Freie Universität Berlin

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Development of micro CHP in Germany:

analyzing the influences of regulatory framework and institutional setting in combination with German culture on development of entrepreneurial activities

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Preface

In this research, we emphasized the role of entrepreneurs in the adaption of technological innovations regarding micro Combined Heat and Power (micro-CHP) to the Germany's energy system. This research is going to make a contribution in following areas:

- Analyzing the institutional setting and the role of macro phenomena and the dynamics of the regime in a multi-level perspective analysis.
- Discussion of the cultural dimension in Germany and its influence on micro-CHP development.
- Analyzing the current regulatory framework regarding micro-CHP and its effects on benefits or costs of technology users.

The main research question is: How do the regulatory framework and institutional setting in combination with German culture influence the development of entrepreneurial activities regarding micro-CHP? The approach to answer this question includes mixture of qualitative and quantitative analysis. For studying the interaction between the institutional setting, regulations and culture to understand the development of the technological innovation system of micro-CHP in Germany, one theory and two approaches were used for analysis: 1) Economic theory of entrepreneurship, 2) Multi-level perspective analysis to explaining Institutional changes, 3) Value proposition concept for analyzing the regulatory framework.

This research has been structured in six chapters as follows:

In chapter 1 as an Introduction, after a short description of Germany's energy system, the importance of this research and motivations are explained.

In chapter 2, the state of the art and analysis paradigm are explained. The research questions, dependent and independent variables, hypotheses and methodology for conducting the research are discussed.

In chapter 3, the theoretical formulation of the first hypothesis regarding the importance of the entrepreneurial activities and theoretical framework for analyzing entrepreneurial activities in the technological innovation system of micro-CHP are discussed. Because entrepreneurs' innovations must propose more value to the economy and all stakeholders inside it, we argued that the economic theory of entrepreneurship, Multi-Level Perspective analysis and value model approaches fit the aim of this research.

Chapter 4 is focusing on general factors and the role of institutional setting on the development of micro-CHP. The cultural dimensions in Germany and its effects on entrepreneurial activities regarding micro-CHP development are analyzed in this chapter. Moreover, a multi-level perspective analysis on the transition of Germany's energy system is conducted to explain the institutional setting changes.

In chapter 5, Regulatory framework regarding development of micro-CHP in Germany is analyzed. Quantitative analysis of different supportive policies such as CHP Act and RE Act is the aim of this chapter. The analysis shows that the installed capacity of micro-CHP in Germany is directly related to the amount of incentives provided by each state. Among several incentives, CHP Act is the most positively influencing factor for reducing risks regarding development of micro CHP in Germany.

Chapter 6 is discussion and conclusion. In this chapter we discuss, summarize and integrate the previous chapters in order to draw a conclusion and to answer the research questions. Following hypothesizes discussed in chapter 6:

- The cultural and institutional system in Germany is positively affecting entrepreneurial activities but it has some weaknesses. The uncertainty avoidance culture of Germans and complexity of regulations are among them.
- Macro level phenomena at global and EU level, helped establishment of a supportive institutional setting in favor of micro CHP development positively. For example, Phase out of nuclear and less supports of Renewable energies in recent years provide more space for micro CHP development
- At regime level, the institutional setting also was against the development of micro CHP in the past; however, both market liberalization and purchasing the micro CHP developers by big utilities provided more hopes for future development. For example, the goal of energy market liberalization was raising competitiveness and innovation, and several CHP acts passed by the government in order to support the technology.

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List of Abbreviations

ANT	Actor Network Theory
bcm	billion cubic meter
BM	Business Model
CDM	clean development mechanism
CHP	Combined Heat and Power
CIS	Community Innovation Survey
DG	Distributed Generation
DMFC	Direct Methanol Fuel Cell
EEG	Erneuerbare-Energien-Gesetz
EEG	Erneuerbare-Energien-Gesetz
EFC	European Fuel Cell
EnEV	Energieeinsparverordnung
EPBD	Energy Performance of Buildings Directive
ETD	Energy Taxation Directive
ETS	Emission Trading System
EU	European Union
GAD	Gaseous Appliances Directive
GE	General Electric
GHG	greenhouse gas
ICT	information and communications technology
IEKP	Integriertes Energie- und Klimaprogramm
IMD	Institute for Management Development
IT	Information Technology
kWe	Kilo Watt of Electricity
KWK-G	Kraft-Wärme-Kopplung Gesetz
LFPSE	linear free piston Stirling engine
LTS	Large Technical Systems
Micro-CHP	Micro Combined Heat and Power
MLP	Multi-Level Perspective

NCPP	National Climate Protection Programme
NEEAP	National Energy Efficiency Action Plan
NIP	National Innovation Programme
NIS	National Innovation System
OECD	Organization for Economic Co-operation and Development
ORC	Organic Rankine cycle
PEFC	Proton Exchange Fuel Cells
PEM	polymer electrolyte membrane
R&D	Research and Development
RE	Renewable Energy
SCOT	Social Construction of Technology
SOFC	solid oxide fuel cell
SoS	System of Systems
TIS	Technological Innovation System
UNFCCC	Nations Framework Convention on Climate Change
VAT	Value Added Tax
VC	venture capital
VDEW	Verband der Elektrizitätswirtschaft

1 An introduction to the situation of micro-CHP in Germany's energy transition

1.1 Energy system of Germany

The industrialization of modern society led to the problems of global warming and air pollution. To cop sustainability problems, from decades ago innovative activities were started to solve sustainability problems of industrialization. The goals of establishing a new energy system with lower adverse side effects and better efficiency in resource usage all are elements in the process of transition. Europe's growth strategy for the next decade is formulated in the Europe 2020 initiative (EC 2013). "Europe 2020 strategy is about delivering growth that is: smart, through more effective investments in education, research and innovation; sustainable, thanks to a decisive move toward a low-carbon economy; and inclusive, with a strong emphasis on job creation and poverty reduction. The strategy is focused on five ambitious goals in the areas of employment, innovation, education, poverty reduction and climate/energy." p. 202[1] Energy is one of the most important sectors in the European growth strategy. Today, Germany's energy system is a very complicated socio-technical system of complex interdependent relations between its components, which has changed rapidly over time. In the early 1920s, the energy system of Germany changed its main energy source from wood to coal. Coal extraction increased by 300 percent from the 1880s to 1913 and Germany alone was consuming 25% of the world's entire coal production at that time[2]. During the 1920s, forest degradation and environmental problem caused by coal consumption, raised discussions about environmental protection. Some German scientists such as Clemens Winkler, (professor of chemistry at the Freiberg Mining Academy) warned about the limited capacity of the

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[1] Andrea Bikfalvi , R. d. C. V., and Xavier Muñoz (2014). Toward Joint Product–Service Business Models: The Case of Your Energy Solution. Eco-Innovation and the Development of Business Models. S. G. Azevedo, M. B. H. Carvalho and V. Cruz-Machado, Springer International Publishing Switzerland.

[2] Blackbourn, D. (2013). The Culture and Politics of Energy in Germany A Historical Perspective. K. R. Christof Mauch, Helmuth Trischler, Rachel Carson Center Perspective.

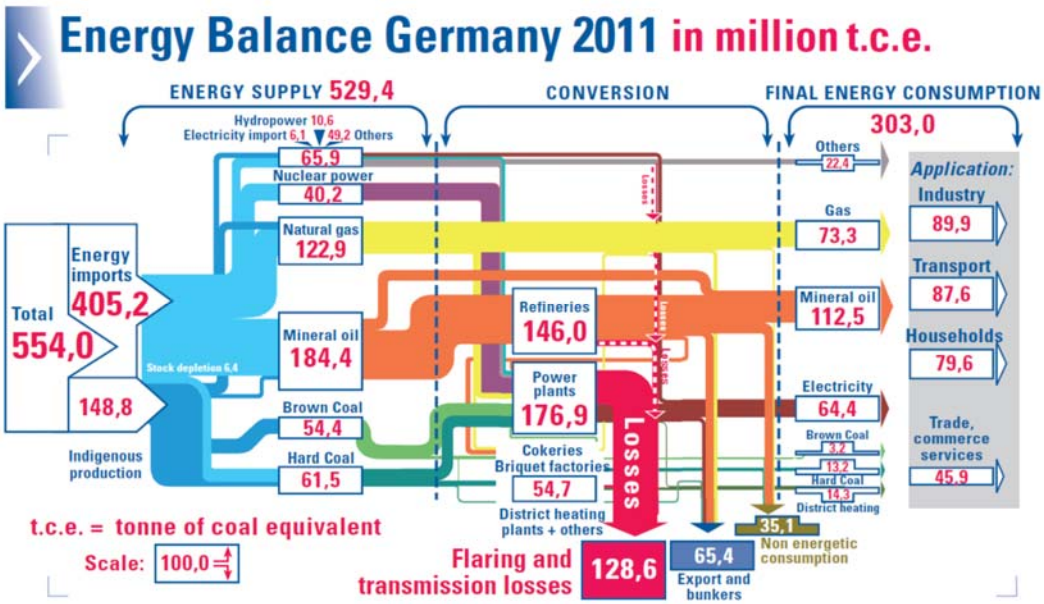
environment for entropy resulting from the irreversible degradation of natural resources. Some other scientists such as Wilhelm Ostwald (winner of chemistry Nobel Prize in 1909) suggested the use of solar energy instead of fossil fuels[3]. At that time, the first renewable source of energy that came into focus was hydropower as a clean and infinite source of energy. Due to the advancement of Germany in the development of electricity generators and in other engineering areas, many dams and hydropower plants were constructed. At that time, the culture of Germany played an important role in shaping the country's energy system. For example, dams collapsed everywhere in the world and Germany's culture of uncertainty avoidance led to a negative public opinion about the constructions of dams. Like today's opposition against nuclear energy, many Germans started to oppose hydro energy. As a result, German engineers designed and constructed dams with very high safety standards. Consequently, we can see that despite of 200 disasters that occurred worldwide in the 20th century; in Germany, no incident was recorded. In the early 1950s and by utilization of nuclear energy for peaceful purposes, nuclear energy became popular in Germany as an alternative to coal. Very quickly, R&D programs for the development of nuclear energy had been implemented and Germany was able to produce 30% of its electricity from nuclear power plants[4]. Before the 21st century, the two main incidents of Three Mile Island (USA 1979) and Chernobyl (USSR 1986) raised severe criticism among people about the safety of nuclear energy. After 2000, the incident in Forsmark (Sweden 2006) and the Fukushima disaster (Japan 2011) completely ruined the picture of nuclear energy in the eyes of Germany's public. The phase-out of nuclear energy in Germany provided huge space for other environmentally friendly technologies as well as micro-CHP. Undoubtedly, the formation of the Green Party in 1980 (a formation of the peace and environmental movements) played a very important role in the history of Germany's energy system transition. Currently, the core issue regarding Germany's energy system is a long-term plan for energy transition. The goal of energy transition in Germany includes 80-95 % reduction of GHG until 2050 based on the level of 1990. Reaching this goal requires significant changes in the energy system that shapes all future

[3] Ibid.

[4] Ibid.

activities within the system[5]. Figure 1-1 shows the energy balance of Germany, and illustrates the supply demand chain of the energy sector in a general manner.

Figure 1-1 Energy balance of Germany



Source: (Energiebilanzen.e.V. 2014)

About 23% of total primary energy is lost and about 11% is exported. Germany imports 73% of its energy from outside resources. This amount of imports attracts many attentions regarding energy security of the country and shows a high dependency on other countries. Looking at the trend of energy consumption in Germany shows a relatively constant and even descending consumption pattern. On the other hand, the German government set new targets for the complete phase-out of nuclear power plants until 2022. Energy security and the phase-out of nuclear plus the ambitious targets on CO2 reduction, exert a lot of pressure for changes on the energy system. The trend of energy consumption shows that the EU 28 reduced its energy consumption by 8% from 2006. The reduction of energy consumption in Germany is 9%[6]. Figure 1-2 depicts the future of the German energy system in comparison to its neighbor countries and shows an obvious difference in terms of energy security, GHG emissions and popularity.

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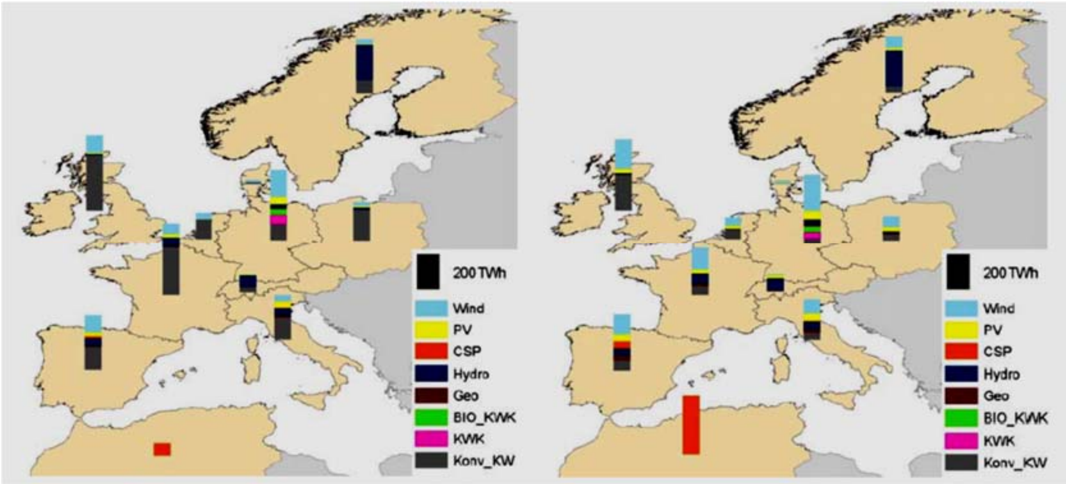
[5] BMU (2012). Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global.

[6] ALLEN, T. (2014). Energieverbrauch in der EU28 zwischen 2006 und 2012 um 8% gefallen.

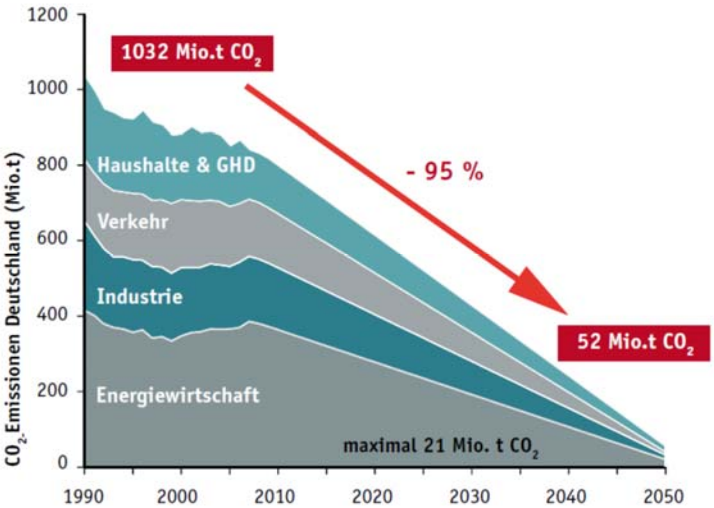
Figure 1-2. Prognosis for German energy system. Left in 2022 and right in 2050



Source: (BMU 2012) p. 166

The first goal in the energy transition plans, (set by the German government) is a reduction of CO2 emission by 80-95 % of 1990 level until the year 2050 (See Figure 1-3). This target forces heavy changes upon the energy system. The first consequence of such a target is the reduction of energy consumption and replacing the conventional energy production from fossil fuels with new methods without creating any emission (See Figure 1-4).

