EU and U.S., a few years ago their only options would be nuclear energy and energy savings.

The latter criterion questions the nature of the landscape and niche interaction with the system level. Reinforcing landscape development have stabilizing effect on the regime, thus no incentive for transition is created. Disruptive landscape development may, on the other hand, put some pressure on the regime incentivizing the change. In similar pattern, niche innovations may aim on replacing existing regime or on having symbiotic relationship through co-operation with existing configuration.

Combining these two criteria, Geels and Schot (2007, pp. 406-413) developed one status quo pathway ("reproduction") and four transition pathways: "transformation," "substitutions," "re-alignment and de-alignment," and "reconfiguration." After sustaining some academic criticism and being subjected to multiple theoretical suggestions, these pathways were refined about ten years later in Geels et al. (2016). Using the terminology of Poole and van de Ven (1989, p. 643), the authors noted that in their previous research they had focused on a "global" conceptual logic; "the overall course of development of an innovation," which "takes as its units of analysis the overall trajectories, paths, phases, or stages in the development of an innovation." While acknowledging the benefits of this approach, they felt it necessary to supplement it with "local" logic, which depicted "the immediate action processes that create short-run developmental patterns," focusing on "the micro ideas, decisions, actions or event of particular developmental episodes" (Geels et al., 2016). Employing fragments of different theoretical approaches, particularly that of neoinstitutionalism, structure and agency (as well as the interaction between the two) were captured more effectively and in a more sophisticated and nuanced way.

The original pathways and their updated version are described as follows.

The "reproduction" pathway describes a situation with no disruptive landscape pressure and with no significant development at the niche level. Even if radical niche innovations are present, they have only limited chances to break through due to the stability of the sector. Despite some ever-present dynamics, development is controlled by stable rules and results in predictable trajectories. The system reproduces itself and only incremental innovation may occur. Transition does not occur.

The “reproduction” pathway was not updated.

The “transformation” pathway describes a combination of moderate landscape pressure with unfinished niche development, resulting in actors modifying the direction of development path and innovations. Actors perceive the landscape pressure and have some desire to respond to it, but no finished technologies on the niche level are available to be employed. Social pressure groups and movements (including those from outside of the sector) voice protest, accompanied by experts, researchers, and firms. New ideas emerge to deal with the situation, which are accepted by actors as a viable solution. As a result of this mainly societal pressure, innovation activities are reoriented to these new solutions. A new regime emerges through cumulative adjustment and reorientation. The existing actors adapt but survive, sometimes at the expense of the traditional networks of their mutual relations. Actors may even import external knowledge, provided that it is not too distant from the existing one.

After the “transformation” pathway was reformulated, incumbent actors were no longer considered to be locked in into the existing regime, pursuing only incremental changes. Like new entrants, they also may reorient themselves to radical niche innovation. Moreover, the dimension of technology became more differentiated, with the introduction of new ways of development: the integration of new knowledge within existing regimes, and reorientation towards new technologies without deeper changes in normative rules. These new options also affect the way institutions develop. Incremental technical change likely leads to limited institutional change, while more aggressive technical change leads to a higher degree of institutional change, with corresponding enhanced pressure on incumbents.

The “de-alignment and re-alignment” pathway assumes sudden and major changes on the landscape level, causing actors to give up on setting the status quo (de-alignment). With the system unable to deal with the pressure, actors start to look for the solutions on the niche level. If there is no obvious developed substitute, a window of opportunity is created for multiple niche solutions to emerge. These *do* compete with each other, sometimes fiercely; eventually one wins, creating the basis for a new arrangement (re-alignment).

In an effort to reformulate this pathway, Geels et al. (2016) admitted that a lot of research is still needed here, since major shocks (wars, economic collapses) and their impact on transition are rarely analyzed in MLP research. As such, we have little information on how actors react to the sudden disruption of existing technologies; we may assume only some period of uncertainty (institutional vacuum) before a new arrangement is created. Competition and struggle between different interest groups is likely, until one emerges as a winner and delivers some stability.

The “technological substitution” pathway describes a combination of landscape pressure with sufficiently developed innovations on the niche level. It is because of these sudden changes on the meta-level that innovations may break through and replace the existing regime. This triggers competition between status quo actors, who find themselves on the defensive, and newcomers representing the change. In some cases, we may see the downfall of incumbent companies.

Over the course of its reformulation, this approach gave more attention to actors. Innovation can be delivered not only by new entrants (new companies), but also by other kind of outsiders. This could include activists, social movements, or citizens with normative motivations, as well as companies stretching their activities to complete new areas (Seyfang & Smith, 2007).

Regarding institutions, the "technological substitutions" pathway lays out two possible patterns of development. Limited institutional change results from the disruption of existing technologies due to the economically superior innovations. Nevertheless, these innovations are still developed to fit into existing rules and institutions. A second option is that rules and institutions are adjusted to accommodate niche innovation. In this pathway, power struggles, social mobilization, and counter-mobilization can be expected (Schneiberg & Lounsbury, 2008).

The "reconfiguration" pathway depicts situations in which symbiotic innovations are initially adopted in the regime to partially solve problems, based on their technical or economic superiority. While the structure stays intact initially, over the course of time, actors start to learn more about advancements, using them in a more active and a broader way and, eventually, this leads to major reconfiguration and regime changes.

Reformulation of the "reconfiguration pathway" offers cooperation between incumbents and new entrants as a substitute option, next to competition (Roathaermel, 2001). Technologies may be incorporated as modular innovations or add-ons, which nevertheless create new possibilities and problems, inviting new changes. As such, this transition pathway has a strongly open-ended character. Regarding institutions, limited change is expected, escalating in more substantial change, and involving friction between incumbents and new entrants.