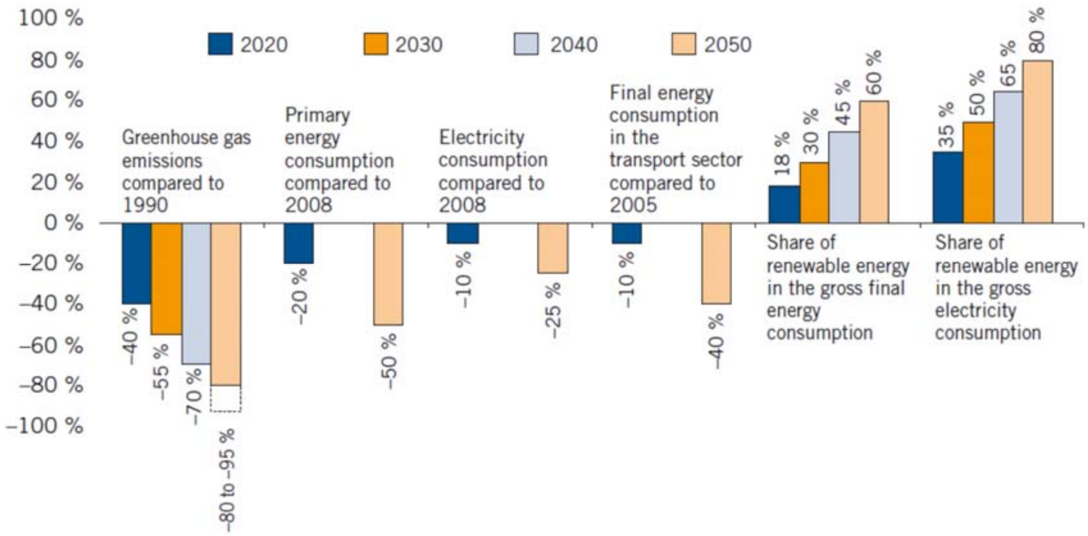
Figure 1-3. The main goal of Germany's energy transition



Source: (Eva-Maria Forstmeier 2010)

However, Germany had reduced its emission by 27% until 2011, which is better than its plan of 21%[7].

Figure 1-4. Energy transition in Germany by increasing the efficiency and share of renewable sources



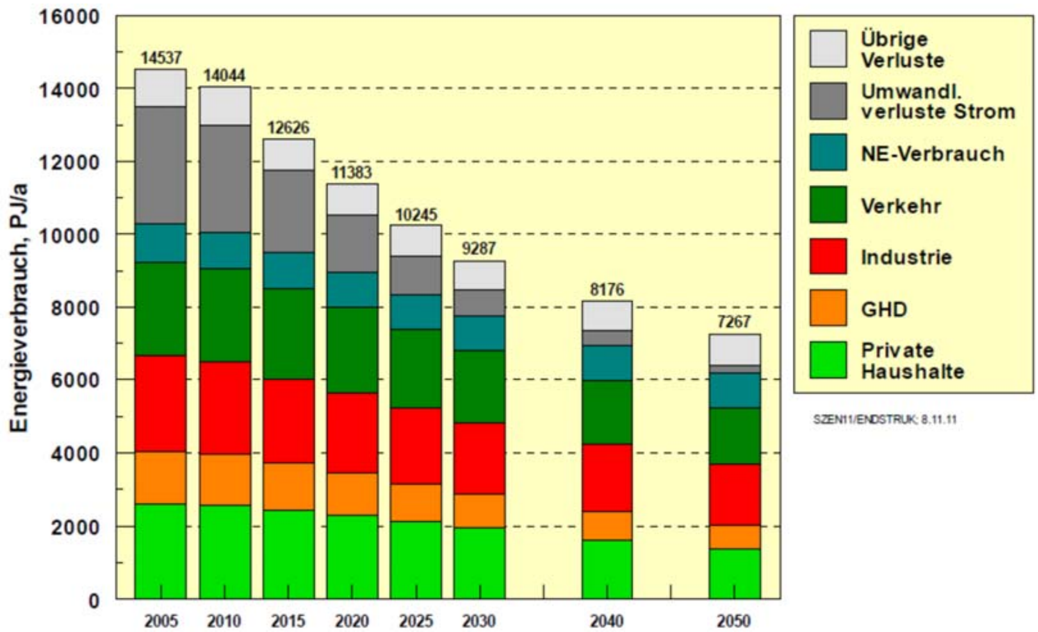
Source: (Rolle 2011) p.4

It is necessary that energy consumption be reduced by 50% of its level in 2008 and replacing the remaining demand from renewable resources. The highest potential for energy saving is related to the electricity grid as well as the commercial and household sectors (see Figure 1-5). Among them, the household sector and commercial sector consume 41.5% of final energy. In this regard, micro-CHP can play an important role. Germany intend to reduce the energy lost from by increasing the share of distributed generation such as micro-CHP. Moreover, the energy demand in households and the commercial sector can be provided by micro-CHP with an efficiency of 90% that is much higher than the average of the traditional energy supply efficiency of Germany (60%). In addition to energy efficiency, other important issues necessitate the development of distributed generation technologies such as micro-CHP. However, the current electricity

7 Craig Morris, M. P. (2012). Energy Transition The German Energiewende, Heinrich Böll Stiftung.

network of Germany is designed based on the location of conventional thermal power plants and is not suited for a high share of renewable energy production from wind[8],[9].

Figure 1-5. Energy consumption plan for Germany.



Source: (BMU 2012) p. 101

Figure 1-6 schematically shows a map of the electricity generation and transmission problem in Germany. As can be seen, the high voltage grid is not able to transmit enough power from different regions. This resulted in serious conditions of tightness in the grid during the winter of 2012 and raised some worries about grid infrastructure[10]. There are two main solutions to this problem: firstly, improving the current network infrastructure by building new transmission lines and secondly, increasing the share of distributed generation technologies as well as micro-CHP and thereby producing electricity at the demand point.

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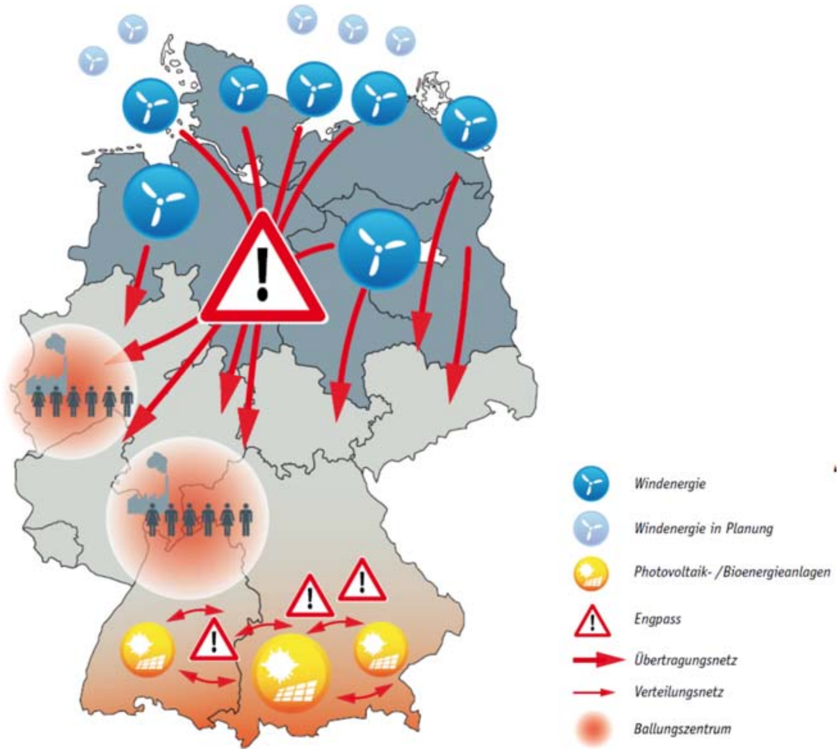
[8] Eva-Maria Forstmeier, R. H. (2010). Das Stromnetz der Zukunft.

[9] Bauknecht, B. P. D., et al. (2009). Innovation for Sustainable Electricity Systems Exploring the Dynamics of Energy Transitions, Springer.

[10] BUNDESKARTELLAMT, B. (2014). Monitoringbericht 2014.

Figure 1-6 Bottleneck in electricity network of Germany

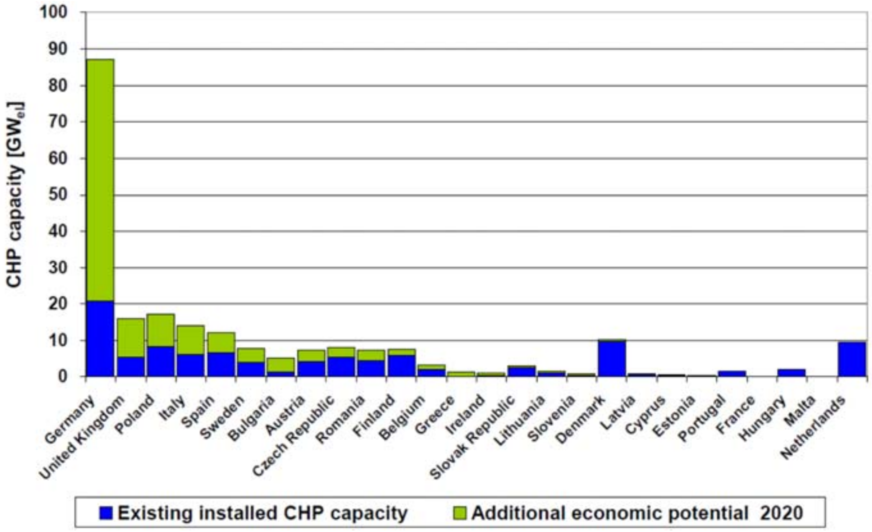


Source: (Eva-Maria Forstmeier 2010) p.7

1.2 Distributed generation and combined heat and power (CHP)

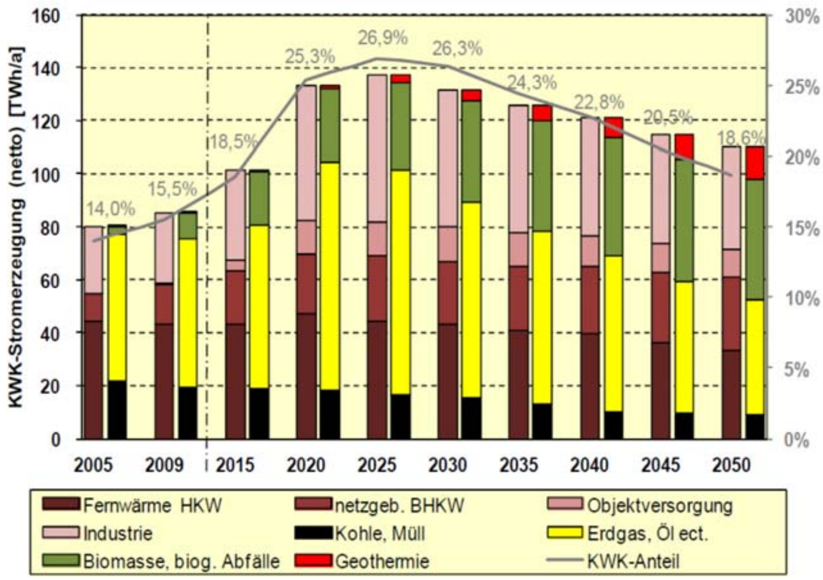
Figure 1-7 shows the situation and potential of CHP in Germany in comparison with other EU member states. CHP development plays an important role in the energy transition plan of Germany while it can produce electricity and the exhaust heat can be recovered for generating hot water. Consequently, they are very efficient systems for converting primary sources of energy to final useful energy. If a CHP plant can be installed near demand points, it can also help the problems of network operators and can increase energy supply security. Figure 1-8 shows the planed share of CHP in the energy system transition of Germany. There are two main categories of CHPs. Micro-CHP plants are mostly suitable for family houses and small apartments. For micro-CHPs, the main purpose of a plant is to produce hot water and the electricity is the by-product of the system. The second types, which have much bigger capacities, are built for electricity generation and the hot water is their by-product.

Figure 1-7. CHP situation in Germany



Source: (www.code-project.eu 2011)

Figure 1-8. Projected development of CHP generation in Germany



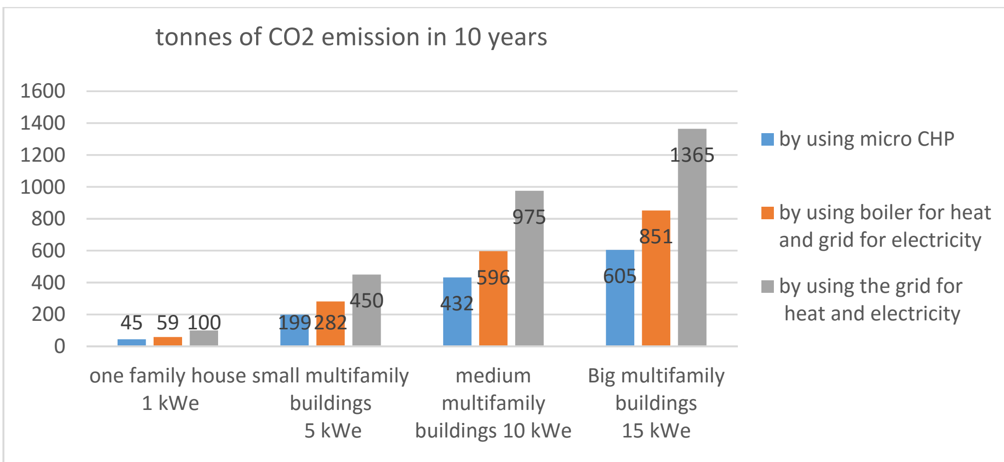
Source: (BMU 2012) p.5

In spite of many incentives in Germany for promotion of more CHP, analysis of different CHP technology in Germany by size and technology in 2010 proposed that the goal of Germany to reach 25 % of its electricity by CHP is ambiguous and cannot be reached because the current policies do not support investors enough[11]. Later in 2012 and 2013, the federal government modified the regulations to include more incentives to attract investors.

1.3 Micro-CHP: principle, concepts and technologies

Micro-CHP is the abriviation of micro Combined Heat and Power. The CHPs in the power range of (1-15 kWe) are categorized as micro-CHP. In comparison with the use of electricity and the gas from grid, micro-CHPs produce 50% less CO2 emision for generation of electricity and heat (See Figure 1-9).

Figure 1-9. Comparison of CO2 emissions between conventional energy supply and micro-CHP for residential sector

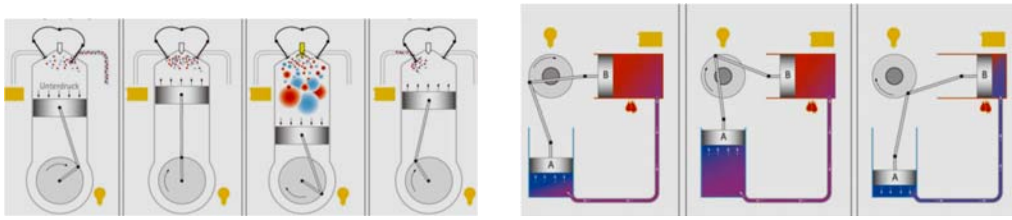


Source: (author)

There are 5 types of micro-CHP technologies. The most common type is the Otto engine, the concept of which is similar to a car engine which uses part of the energy for producing heat. The other technology is the sterling engine in which the fuel burns outside the engine and the hot and cold air produces mechanical movement that is used for electricity generation. Sterling engines are simpler than Otto engines but their electrical efficiency is lower (less than 10%). Figure 1-10 shows a schematic of these two technologis.

[11] Günther Westner, R. M. (2010). Development of Cogeneration in Germany: A Dynamic Portfolio Analysis Based on the New Regulatory Framework, Institute for Future Energy Consumer Needs and Behavior (FCN).

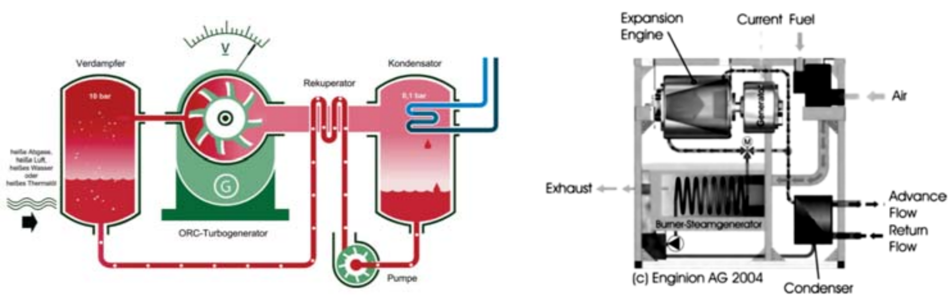
Figure 1-10. Left- Schematic of Otto engine and Right- schematic of Sterling engine



Source: (VDI 2013) p.10-11

Another type of micro-CHP which is not being used often, is based on turbo machines. The Organic Ranking Cycle (ORC) uses organic materials such as penthan for moving a turbine. Expansion turbines use water instead of penthan (See Figure 1-11).

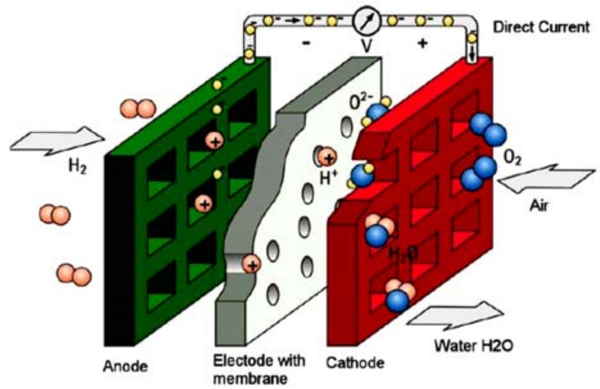
Figure 1-11. ORC on the left and Steam Expansion Turbine on the right



Source: (VDI 2013) p.13, (Martin Pehnt 2006) p.12

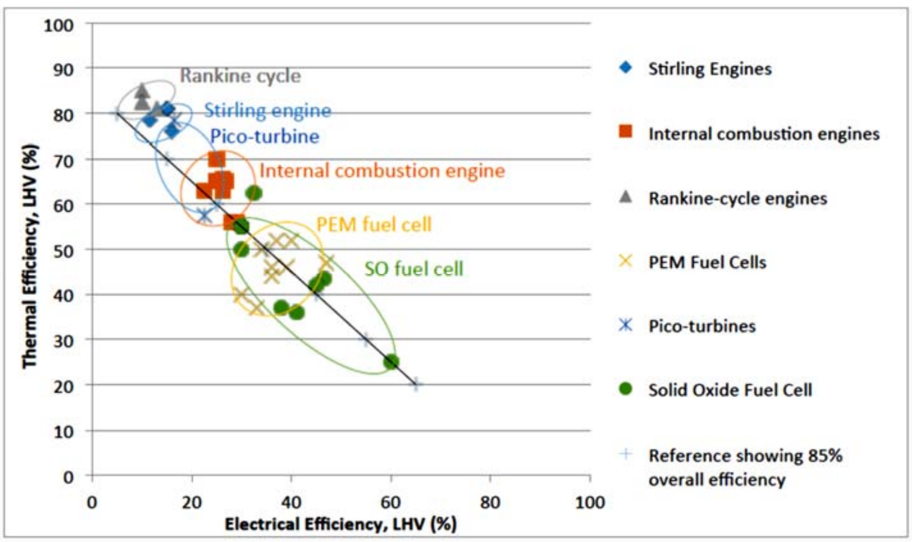
The most advanced and electrical efficient technology of micro-CHP is the fuel cell. However, today it is still expensive (about 17,000 euro per kWe) and still under development for being commercialized. Figure 1-12 shows the concept of the fuel cell. The appropriate fuel cells technology for residential application uses hydrogen as input fuel. The technical concept is based on transferring electrons through wire instead of a direct exchange between hydrogen and oxygen atoms. They have zero emission and the output is only water, heat and electricity. The electrical efficiency of sterling engines is lower than 10% but fuel cells can reach an electrical efficiency of up to 60%. Figure 1-13 presents the tradeoff between thermal and electrical efficiency. The higher electrical efficiency is more suitable for energy system. A small size micro-CHP plant can be used in houses for providing heat and elctricity. The extra electricity can be fed into the grid. Figure 1-14 schematically explains how micro-CHP can be implemented in buildings for producing electricity and heat.

Figure 1-12. Schematic of fuel cell technology



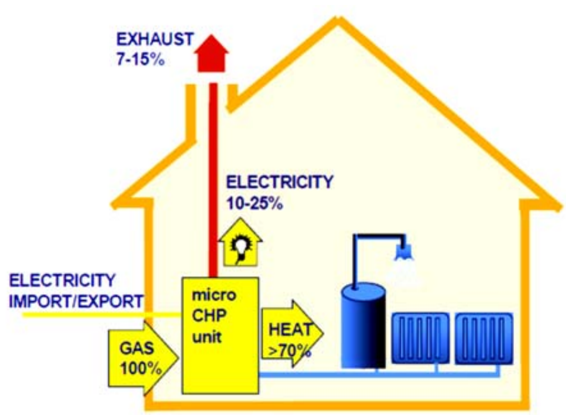
Source: (Kattenstein 2012) p.13

Figure 1-13. Micro-CHP product efficiencies grouped by technology



Source: (Dwyer 2014) p.569

Figure 1-14. The concept of micro-CHP for residential households

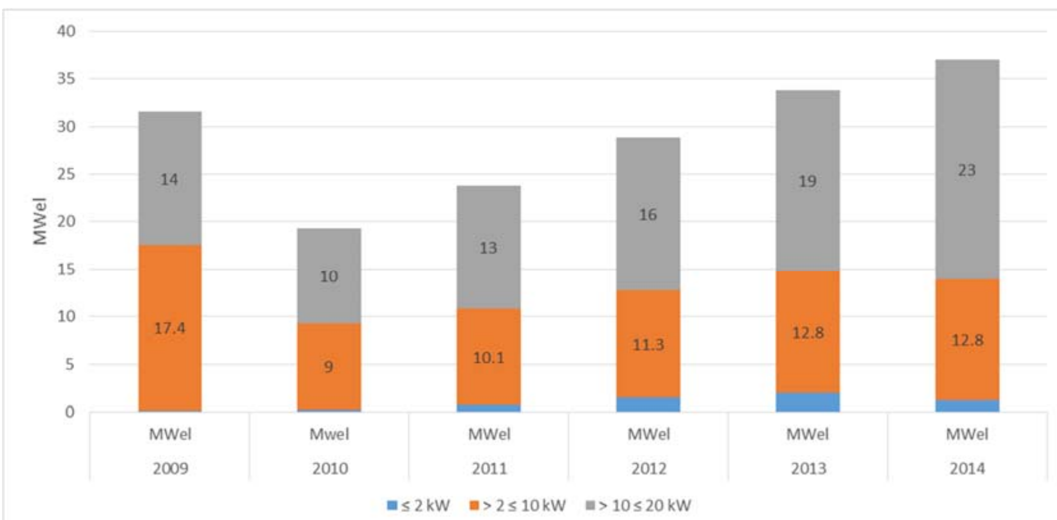


Source: (EU 2002)

1.4 Research Motivation: Micro-CHP development in Germany

As mentioned before, the main duty of micro-CHP plants is the generation of heat and electricity is the by-product of the system, which can be internally consumed or fed into the grid. Normally, the efficiency of micro-CHPs stands at about 90% of which 80% is attributable to heat while the share of electricity is about 10%. Each residential building in Germany consumes about 2.8 MWh/year of electricity, 16.5 MWh/year heat for room space and 2.4 MWh/year of hot water. With a number of 40 million households in Germany, the potential for micro-CHP systems is considerable[12]. "Even in comparison with the combination of a modern condensing boiler and centrally produced electricity from state-of-the-art gas-fired power plants, micro CHP can reduce CO2 emissions by 10 to 30 %."[13] p.65. Micro-CHP is economically better when it is possible that its electricity can be shared with others and heat demand is not very low. Installed capacity of micro-CHP units per year in Germany from 2009 to 2014 is shown in figure 1-15.

Figure 1-15. Installed capacity of micro-CHP units per year in Germany from 2009 to 2014



Source: author(data gathered and adapted from (BAFA 2015))

The development of micro-CHP in Germany shows a positive trend in recent years but its share in the total energy supply system is still less than few percent. Micro-CHP

[12] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

[13] Ibid.

as a technological innovation, requires support and long-term planning at the governmental level. how technological innovations such as micro CHP defuse to the energy system and what Germany is doing for more development is the subject of this research for demarcation of the problem, we can use a means-ends diagram [14](see Figure 1-16). Electricity production is responsible for around 43% of GHG emissions in Germany[15]. There is a need to incorporate more environmentally friendly technologies into the electricity supply system. One alternative is to promote distributed technologies such as micro-CHP. So what should be done for the promotion of micro-CHP? How do the surrounding conditions in Germany influence the development of micro-CHP? How does the regulatory framework act in this regard? What is the role of the institutional setting? Which kind of micro-CHP can be developed better? Which technologies are more suitable in combination of with existing institutional structures?

These questions motivate this research. In spite of general plans and cultural reasons behind the use of decentralized micro-CHPs, there are still some hindering factors in the way of technology implementation. The main question to which this research is dedicated to find an answer to is: how do regulations and public policies affect the innovative activities in the market of micro-CHP in Germany. These regulations and laws on the one hand provide values to stakeholders and on the other hand reduce the transaction costs of technology diffusion in the energy system. As a hypothesis, we argue that the core of a successful technological innovation system is the entrepreneurial system. Then we will focus on factors affecting the entrepreneurial system by using the economic theory of entrepreneurship and the concept of the value model for analyzing the proposed values and cost.

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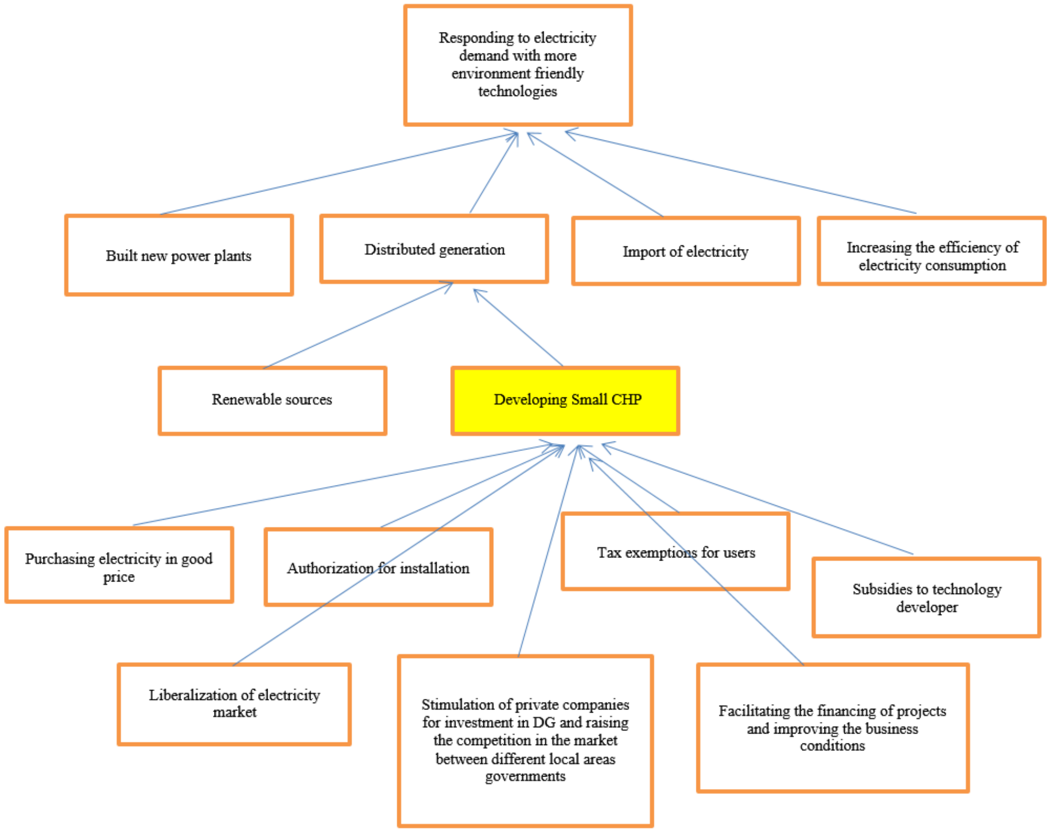
[14] Bert Enserink , L. H., Jan Kwakkel, Wil Thissen, Joop Koppenjan and P. Bots (2013). "Policy Analysis of Multi-Actor Systems."

[15] Bauknecht, B. P. D., et al. (2009). Innovation for Sustainable Electricity Systems Exploring the Dynamics of Energy Transitions, Springer.

Figure 1-16. Micro-CHP and supplying electricity in Germany with more environmentally friendly technologies (author)



Source: author

2 State of the art, research questions and Methodology

The study of the interaction between innovation systems, policies and the economy has emerged in the early 20th century as a multidisciplinary activity that necessitates research in technology, policy, industry and the economy simultaneously[16]. Innovations can take place in every part of the system such as in the technical part of the supply system, the institutional framework, the policymaking process or even in user behavior on the demand side. Governments are trying to facilitate and encourage the growth of entrepreneurship because it is understood as a capital and can lead to the creation of value in several domains of society[17]. The innovation study in this research is multi-disciplinary in nature and requires considering several fields of science. In this chapter, we define the required terminology for the implementation of the research.

2.1 State of the art and research contribution

2.1.1 Literature on the theoretical framework of innovation

Eurostat (2005) in the OSLO MANUAL, Audretsch et al (2011) and Gault, F. (2013) defined the concept of innovation and all its aspects. Although because of the immaterial nature of knowledge, scholars mentioned that directly measuring innovative activities is impractical, however, Jaff e et al. (1993) argued that the level of innovations could be deducted by examining registered patents and citations of scientific papers[18]. "The community innovation survey" (CIS) which was developed by the OECD, have been increasingly used by scientists as a standard means of measuring innovations (See Figure 2-1). Greenacre et al (2012), Suurs et al (2009) and Audretsch et al (2011) explained what the theoretical framework of innovation is and its story from Marx' theory to the theory of evolutionary economics. Elzen, B., et al. (2004), Godin, B. (2006) and GEA (2011) explained the linear model of innovation and some of its applications.

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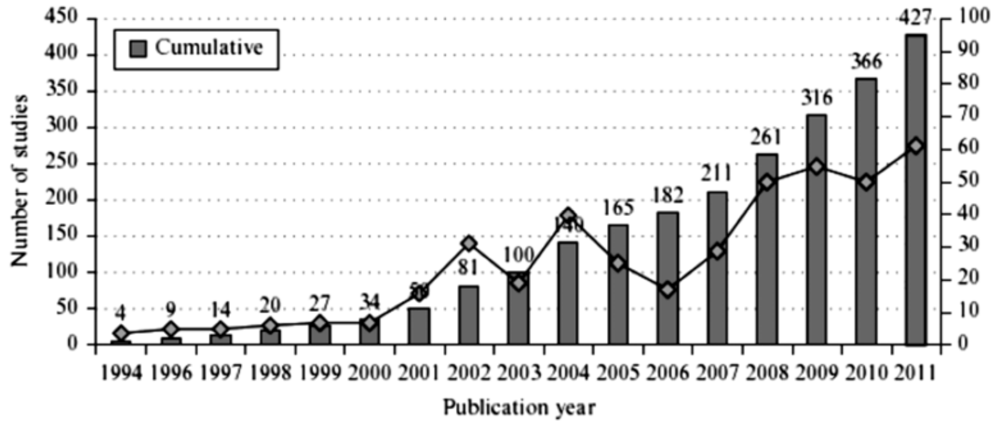
[16] Eurostat, O. (2005). OSLO MANUAL, E. European Commission, Organisation for Economic Co-operation and Development.