Transition pathways are summarized in Table 2.

*Table 2: Transition pathways*

| | **Actors** | **Infrastructure** | **Institutions** |
|---|---|---|---|
| **Substitution** | New firms struggling against incumbent firms, leading to incumbents' overthrow<br>Different kinds of "new entrants" (e.g. citizens, communities, social movement actors, incumbents from different sectors) that replace incumbents | Radical innovation(s) substituting existing technology | Limited institutional change, implying that niche-innovation needs to compete in the existing selection environment |
| **Transformation** | Incumbents reorienting incrementally by adjusting search routines and procedures | Incremental improvement in existing technologies (leading to major performance | Limited institutional change<br>Substantial change in institutions |

|  |  |  |  |
|---|---|---|---|
|  | Incumbents reorienting substantially to radically new technology or, even more deeply, toward new beliefs, missions, and business models | enhancement over a long-term period)<br>Incorporation of symbiotic niche innovation and add-ons (competence-adding, creative accumulation)<br>Reorientation towards new technologies: a) partial reorientation (diversification with incumbents developing both old and new technologies b) full reorientation, leading to technical substitution |  |
| **Reconfiguration** | New alliances between incumbents and new entrants | From initial add-ons to new combinations between new and existing technologies; knock-on effects and innovation cascades that change system architecture | From limited institutional change to more substantial change, including operational principles |
| **De-alignment and re-alignment** | The collapse of incumbents because of landscape pressure, creating opportunities for new entrants | Decline of old technologies creating space for several innovations which compete with one another | Institutions disrupted by shocks and replaced, possibly after prolonged uncertainty |
| **Reproduction** | - | - | - |

*Source: Geels et al., 2016, p. 900.*

## 4. Comments on following research

Having answered the research question, it is now an appropriate time to elaborate briefly on what the process of conducting this study itself can reveal about the MLP theoretical approach and its applicability to energy case studies.

The first comment results from the obvious finding that the landscape (meta) level may affect system (meso) level significantly. In this case it was the EU that initiated the whole transition, and Germany that fueled it and emphasized some of its trends. The Czech system has primarily been on the recipient side of this relationship. Acknowledging this, it nevertheless is crucial to point out that the landscape level is seriously underdeveloped in the MLP, both theoretically and conceptually. Being a "black box," its impact is acknowledged but there is no effort to capture it properly. In an effort to analyze this level, researchers are provided with almost no tools; this is a situation that needs to be fixed.

Operationalization is another significant weakness of the MLP approach. Despite a mounting body of empirical research, MLP offers rather poor guidance on how to demarcate infrastructure, institutions, and actors of a given sector, or how to distinguish them from other sectors and from the landscape level. In other words, the practical operationalization of elements (actors, institutions, and infrastructure) and levels (meta, meso, and micro) seems to be arbitrary to a great extent, with the validity of this operationalization depending on the qualification of individual researcher. This problem has been raised before, for example, by Berkhout, Smith, and Stirling (2004), Genus and Coles (2008), and by Markard and Truffer (2008, p. 606), with the last ones calling for more "conceptual rigor in the identification and delineation of a regime [system in this sense])." Additional work thus needs to be done regarding the rules of how to delineate individual components of the system, and how to identify which elements should be included and which should be excluded.

Despite some recent modifications, the MLP approach is still heavily focused on technological development on the niche level and on how the (technical) innovation struggles to break into the system. In dealing with agency, institutions, and their mutual interaction, the MLP approach is considerably weaker. This has been mentioned by Genus and Coles (2008), and by Smith, Stirling, and Berkhout (2005, p. 1492) in Geels and Schot (2007): "[MLP] is overly functionalistic. Despite the breadth of the regime concept [i.e. the system], there is a tendency to treat regime transformation as a monolithic process, dominated by rational action and neglecting important differences in context." What is thus needed is a more developed theoretical explanation of why actors behave the way they behave. As Geels acknowledges (2011, p. 30): "it is probably fair to say that certain types of agency are less developed, e.g. rational choice, power struggles, cultural-discursive activities." MLP considers actors in a mostly apolitical way, not acknowledging the fact that energy transitions are inherently political adventures. Transitions are subjects of different interests, they change institutional and governance arrangements, and they weaken or strengthen existing power relations (Moss & Gailing, 2016; Rutherford & Coutard, 2014). The same applies to institutions. They are approached in the MLP in a rather disorganized way, not distinguishing properly between the different levels of generality. Written agreements are treated the same way as informal codes of behavior, laws the same as rules of thumb.

Some of these issues have been addressed in the last few years with promising results. There has been, for example, increasing involvement by representatives of (neo)institutionalism to contribute to the MLP approach; the works of Philip Andrews-Speed on energy transitions in China and the United Kingdom (Andrews-Speed, 2012; 2015a; 2015b), emphasizing the potential of historical neoinstitutionalism and institutionalism of rational choice are especially promising examples (Andrews-Speed, 2016). The increasing utilization of Hacker's (2004) typology of "Drift, Conversion, Layering, and Revision" in explaining of how institutions change is another example of the MLP becoming interdisciplinarily enriched.

Regardless of this criticism, the validity of the MLP approach and its applicability in the energy-related social research is high. In the case of this study, it has served as a useful tool, revealing the patterns and trends within electricity transitions, as well as the motivation(s) driving this transition. With the growing amount of empirical research, it should not be unsurprising to see the theoretical qualities of the concept improving in the coming years.

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