[17] OECD , A., N. R. G. Seymour Defining Entrepreneurial Activity, OECD Publishing.

[18] David B. Audretsch, O. F., Stephan Heblich and Adam Lederer (2011). Handbook of Research on Innovation and Entrepreneurship, Edward Elgar Publishing Limited.

Figure 2-1. “Academic papers in English have used CIS data”



Source: (Gault 2013) p.61

Later Swaminathan and A. L. S. (2007) discussed the Chain-linked Innovation Model. Rogers et al (2003) developed the theory of the Innovation Adoption Life Cycle. Many researchers have used this concept. For example, Huber (2008) analyzed technological environmental innovations[19]. Benjamin Miethling (2012) used this approach for analyzing the innovation policies in the development of geothermal technology in Germany, Island and USA[20]. Metcalfe et al (2000), Elzen, B., et al. (2004), Greenacre et al (2012) and Arnold & Kuhlman (2001) studied the systematic approach to innovation. They discussed the Model of National Innovation Systems as a theoretical framework for analyzing innovation activities at the national level. In order to simplify the complexity of analysis, many authors proposed methods and new approaches for defining the borders and demarcation of systems. By focusing on causes of socio-technical transitions, F.W.Geels (2001) reviewed all theories and approaches about transition of socio/technical systems and concluded that none of them was able to capture all aspects of the transition process. He tried to integrate all theories in one approach to explain every aspect of transition. Many researchers such as Kern (2012) used the MLP to analyze socio-technical transitions and assess innovation policy. In order to reduce the

[19] Huber, J. (2008). "Technological environmental innovations (TEIs) in a chain-analytical and life-cycle-analytical perspective." Journal of Cleaner Production **16**(18): 1980-1986.

[20] Miethling, B. (2011). Politische Triebkräfte der Innovation eine Analyse der Rolle von Politik in Innovationssystemen der Geothermie. Frankfurt am Main, Berlin, Freie Univ. **PhD**.

complexity of the National Innovation System (NIS) approach, the concept of the Technological Innovation System (TIS) has been developed by Hughes (1983, 1990) and later by Carlsson and Stankiewiz (1995). Carlsson and Stankiewiz (1995) introduced the concept of the Technological System by stressing the learning process and the importance of the institutional framework in absorbing risks[21]. Their work was inspired from institutional economics theories, which emphasize the essence of proper institutions for reducing transaction costs[22]. Johnson, A. (2001) proposed the functional characteristics of TIS. The last version of Technological Innovation System functions was proposed by Hekkert et al. (2006) by summing up the previous works and submitting seven functions of innovation systems[23]. Following this list of seven functions is a modification of Hekkert et al. (2006) proposed by (Bergek, Jacobsson et al. 2008) as they combined the two functions of knowledge development and knowledge diffusion and added the new function of positive externalities development[24].

"Function 1: Entrepreneurial activities"[25] p.422. "Function 2: Knowledge development and diffusion: [26]. "Three typical indicators to map this function over time are: 1) R&D projects, 2) patents, and 3) investments in R&D. While these indicators map the effort put into knowledge development, one might also map the increase in technological performance by means of so-called learning curves."[27] p.423 "Function 3:

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[21] Johnson, A. (2001). Functions in Innovation System Approaches. The DRUID 2001 Nelson and Winter Conference.

[22] Swaminathan, A. L. S. (2007). Innovation Theories: Relevance and Implications for Developing Country Innovation, DIW Berlin.

[23] Philip Greenacre, R. G., Jamie Speirs (2012). Innovation Theory: A review of the literature. Imperial College Centre for Energy Policy and Technology.

[24] Bergek, A., et al. (2008). "Analyzing the functional dynamics of technological innovation systems: A scheme of analysis." Research Policy **37**(3): 407-429.

[25] Hekkert, M. P., et al. (2007). "Functions of innovation systems: A new approach for analysing technological change." Technological Forecasting and Social Change **74**(4): 413-432.

[26] Bergek, A., et al. (2008). "Analyzing the functional dynamics of technological innovation systems: A scheme of analysis." Research Policy **37**(3): 407-429.

[27] Hekkert, M. P., et al. (2007). "Functions of innovation systems: A new approach for analysing technological change." Technological Forecasting and Social Change **74**(4): 413-432.

Guidance of the search:"[28] p.424. "Function 4: Market formation"[29] p.425. "Function 6: Creation of legitimacy/counteract resistance to change"[30] p.425."Function 7: Development of positive externalities"[31] p.418. Yuan-Chieh Chang and Ming-Huei Chen (2004) compared different innovation systems based on their geographical focal points. It is also possible to categorize innovation system approaches based on their geographical level of analysis. Yuan-Chieh Chang and Ming-Huei Chen (2004) recognized three approaches: "1) the national approach, as suggested by Freeman, Lundvall, and Nelson; 2) the technological/sectoral approaches used by Carlsson and Stankiewicz and Breschi and Malerba; 3) the local/regional approaches, as proposed by Cooke et al. Braczyk et al., and De la Mothe and Paquet ."[32] P.18. In another analysis by Hekkert and Suurs et al. (2007), the classification is the same with some differences in taxonomy. Jamshidi, M. (2009) discussed the System of Systems concept and how analysis of such systems are different with Systems of Subsystems. Gorod, Sauser et al. (2008) compared the system of Systems with System of Subsystems. Mostafavi et al (2011) introduced the Technological Innovation System as a System of System. However, their analysis and assumptions about innovation systems are not enough. As they assumed, the level of innovation systems analysis are only at the three geographical levels of National, Regional and Sectorial, which does not include all the different dimensions of innovation systems[33].

2.1.2 Literatures on theoretical Framework of entrepreneurial activities

Bruno and Tyebjee (1982) explained the factors influencing entrepreneurial activities. Their work was later used by Spilling, O. R. (1996). He suggested the concept

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[28] Ibid.

[29] Ibid.

[30] Ibid.

[31] Anna Bergek, M. H. a. S. J. (2008). Functions in innovation systems: A framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers.

[32] Chang, Y.-C. and M.-H. Chen (2004). "Comparing approaches to systems of innovation: the knowledge perspective." Technology in Society **26**(1): 17-37.

[33] Mostafavi, A., et al. (2011). "Exploring the Dimensions of Systems of Innovation Analysis: A System of Systems Framework." Systems Journal, IEEE **5**(2): 256-265.

of the entrepreneurial system for explaining the interaction between environmental factors and entrepreneurial events[34]. The evolution of entrepreneurship theories (related to the economy) is summarized in Table 2-1.

Table 2-1. Evolution of the definition of entrepreneur based on scholars' contribution to economic theory.

Scholar	Contribution to Economic Theory	Main Characteristics
Richard Cantillon (1755)	introduction to economic theory	Entrepreneur is a specialist in taking risk
Frank Knight (1921),	Introduced two kind of risks: insurable and uncertainty	Entrepreneur's profit is a reward for bearing uncertainty risks which no one can insure against
Joseph A. Schumpeter (1934)	Heroic vision and introducing entrepreneur as innovator as the core of economic growth	Other motivating factors than only profit, willingness for creating and superiority
Alfred Marshall (1919)	Considered the role of small firms in economic development	Not only high-level and big companies are entrepreneurs but also innovators in small firms are.
Friedrich A. von Hayek (1937) and Israel M. Kirzner (1973)	Emphasis on the importance of low-level entrepreneurship. Considers them middle-men in the market, buying cheap and selling for a higher price	Entrepreneurs offer price as an invitation to trade the approach organization and firm characteristics
Mark Casson (2010)	Emphasis on the judgment of entrepreneurs and demand-supply mechanism of entrepreneurs	Entrepreneurs are at low and high levels. Their judgments can be improved by policies and environmental factors

Source: adopted from (Casson 2010)

The OECD defines: 1) Entrepreneurs as persons who create economic activity by generating values. 2) Entrepreneurial activity as enterprising human activities with the same purpose of entrepreneurs. 3) Entrepreneurship as resulted and associated phenomena regarding entrepreneurial activities[35]. Wennekers and Thurik (1999) defined entrepreneurs as having three main characteristics. Casson, M. (2010) proposed the Economic Theory of Entrepreneurship. He assumed that the judgment of entrepreneurs

[34] Spilling, O. R. (1996). "The entrepreneurial system: On entrepreneurship in the context of a mega-event." Journal of Business Research **36**(1): 91-103.

[35] OECD , A., N. R. G. Seymour Defining Entrepreneurial Activity, OECD Publishing.

about other people (and themselves) is at the core of entrepreneurs' characters. He defined judgment as the ability to make decisions under the condition of incomplete information[36]. Braunerhjelm (2011) suggested seven factors, which public policy designers can consider for raising entrepreneurial activities. W. Edward Steinmuller (2010) in the "Handbook of Economics of Innovation" analyzed the technological policies for supporting both the demand and supply side of new technological innovations[37]. Birley, S. (1985), Giusta, M. D. (2010) and Casson, M. (2010) analyzed entrepreneurship in networks. They insist on trust as social capital, which can be shaped in effective networks. Especially, Della Giusta (2010) argues that social capital influences the entrepreneurial activities in the three dimension of opportunity seeking, resource acquisition and market organization[38]. Moreover, Casson, M. (2010) deeply analyzed the role of culture on entrepreneurial activities. He classified the combination of different cultural dimensions and showed how each combination can shape a socio-economic system. A new combination of cultural dimensions was suggested by Mark Casson (2010) which, are a trade-off between benefits and disadvantages of all aspects. Berbegal-Mirabent, S. T. J. (2012) suggests technology-based entrepreneurs can speed up product diffusion by innovative activities in using regulations and contact with customers and other stakeholders.[39] Silvana Trimi & Jasmina Berbegal-Mirabent (2012) analyzed the relation of business model to the entrepreneurship in new technology-based firms. Solmes, L. A. (2009) proposed an opportunity assessment procedure. She believes in the mitigation of investment risks in small energy systems such as micro-CHP where all the people involved in the business model should have the opportunity to communicate with

[36] Casson, M. (2010). Entrepreneurship: Theory, Networks, History, Edward Elgar.

[37] Steinmuller, W. E. (2010). ECONOMICS OF TECHNOLOGY POLICY. HANDBOOK OF THE ECONOMICS OF INNOVATION. M. D. I. KENNETH J. ARROW, Elsevier. **2**.

[38] Giusta, M. D. (2010). Entrepreneurial networks as social capital. Entrepreneurship: Theory, Networks, History

M. Casson, Edward Elgar.

[39] Berbegal-Mirabent, S. T. J. (2012). "Business model innovation in entrepreneurship." Springer Science+Business Media,.

each other and share their knowledge and interests[40]. Table 2-2 listed all literature on technological innovation reviewed for theoretical grounds.

Table 2-2. Literature on the theoretical framework of innovation

Bruno and Tyebjee (1982)	Godin, B. (2006),	Della Giusta (2010)
Birley, S. (1985)	Swaminathan, A. L. S. (2007)	Audretsch et al (2011)
Hughes (1983, 1990)	Hekkert, Suurs et al. (2007)	GEA (2011)
Spilling, O. R. (1996)	Huber (2008)	Mostafavi et al (2011)
Wennekers and Thurik (1999)	Hekkert et al. (2006)	Braunerhjelm (2011)
Metcalfe et al (2000)	(Bergek, Jacobsson et al. 2008	Greenacre et al (2012)
Arnold & Kuhlman (2001)	Gorod, Sauser et al. (2008)	Miethling (2012)
F.W.Geels (2001)	Suurs et al (2009),	Greenacre et al (2012)
Johnson, A. (2001)	Jamshidi, M. (2009)	Kern (2012)
Rogers et al (2003)	Solmes, L. A. (2009)	Berbegal-Mirabent, S. T. J. (2012)
Elzen, B., et al. (2004)	Casson, M. (2010)	Silvana Trimi & Jasmina Berbegal-Mirabent (2012)
Yuan-Chieh Chang and Ming-Huei Chen (2004)	W. Edward Steinmuller (2010)	
OSLO MANUAL (2005)	Giusta, M. D. (2010)	Gault, F. (2013)

Source: author

2.1.3 Literature on the cost-benefit model of micro-CHP development

The concept of eco-innovation by emphasizing the business model was introduced by many authors recently (S.G. Azevedo, et al 2014). Boehnke (2007) dedicated his PhD research to analyzing the different business models of residential micro-CHP in Germany and the UK. He did many interviews to find out the tastes of customers and entrepreneurs in the market.[41]. Boehnke mentioned limitations of his research and the necessity of more detailed research for analyzing the BM of micro-CHP by considering the long terms contracts. Another recent work done by A. Bikfalvi , R.C.Vila , and X.Muñoz (2014) focuses on improving energy efficiency through an intelligent energy management system (EMS) with the overall aim of optimizing energy consumption[42]. They suggest an energy service BM based on ICT and discuss how such a BM is eco-innovative. They

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[40] Solmes, L. A. (2009). Energy Efficiency Real Time Energy Infrastructure Investment and Risk Management, Springer Dordrecht Heidelberg London New York.

[41] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

[42] Andrea Bikfalvi , R. d. C. V., and Xavier Muñoz (2014). Toward Joint Product–Service Business Models: The Case of Your Energy Solution. Eco-Innovation and the Development of Business Models. S. G. Azevedo, M. B. H. Carvalho and V. Cruz-Machado, Springer International Publishing Switzerland.

emphasize the “[k]ey success factors: network, position, and reputation.”[43] p.217. Also they suggest that ICT plays a role in eco-innovation BMs via the three main characteristics of ICT as they named it “3S model of ICT for eco-innovation”[44] p.217. A. Tsvetkova, M. Gustafsson, and K. Wikström (2014) suggested a BM for integration of biogas into the energy system and named it “boundary-spanning business model”. They describe how such a business model can be developed through incentivizing various actors in the ecosystem, redistributing system benefits, and sharing the necessary investments and burden of risk”.[45] p.223. They argue the "entrepreneurs must integrate their BM to the socio-technical system by cooperation with all stakeholders and increase the interdependency”.[46] p.238. In the book “Managing Green Business Model Transformations” by Sommer .A et al (2012) accomplished a comprehensive analysis on how BMs can be environmentally sustainable. The book suggests BM as the center of an integrated approach for implementing the innovation in green technologies[47]. Mario Richter (2013) investigated the business models of big energy utilities in Germany with respect to renewable energy technologies based on several interviews. He found that despite of developed BM for large-scale utilities still there are not enough successful BMs for small scale distributed RE on the customer side. He insists on requirements of innovation in developing BMs for renewable energies[48]. In another research, Moritz Loock (2012) analyzed 380 choices of renewable energy investment preferences by investors in different business models and found that customer service plays an important role in absorbing investment, even more than price and technology[49][50]. He suggests that

[43] Ibid.

[44] Ibid.

[45] Anastasia Tsvetkova , M. G., and Kim Wikström ibid.Business Model Innovation for Ecoinnovation: Developing a Boundary-Spanning Business Model of an Ecosystem Integrator.

[46] Ibid.

[47] Sommer, A. (2012). Managing Green Business Model Transformations, Springer.

[48] Richter, M. (2013). "Business model innovation for sustainable energy: German utilities and renewable energy." Energy Policy **62**(0): 1226-1237.

[49] Loock, M. (2012). "Going beyond best technology and lowest price: on renewable energy investors' preference for service-driven business models." Ibid. **40**: 21-27.

[50] Loock, M. (2011). HOW DO BUSINESS MODELS IMPACT FINANCIAL PERFORMANCE OF RENEWABLE ENERGY FIRMS? The Handbook of Research on Energy Entrepreneurship

“customer intimacy’’ business models which propose the best services to the customers are preferred by investors. This implies that policy makers must pay attention to service-driven business models from the customer’s point of view rather than just technology or price. Other authors (Mike Provance, RichardG. Donnelly, Elias G. Carayannis. 2011) analyzed the effects of politico-institutional and socio-institutional dynamics. They compared institutional factors in different countries in the choice of three different business models for micro generation ventures[51]. Figure 2-2 illustrates the choice between three business models in different institutional context. Lasse Okkonen and Niko Suhonen (2010) suggested a detailed business model of heat entrepreneurship in Finland by analyzing "the business model of heat entrepreneurships within public companies/utilities, public–private partnerships, private companies and cooperatives, Energy Saving Company (ESCO), network model of large enterprise and franchising”[52] p.3443. A.Chaurey, P.R.Krithika, Debajit Palit, Smita Rakesh, Benjamin K.Sovacool (2012), analyzed the role of innovations, in terms of partnerships and business models and policy choices in facilitating energy access for end users. They analyzed the access to energy in developing countries in the case of India[53]. Another Studies by Fischer, C. (2006) showed that the pioneer users of micro-CHP have the following characteristics:

- Educated, very often in technical fields
- Good income, located in the middle class of society
- House ownership, mostly living in family houses in rural or small cities
- Mostly older single men
- Aware of environmental problems and highly interested in technical innovations
- Very interested in independence and privacy[54].

R. Wüstenhagen and R. Wuebker, Edward Elgar Publishing Limited.

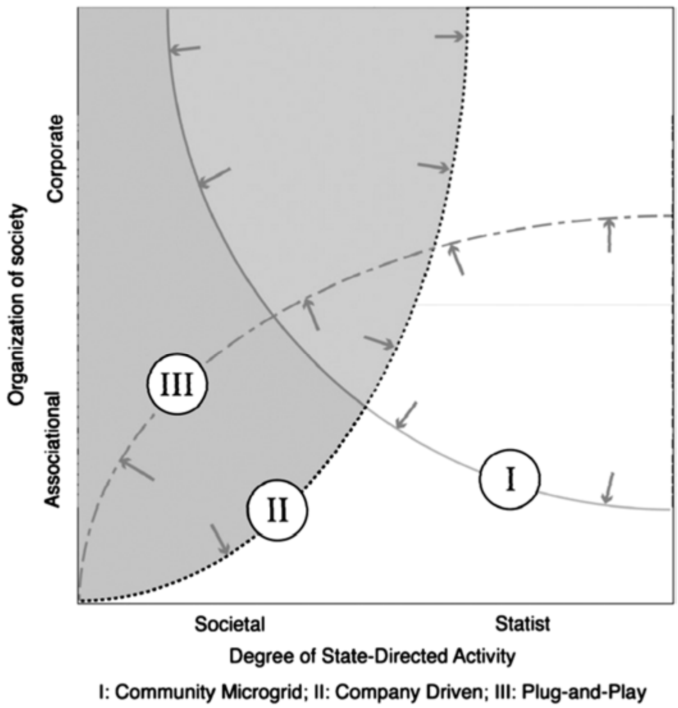
[51] Provance, M., et al. (2011). "Institutional influences on business model choice by new ventures in the microgenerated energy industry." Energy Policy **39**(9): 5630-5637.

[52] Okkonen, L. and N. Suhonen (2010). "Business models of heat entrepreneurship in Finland." Ibid. **38**(7): 3443-3452.

[53] Chaurey, A., et al. (2012). "New partnerships and business models for facilitating energy access." Ibid. **47, Supplement 1**(0): 48-55.

[54] Fischer, C. (2006). From Consumers to Operators: the Role of Micro Cogeneration Users. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

Figure 2-2. Institutional framework setting and business model choice for micro generation



Source: (Provance, Donnelly et al. 2011) p.5634

(Krushna Mahapatra, Leif Gustavsson, Trond Haavik, Synnøve Aabrekk, Svend Svendsen, Lies Vanhoutteghem, Satu Paiho, Mia Ala-Juusela (2013) have studied the case of full service energy renovation of single-family houses in Nordic countries. They "analyzed the opportunities for implementation of one-stop-shop business models where an overall contractor offers full-service renovation packages including consulting, independent energy audit, renovation work, follow-up (independent quality control and commissioning) and financing."[55] p.1558. More research was conducted by Jaap Gordijn and Hans Akkermans (2007) about "[b]usiness models for distributed generation in a liberalized market environment"[56]. They investigated many case studies for DG in a liberalized market environment based on networked business modeling and analysis

[55] Mahapatra, K., et al. (2013). "Business models for full service energy renovation of single-family houses in Nordic countries." Applied Energy **112**(0): 1558-1565.

[56] Gordijn, J. and H. Akkermans (2007). "Business models for distributed generation in a liberalized market environment." Electric Power Systems Research **77**(9): 1178-1188.

methodology[57]. Antonio Pantaleo, Chiara Candelise, Ausilio Bauen and Nilay Shah (2014) analyzed the business model of energy service companies (ESCOs) for biomass heating and CHP in Italy. They concluded that the heat load rate has more influence than the energy price[58]. An analysis of the "financial impacts of an Energy Efficiency Resource Standard on an Arizona electric utility using a pro-forma utility financial model, including impacts on utility earnings, ROE, customer bills and rates" was done by A. Satchwell , P. Cappers and C. Goldman (2011). They show "how a viable business model can be designed to improve the business case while retaining sizable benefits for utility customers "in the US[59]. p.218. The business model of customer-owned, on-site distributed generation was studied by Ray C. Duthu, Daniel Zimmerle, Thomas H. Bradley and Michael J. Callahan (2014) by presenting an economic model and quantitative results in the case of the US. Figure 2-3 shows the traditional business model of DG in the US which they analyzed. Their study "provided a means to understand the true costs and benefits to stakeholders in this type of Smart Grid demonstration." They suggests that most of the new business models "better internalize the costs and benefits of distributed generation projects between the three major market participants (G&T, distribution utilities, and customers)"[60]. p. 51. Hisham Zerriffi (2011) studied access to energy by the poorest people. They reviewed "options for innovative business models to scale up energy access and, in particular, focuses on both producer and consumer-side financing options that can ensure sustainability of energy access efforts"[61] p.273. He suggests, "[c]reating a stable and supportive policy and regulatory environment (i.e. through rationalized subsidy programs and appropriate regulatory requirements) is an absolute necessity for businesses making investment decisions to provide energy access."[62] p.276.

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[57] Ibid.

[58] Pantaleo, A., et al. (2014). "ESCO business models for biomass heating and CHP: Profitability of ESCO operations in Italy and key factors assessment." Renewable and Sustainable Energy Reviews **30**(0): 237-253.

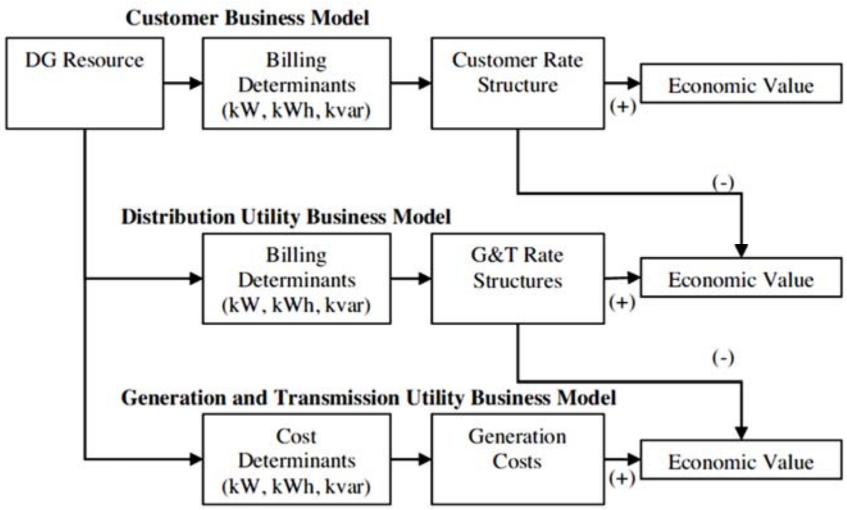
[59] Satchwell, A., et al. (2011). "Carrots and sticks: A comprehensive business model for the successful achievement of energy efficiency resource standards." Utilities Policy **19**(4): 218-225.

[60] Duthu, R. C., et al. (2014). "Evaluation of Existing Customer-owned, On-site Distributed Generation Business Models." The Electricity Journal **27**(1): 42-52.

[61] Zerriffi, H. (2011). "Innovative business models for the scale-up of energy access efforts for the poorest." Current Opinion in Environmental Sustainability **3**(4): 272-278.

[62] Ibid.

Figure 2-3. Traditional Customer, Distribution Utility and Generation and Transmission Utility Business Models for DG



Source: (Duthu, Zimmerle et al. 2014)

2.1.4 Literature on micro-CHP development in Germany

There exists a lot of literature on the case of micro-CHP development in Germany. Many books and technical reports are available with highly qualified quantitative and qualitative analysis. A publication from Verein Deutscher Ingenieure (VDI) (2013) provides a status report about the technical and economic aspects of micro-CHP. Several scientists from industry and universities analyzed all probable technical configurations of micro-CHP integration into the energy system of Germany with a focus on the role of micro-CHP in shaping a smart grid and smart home[63]. Researchers at Stuttgart University published a report about the role of micro-CHP in Germany's energy transition. The report is the result of the LITRES project (Lokale Innovationsimpulse zur Transformation des Energiesystems). In cooperation with Bundesministerium für Bildung und Forschung and Forschung für Nachhaltige Entwicklungen (FONA) and Sozial-ökologische Forschung (SÖF) analyzed the socio-technical aspects of micro-CHP integration in the process of Germany's energy system transition. The report suggests that mini-CHP (15-50 kWh) would play an important role in the energy transition of Germany if it could be integrated with other innovative technologies such as renewable energies and other

[63] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

electricity and heat supply systems. The most comprehensive study about micro-CHP innovation systems in Germany was published in the Sustainability and Innovation series, by authors from different organizations and with support from the German Ministry for Education. Jan-Peter Voß and Corinna Fischer (2006) focused on the Dynamics of Socio-Technical Change by analyzing four scenarios (forecasts, technology foresight, policy scenarios, and explorative scenarios) for energy system transition in Germany[64]. Martin Pehnt and Lambert Schneider (2006) analyzed the future of the heat market in Germany's residential sector and its potential for the development of micro-CHP. They concluded that the heat demand in the residential sector of Germany in a sustainable scenario would be less than 0.6 GW, which would not provide sufficient opportunity for micro-CHP as expected by the industry[65]. Lambert Schneider (2006) conducted a comprehensive analysis of the economic aspects of micro-CHP[66]. This study analyzed the two technologies of Sterling engines and reciprocating engines. Figure 2-4 shows a comparison of the cost in different situations between Sterling engines and reciprocating engines. Their analysis shows these technologies must work for more than 4000 hours annually to become economically feasible. Many characteristics of micro-CHP users such as age, education, attitudes toward politics, the environment and especially the pioneers were analyzed by (Fischer 2006). Barbara Praetorius (2006) studied german energy markets, entrepreneurial actors and their influence on micro-CHP diffusion. She analyzed the interests, motivations, and strategies of actors that foster or hinder the development of micro-CHP. The results of her analysis are summarized in Table 2-3. Based on her analysis, the highest potential for benefiting from micro-CHP exists for local energy companies that own both a power and a natural gas grid[67]. The importance of the institutional framework in shaping the path of changes is mentioned previously.

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[64] Jan-Peter Voß, C. F. (2006). Dynamics of Socio-Technical Change: Micro Cogeneration in Energy System Transformation Scenarios. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

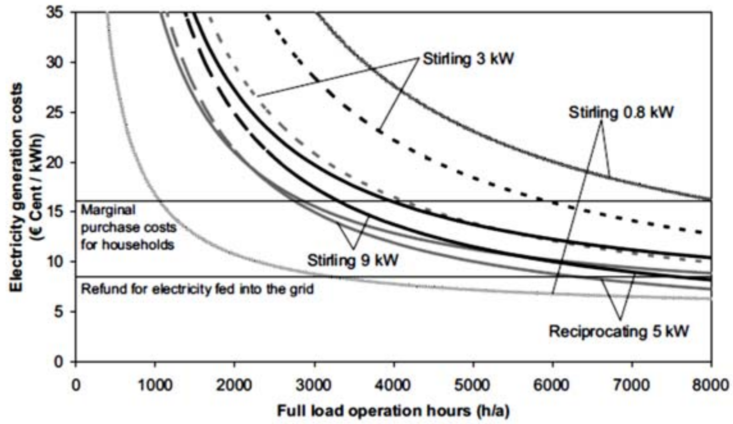
[65] Martin Pehnt, M. C., Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß (2006). Micro Cogeneration: Towards Decentralized Energy Systems, springer.

[66] Schneider, L. (2006). Economics of Micro Cogeneration. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

[67] Praetorius, B. Ibid.Micro Cogeneration – Setting of an Emerging Market

Market.

Figure 2-4. Comparison of the cost in different situations between Sterling engines and reciprocating engines.



Source: (Schneider 2006) p.78.

M. Cames, K. Schumacher, J.P. Voß, K. Grashof (2006) analyzed the social rules and governmental policies related to micro-CHP and especially the effect of market liberalization, the tax system and CHP laws, emission trading schemes and investment subsidies in Germany[68]. Due to the fact that electricity production by everyone is against the economic interests of monopolized electricity suppliers, Sylvia Westermann (2006) describes experiences of micro-CHP operators by considering the various types of users and the unexpected problems occurring in the everyday operation of micro-CHP[69]. Barbara Praetorius, Mari Martiskainen, Raphael Sauter, and Jim Watson (2012) studied the functions of the Technical Innovation System for micro generation. They studied the seven functions of innovation systems based on previous studies and collected data[70]. Regardless of a lot of the research about innovation systems, there are many deficiencies regarding the mutual economic and policy impacts of innovations[71]. Barbara Praetorius

[68] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof ibid.Institutional Framework and Innovation Policy for Micro Cogeneration in Germany.

[69] Westermann, S. Ibid.The Micro Cogeneration Operator: A Report from Practical Experience.

[70] Barbara Praetorius, M. M., Raphael Sauter, and Jim Watson (2012). Microgeneration in the UK and Germany from a Technological Innovation Systems Perspective. Sustainability Innovations in the Electricity Sector

E. Feess, J. Hemmelskamp, J. Huber et al.

[71] Eurostat, O. (2005). OSLO MANUAL, E. European Commission, Organisation for Economic Co-operation and Development.

and her colleagues analyzed the situation of micro-CHP in Germany and the UK by using the Technological Innovation System (TIS) approach and by focusing on seven functions of innovation systems[72].

Table 2-3. Main actors on the micro-CHP market

Actors	Incentives	Disincentives
Technology developers	Expected market growth Perception of a trend towards decentralization	High transaction costs Dismissive attitude of DNOs
Gas industry	Increase in gas sales Customer retention	Often ownership by electricity companies Existing cogeneration/local heating grids
Large electricity companies	Low investment risks Short lead-time Customer retention	Risk of stranded assets Existing cogeneration/local heating grids
Local energy companies	Customer retention Low investment risk Short lead-time Increased sales volume/self generation	High transaction costs Losses in electricity sales vs. gains in gas sales
ESCOs	Business opportunities	High transaction costs/small margin
DNOs	Disburdening of local network Reduced demand peaks	Ownership structures (vertically) Loss of revenue (reduced transmission)
Customers	Electricity generation at home Environmental benefits Large customers: economic benefits	High transaction costs Small or no economic advantages

Source: (Praetorius, Bauknecht et al. 2008) p.168

Their analysis was mostly descriptive and was based on the examination of general statistics and interviews. They did not publish any details about the models and in-depth analysis of market and entrepreneurship activities or the effect of the current institutional framework and regulations on entrepreneurs' business models. Table 2-4 shows the summary of their analysis[73]. Micro-CHP benefitted from two lobbying groups: first, large CHP owners and fuel cell technology developers[74]. According to the literature, in Germany people are not willing to change their heating system until it becomes old and

[72] Horbach, J. (2012). Sustainability Innovations in the Electricity Sector.

[73] Jens Horbach, E. F., Jens Hemmelskamp, Joseph Huber, René Kemp, Marco Lehmann-Waffenschmidt, Arthur P.J. Mol, Fred Steward (2009). Sustainability and Innovation, Springer.

[74] Horbach, J. (2012). Sustainability Innovations in the Electricity Sector.

useless so it can be concluded that for middle class people the most important factor for using the technology is its economic benefit[75]. One of the most comprehensive studies on micro-CHP innovation systems in Germany has been done by J. Horbach . et al (2009) by analyzing the current infrastructure for shaping the innovation process. They emphasized the four main categories of: financial incentives, R&D and pilot plants, information campaigns and the institutional framework[76]. This research revealed the fact that the current institutional framework of the diffusion of micro-CHP is not suitable and increases costs and risks for end users. Table 2-5 summarizes the literature regarding micro-CHP development and other energy distributed generation technologies.

Table 2-4. Technological Innovation System functions of micro-CHP in Germany

Function	Performance of German TIS
Knowledge development and diffusion	Low but growing performance: Almost no R&D apparent, little attention in conferences or research, no associations
Legitimation	Late but increasing performance: Renewables in the focus of politics, high level of public acceptance, increasing attention for distributed "local" energy, standard procedures for grid connection and remuneration
Influence on the direction of search	Medium growing performance: Bonus since 2000, investment support since 2008
Entrepreneurial experimentation	Growing performance micro-CHP: low performance, increasing number of entrants, diversification (Sterling, reciprocating, etc.) in last couple of years
Market formation	Low but growing performance: Increasing sales numbers and brands with standardization of procedures and financial stimuli
Resource mobilization	Low but growing performance: Little venture capital, mergers and distributors increasingly forming up
Development of external economies	Good performance: spill-over from ICT, self-reinforcing mechanisms of public approval, increasing deployment, cost reductions, reduced uncertainties

Source: author, based on((Horbach 2012))

[75] Jens Horbach, E. F., Jens Hemmelskamp, Joseph Huber, René Kemp, Marco Lehmann-Waffenschmidt, Arthur P.J. Mol, Fred Steward (2009). Sustainability and Innovation, Springer.

[76] Ibid.

Table 2-5. Literature on micro-CHP development

Jan-Peter Voß, C. F. (2006)	Zerriffi, H. (2011)
Martin Pehnt (2006)	Sommer .A et al (2012)
Schneider, L. (2006)	Chaurey, A., et al. (2012)
Fischer, C (2006)	Chaurey, A., et al. (2012)
Praetorius, B (2006)	Praetorius et al (2012)
Westermann, S (2006)	Horbach, J. (2012).
Boehnke (2007)	Mario Richter (2013)
Gordijn, J. and H. Akkermans (2007)	Mahapatra, K., et al. (2013)
Gordijn, J. and H. Akkermans (2007)	VDI (2013)
Horbach et al (2009).	S.G. Azevedo, et al 2014
Okkonen, L. and N. Suhonen (2010)	Bikfalvi , R.C.Vila , and X.Muñoz (2014)
Okkonen, L. and N. Suhonen (2010).	A. Tsvetkova, M. Gustafsson, and K. Wikström (2014)
Moritz Loock (2012)Loock, M. (2011)	Pantaleo, A., et al. (2014)
Provance, M., et al. (2011).	Duthu, R. C., et al. (2014)
Satchwell, A., et al. (2011)	Duthu, R. C., et al. (2014)

Source: author

2.2 Research Design and Methodology

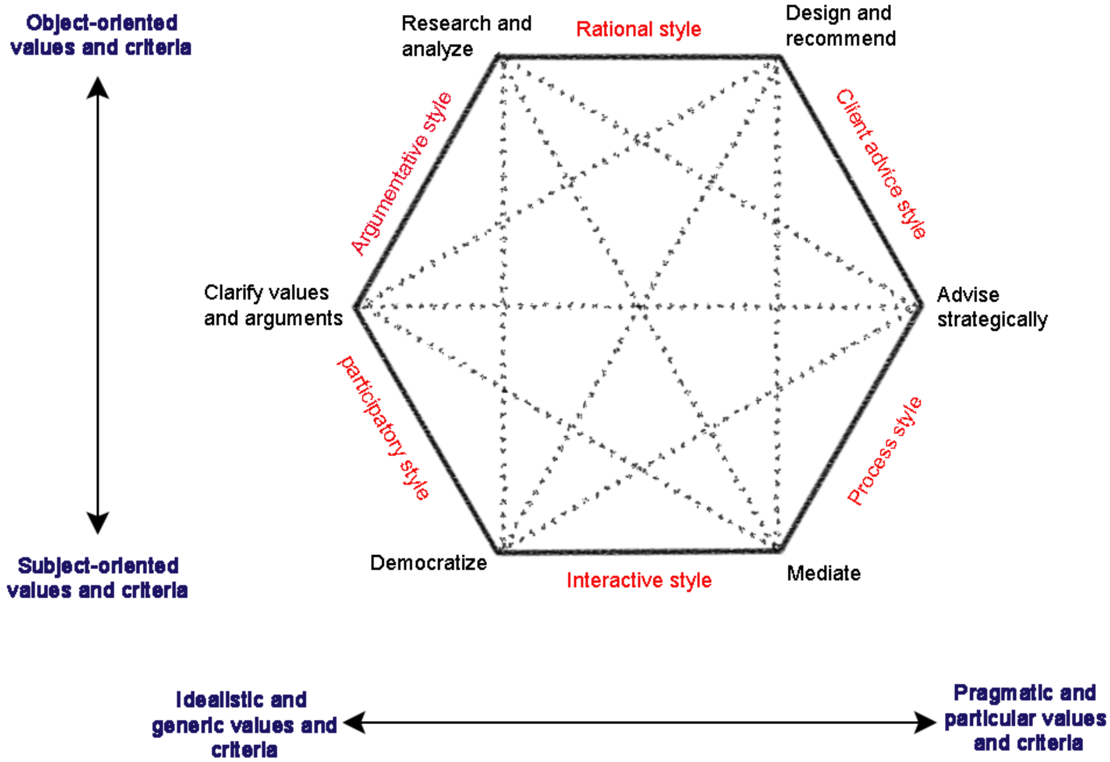
2.2.1 Analytical arena

Our analytical approach in this research is mostly bottom-up, by insisting on objective issues related to micro-CHP. The variety of policy analysis styles is shown in Figure 2-5[77]. The goals of policy analysis are shown in the corners of the hexagon while the sides represent the styles. The activities in the top half of the hexagon are mostly object-oriented and tend to use quantitative methods. Objects are arguments, systems, regulations and policies. On the other hand, the focus of the lower part is qualitative and subjective like the analysis of interactions between actors[78]. This research is going to use styles and activities related to the top half of the policy analysis hexagon, which mostly relate to research and analysis and clarify values and arguments. This research is going to focus on public policies and instruments for promotion of micro-CHP technology in Germany. The policy analysis paradigm of this research is a combination of the bottom-up Value Model with policy processes in small networks of the value proposition system. In order to analyze the effects of policies on entrepreneurial activities, it is not enough to simply mention the policies and discuss their expected influences. The first hypothesis is that without effective entrepreneurial activities, technological innovations cannot take place. In the literature, entrepreneurial activities are the common point of all innovation system studies and the core of economic development in modern economic theory. The aim of policy makers is to increase entrepreneurial activities in society. We are going to study how these supportive instruments are interacting in the case of micro-CHP technology in Germany.

[77] Thissen, W. A. H. W., Warren E. (Eds.) (2013). Public Policy Analysis New Developments, springer.

[78] Ibid.

Figure 2-5. Hexagon of policy analysis style and activities



Source: adapted by author, originally from (Thissen 2013)

2.2.2 Research questions and hypothesis

The informal and formal institutional setting and regulatory framework shape the development path of micro-CHP in Germany. This research is going to find the answer to the main question of the influence of surrounding phenomena on the development of micro-CHP in Germany. Before answering these questions, we are asking other more fundamental questions. Why and to what extent are entrepreneurial activities important in the development of technological innovations such as micro-CHP? We are trying to formulate the requirements for innovative entrepreneurial activities based on theories for the formulation of technological innovation systems. The main research question is:

How do the regulatory framework and institutional setting in combination with German culture influence the development of entrepreneurial activities regarding micro-CHP?

In order to answer the main question, four sub questions must be addressed. The first sub question is more a theoretical question, which helps us define the border of our analysis exactly.

1-1- What are criteria for innovative entrepreneurial activities regarding the development of technological innovations and how to study them?
1-2- How do cultural features of society influence entrepreneurial activities?
1-3- How do the dynamics in the institutional setting of the energy system shape the development of micro-CHP?
1-4- How do regulations and policies influence entrepreneurial activities in the field of micro-CHP in Germany?

By addressing these questions, we are proving three hypotheses:

First hypothesis: entrepreneurship and entrepreneurial activities are at the core of the technological innovation system. Without them, new environmentally friendly technologies cannot be successful.

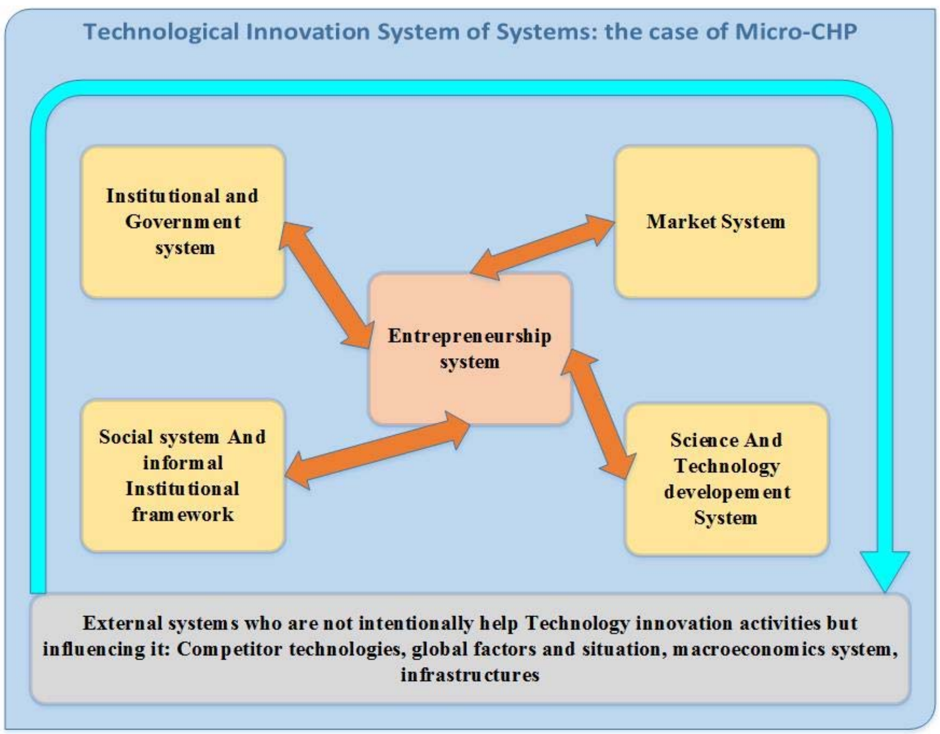
Second hypothesis: the German culture and general factors provide good atmosphere for micro CHP development. However, interaction of cultural characteristics with regulatory framework could be a hindering factor in the way of micro CHP development.

Third hypothesis: institutional setting of Germany's energy system was a hindering factor for development of micro CHP in the past. However, phenomena at global and EU level put pressures and would change the institutional setting in favor of micro CHP.

2.3 Theoretical framework of research

In the next chapter, we reviewed the development of theories and methods for explaining and analyzing innovation from a systematic point of view. Theories about how innovations emerge, how they change the current system and the influence of external factors on them are studied. Figure 2-6 presents our systematic approach toward innovation and the entrepreneurial system as the core of technological innovation systems. In order to analyze traits of entrepreneurial activities, we use the economic theory of entrepreneurship. This theory explains influential factors such as cultural factors, governmental policies and networking. The theory is very broad and is not case-dependent. It mostly focusses on surrounding factors that influence the supply of high-qualified decisions. On the other hand, the aim of entrepreneurial activities is adding value to society and without focusing on the specific technology case, conducting an in-depth analysis is not possible. Accordingly, to answer the second research question, we need a methodological framework to analyze the value adding process of entrepreneurial activities. As it is explained in the theoretical chapter, the concept of the Business Model has been developed for such a purpose. We extend it to the more general concept of the Value Model by just focusing on value creation, proposition and absorption. In this regard, we do not analyze strategies for doing business with deep marketing research.

Figure 2-6. Technological innovation in the form of System of System



Source: author

2.3.1 Dependent and independent variables of research:

According to the research questions, we have two main dependent variables:

1) Criteria for entrepreneurial activities, which are integrated into the technological innovation system,

2) Development of micro-CHP in the energy system of Germany

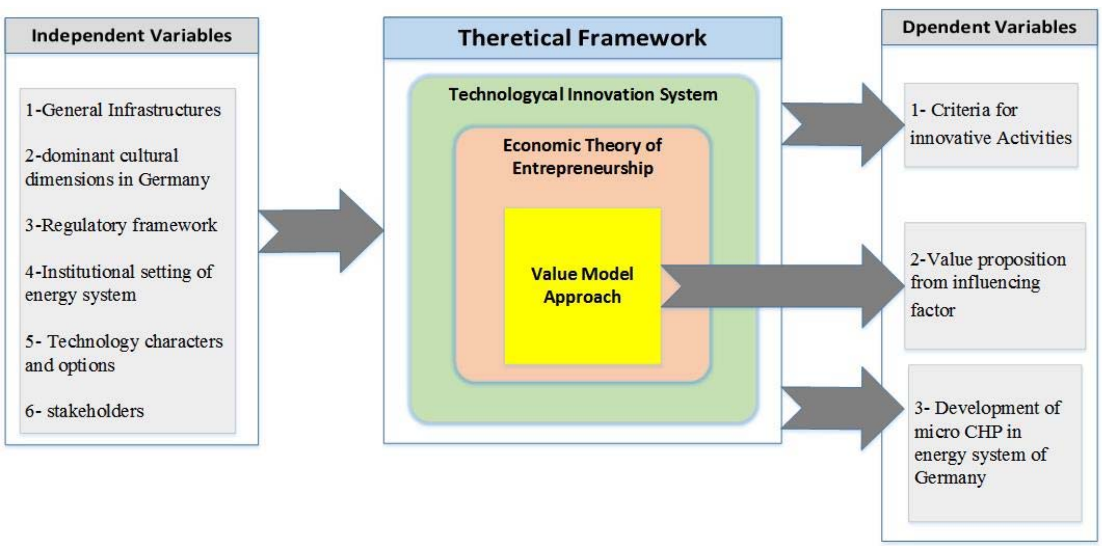
Independent variables:

The independent variables, which are used for finding dependent variables, are:

1- General infrastructure
2- Dominant cultural dimensions in Germany
3- Regulatory framework
4- Institutional setting of energy system
5- Technology characters and options
6- Stakeholders

Figure 2-7 schematically shows the relation of dependent and independent variables within the theoretical framework.

Figure 2-7. Independent and dependent variables and theoretical framework



Source: author

2.3.2 Research methodology

According to the research questions, the analysis should be done in three main stages. First, we discuss the criteria for success of innovative activities. We prove the first hypothesis by doing a comprehensive theoretical literature review. At the second stage, we analyze influential factors on entrepreneurial activities based on the economic theory of entrepreneurship. On this level, the criteria and their situation in Germany regarding micro-CHP development are the dependent variables. Factors such as culture and institutional framework are independent variables. We are finding the hindering and anti-innovation factors as well as those that cause success. On the third level, we focus on the Value Model. We will analyze the different possible situations for value creation. We analyze which innovative activities can influence the value proposing chain to become a successful activity. At this level, the dependent variable is Value Model efficiency and the independent variables are regulations, customers' values, technology values and costs, service costs and service value. In the case of micro-CHP, the stakeholders are DNOs, customers, large electricity companies, energy service contractors (ESCOs), the gas industry and local energy companies.

2.3.2.1 *Cultural features of society and dynamics in institutional setting*

In this research, we define the institutions as social, formal and informal rules that control all actions by inserting incentives and penalties, suggesting orientations or prescribing or prohibiting specific behaviors of actors[79]. In the case of micro-CHP, these institutions are electricity market regulations, actors, and the culture of consumption and business in Germany. We divide the institutions into two different parts, the formal and informal institutions. The informal institutions consist of the dominant culture in the society and personal values. In the case of technological changes, the interaction between these two institutional settings plays a very important role. Because, if the formal institutional settings such as regulations do not match the informal institutions, technological changes cannot be sustainable. If the government and other formal institutions on the other hand constantly adjust themselves to society, it promises a better and faster development. A good example of such an adjustment is the German government's decision for phasing out nuclear power because of society's will. We study external factors, which affect and shape the institutional framework and the development of micro-CHP.

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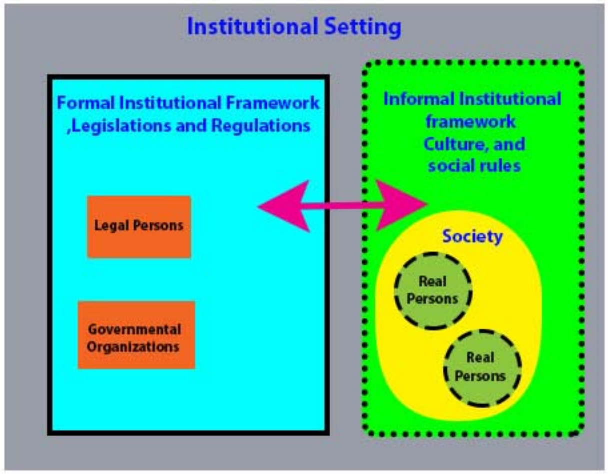
[79] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

Figure 2-8. General concept of institutional setting



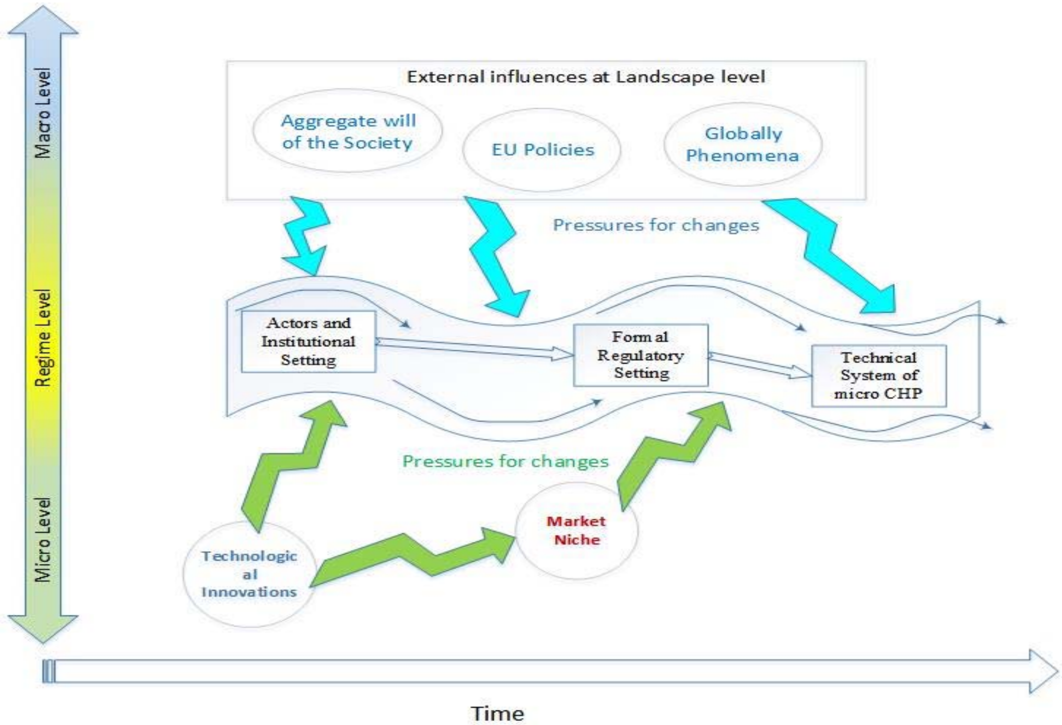
Source: author

These interactions and changes occur on the level of the socio-technical regime. We analyze these changes in different intervals of time. Figure 2-9 explains the concept of multilevel perspective analysis that we are going to use in this research. For a specific period, we focus on the pressures from technological innovations on the niche level. The niche level points out the changes at the micro level, which have limited effects on the system and mostly consist of technological breakthroughs or the introduction of new micro-CHP. The importance of the niche level is that government must protect it continuously by funding programs and providing incentives for pioneer users. Moreover, new technologies provide options regarding the possible future of the energy system. Other influencing factors are global phenomena that put pressure on the system at the macro level. We assumed the regulations at the EU level, and the public's view about energy issues as influential factors on the macro level. By conducting a multi-level perspective analysis, it is possible to summarize the whole process of system transition.

2.3.2.2 *Analyzing of regulatory framework*

The regulatory framework consists of a set of incentives for the promotion of micro-CHP on the end user side. Tax exemptions, feed-in tariffs, bonuses and loan programs are incentives, which can be used by users in a specific regulatory framework. The aim of these regulations is reducing the transaction costs for the utilization of micro-CHP. Therefore, we analyzed the economic costs and benefits of micro-CHP according to each regulation during a period of 10 years.

Figure 2-9. A multi-level perspective in the analysis of the institutional setting of micro-CHP in Germany (author)



Source: author

In order to calculate the transaction costs such as taxes, fees, commissions, investment and operation costs and risks and also values we need to analyze the regulatory framework which shapes the costs and value structures such as fees and incentives. In Germany, there are 5 regulations which directly influence the micro-CHP market:

1. CHP Law (Kraft-Wärme-Kopplungsgesetz (KWKG 2012))
2. Renewable Energy Law (Erneuerbare-Energien-Gesetz (EEG 2012))
3. Energy Tax Law (Energiesteuergesetz)
4. Electricity Tax Law (Stromsteuergesetz)
5. Value Added Tax Law (Umsatzsteuer)
6. Income Tax Law (Ertragssteuer)
7. Renewable Energy Heat Law (Erneuerbare-Energien-Wärmegesetz (EEWärmeG))
8. Mini-CHP Incentives (Mini-KWK-Förderrichtlinie)
9. KfW Incentive Programm (KfW-Förderprogramm)
10. Other incentives programs at local levels

Each regulation has different results in different situations of micro-CHP usage. For calculating the monetary potential value, we need to do some economic analysis. The optimal entrepreneurial strategy in the micro-CHP market is out of the scope of this research. However, based on the relevant literature on the topic, in some cases such as when implementing virtual power plants by running micro-CHP systems in a smart grid, (including exact optimization of monetary and technical processes) some costs can be reduced by up to 10%[80]. For this purpose, we need to sum up all cost-benefits in each year based on the base year prices of 2014. To this end, we use an interest rate of 6%[81]. In this regard, there are two main assumptions:

1- The total economic cost in year t ($C_{T,t}$) = Taxes (Energy, VAT, Income) + Fuel Cost + Maintenance Cost
2- The economic benefits in year t ($B_{T,t}$) = Bonuses + Energy saving + Feed-in Tariff + Investment Aids

$$the\ present\ economic\ value\ = B_T - C_T$$

$$= \sum_{t=1}^{n} \frac{(B_{T,t} - C_{T,t})}{(1+r)^n} - (Initial\ Costs\ in\ the\ 1th\ year)$$

r is the interest rate and n is the period for contract or lifetime of the system, which in our analysis we considered to be 10 years[82].

2.3.2.3 *Analyzing the value proposition of micro-CHP*

The main targets of all regulations and incentives are customers in residential and commercial buildings. Depending on many parameters, installing micro-CHP can provide profit by self-generation of electricity or reduction of costs in comparison with traditional ways of energy supply. However, there are other actors, for which the development of

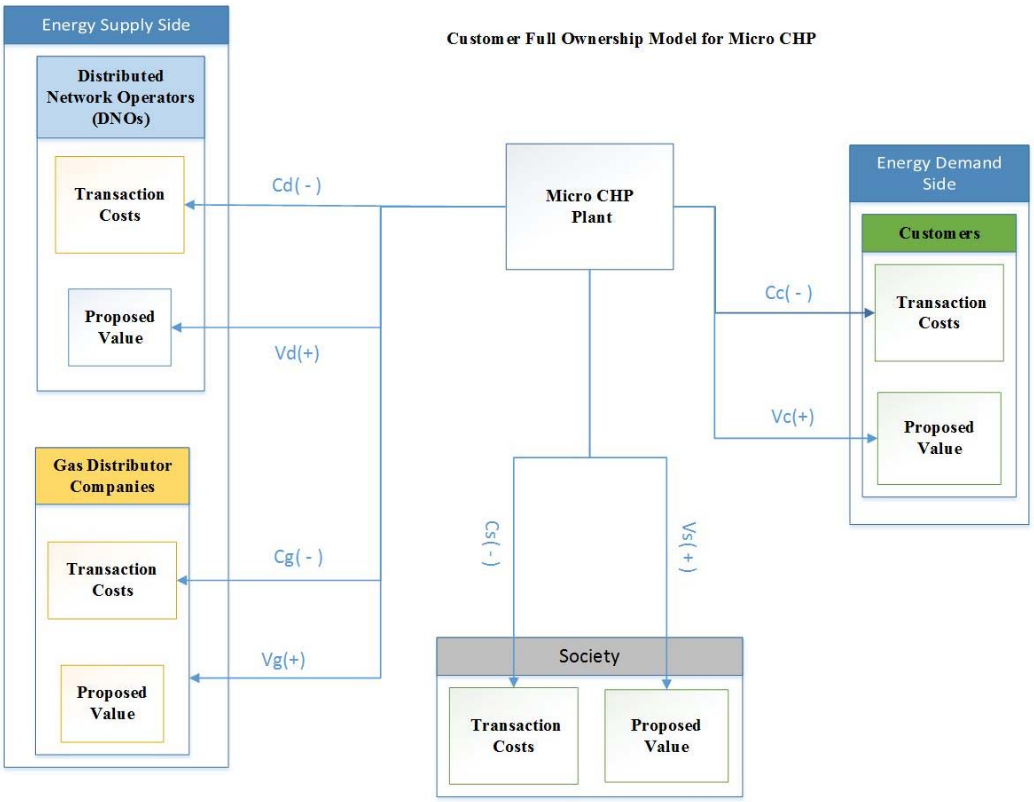
[80] Wille-Haussmann, B., et al. (2010). "Decentralised optimisation of cogeneration in virtual power plants." Solar Energy **84**(4): 604-611.

[81] ProjektIC4-42/13 (2014). Potenzial- und Kosten-Nutzen-Analyse zu den Einsatzmöglichkeiten von Kraft-Wärme-Kopplung (Umsetzung der EU-Energieeffizienzrichtlinie) sowie Evaluierung des KWKG im Jahr 2014.

[82] USGS (2009). Advancing Statewide Spatial Data Infrastructures in Support of the National Spatial Data Infrastructure (NSDI) I. Applied Geographics.

micro-CHP has costs and benefits. Figure 2-10 shows the concept of the Value Model and the costs of micro-CHP for stakeholders.

Figure 2-10. An example of the Value Model with full customer ownership (author)



Source: author

We labeled the cost with the letter C and the value with letter V. The lowercase letter d stands for DNOs, g for gas companies, s for society, c for customers and e for entrepreneurs. These costs and values depend on culture, the institutional framework, regulations and market variables such as prices for energy and technology.

3 The role of entrepreneurial activities in raising technological innovations in society and the theoretical framework of the research.

3.1 The role of entrepreneurial activities in development of technological innovations in society (A theoretical reasoning)

Focusing on the combination of energy science and innovation researches provides strong solutions for businesses, politicians and society.[83] In this chapter, we prove the importance of entrepreneurial activities as the core of innovations in energy systems. To this end, we begin by discussing theories about technological innovation. Different approaches to the analysis of innovation systems are reviewed. Moreover, the system approach to Technological Innovation Systems is analyzed. In this chapter, we answer the following research sub question:

What are criteria for studying the innovative entrepreneurial activities regarding development of technological innovations?

In addition, we prove the first hypothesis of this research:

First Hypothesis for sub question 1: Entrepreneurship and entrepreneurial activities feed and facilitate innovative, environmentally friendly technologies.

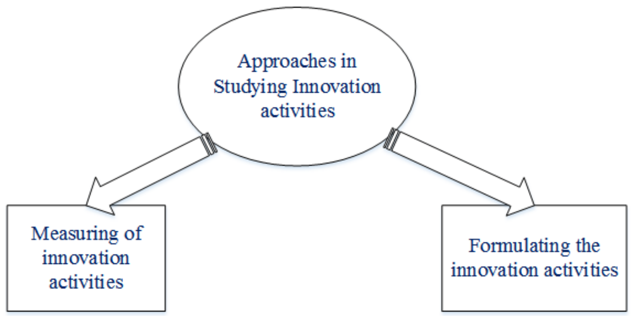
3.1.1 Theoretical framework of technological innovation studies

Developing new products with lower environmental pollution or changes in policies require innovation and expertise for handling ever-changing situations. Innovations do not only include the invention of new technologies and products (by individual technical scientists and engineers) but also require creativity from political and social scientists and management and planning, policymaking and governance. As defined by the OECD, innovation activities are all efforts by scientific institutions, technology developers and financial organizations and individual users everywhere for the creation, implementation

[83] Andrea Bikfalvi , R. d. C. V., and Xavier Muñoz (2014). Toward Joint Product–Service Business Models: The Case of Your Energy Solution. Eco-Innovation and the Development of Business Models. S. G. Azevedo, M. B. H. Carvalho and V. Cruz-Machado, Springer International Publishing Switzerland.

and marketing of new or improved products and processes[84]. All writers and experts insist that measuring innovation and analyzing it, is a difficult subject. There are diverse approaches in the analysis of innovation in scientific resources. One group of researchers tries to develop indicators for measuring the innovative activities by conducting surveys. The second group of scientists try to develop theories aiming to explain innovation scientifically (See Figure 3-1). The first approach is a quantitative and statistical approach while the second one can be classified as more analytic and qualitative.

Figure 3-1. Two main approaches in studying innovation activities



Source: author

3.1.2 Measuring of innovation

The first approach for studying innovative activities is trying to measure innovation from product manufacturers to government policies at the national level. These approaches are very useful for decision makers, managers and policy analyzers when:

- Studying innovation at the national level by comparative analysis between countries or organizations is demanded.
- Policy makers need a data basis for studying trends of innovation activities over time.
- Scientists need measuring tools for policy analysis and for studying the effects of polices on innovation activities.
- Policy makers need to understand the effects of previous innovation policies.

[84] Eurostat, O. (2005). OSLO MANUAL, E. European Commission, Organisation for Economic Co-operation and Development.

In this regard, one of the most developed and used methods for analyzing the innovation system by measuring indicators and standards is the OSLO Manual, which has been developed and used by the EU's statistic office and the OECD. It tries to depict every innovation through quantitative indicators[85]. The OSLO Manual has been prepared in order to provide a standard framework for conducting surveys and to help new researchers in the field of innovation studies[86]. It provides a transparent and well-organized framework for measuring innovation activities mostly based on tangible facts and measures. The study of the interaction between innovation systems, policies and the economy has emerged in the early 20th century as a multidisciplinary activity which necessitates research in technology, policy, industry and the economy simultaneously[87]. Because innovation is at the heart of the OECD economies, developing methods for innovation studying and management becomes more important every day[88]. The first and second version of the OSLO Manual mostly focused on technological innovations in manufacturing. However, because the share of the service sector makes up about 70% of GDP in most industrialized countries, in the third version of the OSLO Manual, measuring the degree of innovation in the service sector and developing a systematic view of innovation became more important[89]. Based on the OSLO Manual, different versions of the Community Innovation Survey (CIS) have been developed and constitute the main source of data for measuring innovation activities in the EU[90]. The first survey on non-technological innovations such as organizational, marketing and management innovations was developed in 2000. Time series data is available at the macro level and is suitable for studying the effects and trends of government's policies at the macro scale. However, CIS is raw in its original form and has many limitations in utilization. Its contribution to policy analysis is mostly related to academic and post-scientific analysis by applying various systematic theories to it. Moreover, the CIS only measures products, not organization, and process innovations[91]. Measuring innovation relies on information

[85] Gault, F. (2013). Handbook of Innovation Indicators and Measurement, Edward Elgar Pub.

[86] Eurostat, O. (2005). OSLO MANUAL, E. European Commission, Organisation for Economic Co-operation and Development.

[87] Ibid.

[88] Ibid.

[89] Gault, F. (2013). Handbook of Innovation Indicators and Measurement, Edward Elgar Pub.

[90] eurostat.ec.europa.eu (2014). science_technology_innovation database.

[91] Gault, F. (2013). Handbook of Innovation Indicators and Measurement, Edward Elgar Pub.

gathered from different organizations about innovative activities in their products or processes and management. It cannot be applied directly for analyzing a system of innovation, because many different types of actors, private and governmental organizations on different levels are interacting with each other. Without a systematic analysis, even aggregated data at the macro level is useless for concluding whether a system is innovative or not. It focuses on the number of patents and RD budgets as well as the number of new products, activities and processes which organizations report. Measuring innovation in this manner does not show the motivating forces and complexity as well as the reasoning behind innovations. Such measurements do not say anything about why and how innovation happens.

3.1.3 Theories in formulating technological innovation

Investigating the causes of innovation requires systematic approaches and a theoretical framework. Early theories about innovation originate in the 18th -19th century in Marx' theory[92]. Later, most authors, which attempted to formulate theories of innovation, got their idea from the theory of Evolutionary Economics, which sees innovation as the core of any socio-technical system transition and any change in socio-technical systems (or system transition) go along with several changes in its components and is related to other parts. Accordingly, system innovations are not only about one innovation but also allows researchers to look at innovation activities beyond mere technology and products. Besides, such an approach to study innovation requires multi-disciplinary research and the combination of different scientific viewpoints with each other. Nevertheless, there are few systematic approaches for integrating different disciplines to address real world questions with regard to innovation[93].

[92] GEA (2011). Global Energy Assessment. Knowledge Module 24: The Energy Technology Innovation System,.

[93] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

3.1.3.1 *Evolutionary Economics theory*

Unlike neoclassical economics, the core concept of which is the economic equilibrium between demand and supply reached via the price mechanism, the theory of Evolutionary Economics proposed by Schumpeter (1942) puts an emphasis on innovation as the motivational force of the economy. Schumpeter recognized the three stages of: 1) Invention, 2) Innovation and 3) Diffusion. In his theory, he described innovation as the commercial presentation of an invented idea to the market[94]. Therefore, in the Schumpeter's theory, entrepreneurs play a pivotal role in accepting the risks of innovation and advancing the economy[95]. The central focus of evolutionary economics is on diversity and selection processes. When entrepreneurs select among diverse options, evolution takes place by pushing the economy to accept new options[96]. Later Nelson and Winter (1982) and Dosi (1982) developed the idea of evolutionary economics by assuming that the quality of human cognition is limited, which causes engineers and innovators to follow rules and cognitive frameworks of groups and organizations. As a result, there is a path dependency of research, innovations and novelties. Each emerging technology that can be more dominant can shape networks, which bring about new regimes of technology[97].

3.1.3.2 *The Linear Model and Chain-linked Model of Innovation*

One of the earlier attempts for formulating a theory of innovation refers to the "linear model of innovation" proposed by V. Bush ([1945] 1995)[98]. The model is a formulation of the theory previously developed by Joseph A. Schumpeter (1942) who

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[94] Philip Greenacre, R. G., Jamie Speirs (2012). Innovation Theory: A review of the literature. Imperial College Centre for Energy Policy and Technology.

[95] Suurs, R. A. A. (2009). Motors of sustainable innovation Towards a theory on the dynamics of technological innovation systems. Faculty of Geosciences, Utrecht University.

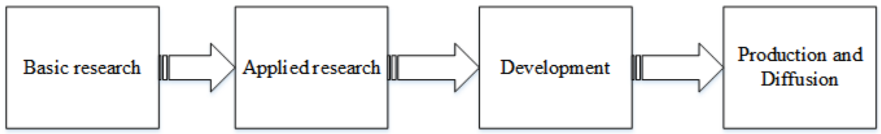
[96] David B. Audretsch, O. F., Stephan Heblich and Adam Lederer (2011). Handbook of Research on Innovation and Entrepreneurship, Edward Elgar Publishing Limited.

[97] Elzen, B., et al. (2004). System Innovation and the Transition to Sustainability: Theory, Evidence and Policy, Edward Elgar Publishing Limited.

[98] Godin, B. (2006). "The Linear Model of Innovation The Historical Construction of an Analytical Framework." Science, Technology, & Human Values.

stressed the roll of entrepreneurs and competition in emerging innovations[99]. Figure 3-2 shows the concept of the linear model of innovation[100].

Figure 3-2. Concept of the linear model of innovation



Source:author

From the beginning of its introduction, this model became popular in all studies related to innovation. It was used by academic lobbyists to affect policy makers and by many economists to justify their ideas. Despite the simplicity of this model, it proved useful in some areas. The OECD used the model in its innovation study projects but later the shortcomings of the theory in explaining the characteristics of innovations and interpreting complexities in the relations between system components, made it obsolete. Due to the weaknesses of linear models of innovation, Kline and Rosenberg (1986) developed the concept further by adding feedbacks between the different stages and connecting all of them to a research unit and thus developing the Chain-linked Innovation Model[101]. Figure 3-3 depicts the Chain-linked Innovation Model. The Chain-linked Innovation Model is mainly useful in analyzing the innovation system inside a firm rather than large systems with many actors and interlinked relations between policy makers and different institutions. It puts an emphasis on the non-stopping link between the market stage and the inventing stage.

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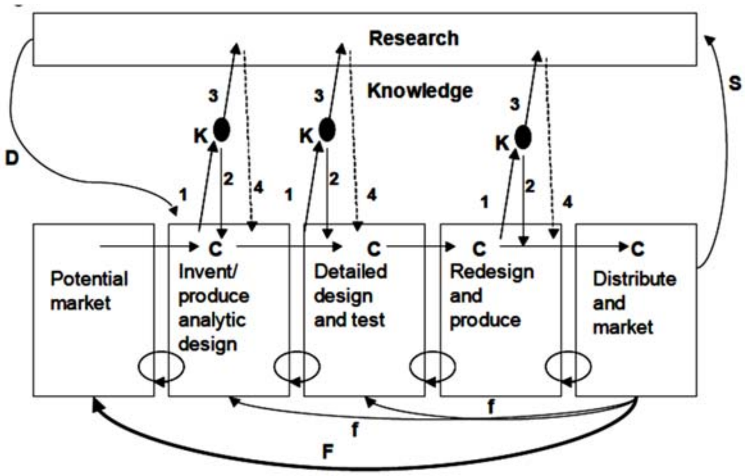
[99] GEA (2011). Global Energy Assessment. Knowledge Module 24: The Energy Technology Innovation System,.

[100] Godin, B. (2006). "The Linear Model of Innovation The Historical Construction of an Analytical Framework." Science, Technology, & Human Values.

[101] Swaminathan, A. L. S. (2007). Innovation Theories: Relevance and Implications for Developing Country Innovation, DIW Berlin.

Figure 3-3. Chain-linked Innovation Model



Source: (Swaminathan 2007)

3.1.3.3 *Technology or Innovation Adoption Life Cycle Approach*

Technology Adoption Life Cycle Theory is a model for explaining the adoption process and diffusion of innovation. Later M. Rogers (2003) developed the theory of the Innovation Adoption Life Cycle[102]. Figure 3-4 shows the concept of the Innovation Adoption Life Cycle. It consist of the three main stages of 1) emergence, 2) take off and 3) saturation of new technologies which lead to another emergence of innovations.The approach is useful for giving insights about innovation processes but innovations do not always have S-shaped characteristics as proposed in the theory.

3.1.3.4 *Innovation System or National Innovation System*

Freeman, Perez and Lundvall, (1988) developed the theory of the Innovation System by introducing the concept of networks between organizations and all actors influencing the shaping and diffusion of new technology[103]. The Innovation System approach is also called the National Innovation System (NIS) by the authors. The concept

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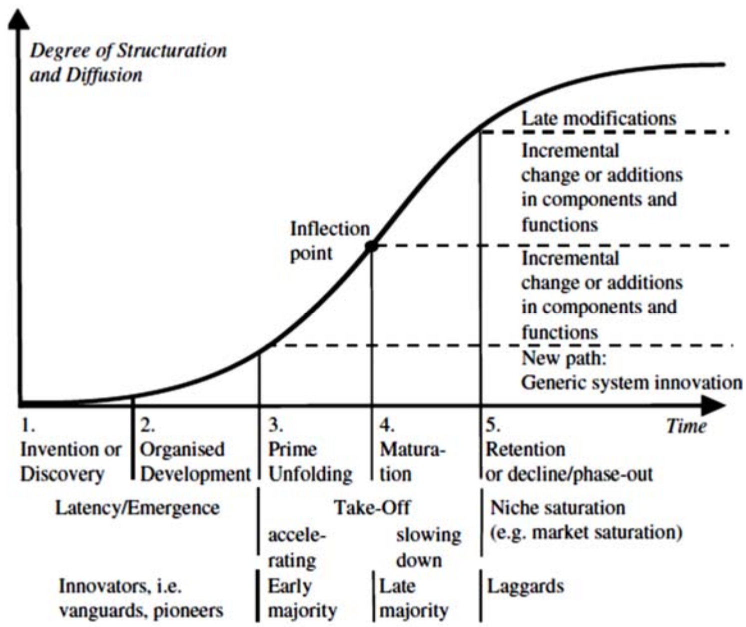
[102] Rogers, E. M. (2003). Diffusion of innovations Free Press.

[103] J. Stanley Metcalfe, l. M. (2000). INNOVATION SYSTEMS IN THE SERVICE CONOMY,MEASUREMENT AND CASE STUDY ANALYSIS, Springer Science+Business Media New York.

is very broad and many other researchers suggested various interpretations of innovation systems, depending on cases and type of the systems under study.

Figure 3-4. The Innovation Life Cycle.



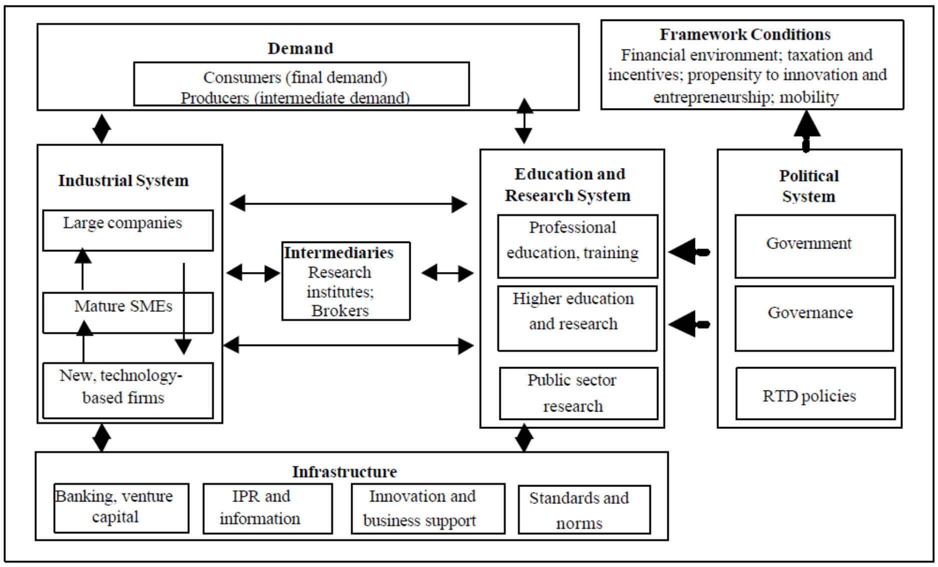
Source: (Huber 2008) p.4

The approach is mostly focusing on functions of the system rather than changes in the system. However, the lack of theoretical connection between current situations of the system and previous states is a major gap in this approach[104]. However, as Figure 3-5 depicts, analyzing innovation activities in the framework of the National Innovation System can be difficult because of the high number of actor groups and interconnections. The innovation system approach underscores that the innovation life cycle of a technology must be developed in parallel with its innovation system. All organizations, markets, users and policy makers in an institutional framework are shaping the innovation system. Freeman and Perez (1988) classified and defined innovations in four main groups: 1) Incremental innovations, which result from the learning process and from feedback. 2) Radical innovations, which occur as the result of R&D activities and have little economic effect unless they can form a network for a new product. 3) Changes of the technology system, which are results of innovation in the economy and technology,

[104] Elzen, B., et al. (2004). System Innovation and the Transition to Sustainability: Theory, Evidence and Policy, Edward Elgar Publishing Limited.

accompanied by organizational and managerial innovations. 4) Changes in the techno-economic paradigm, which occur far away from engineering innovations or process improvement and necessitate changes in social and economic systems.

Figure 3-5. Model of the National Innovation System presented in Arnold & Kuhlman (2001)



Source: (Arnold 2001) p. 9

The idea of technological or market niches (as a protective environment for innovations against existing regimes), underlines the importance of designing policies for nurturing niches. Strategic niche management emphasizes the role of policy makers in fostering the diffusion of new technologies by providing incubation rooms for niches[105]. Combining the idea of strategic niche management with strategic planning led to the idea of “local niche planning”. Quitzau et al. (2012) used this concept to study local actors in society in fostering the transition of the energy system. They focused on the role of local actors in the process of planning. They believe strategic niche management changes the passive planning of policy making to active planning[106]. A “core assumption of the Strategic niche management approach is that sustainable innovation journeys can be

[105] Quitzau, M.-B., et al. (2012). "Local niche planning and its strategic implications for implementation of energy-efficient technology." Technological Forecasting and Social Change **79**(6): 1049-1058.

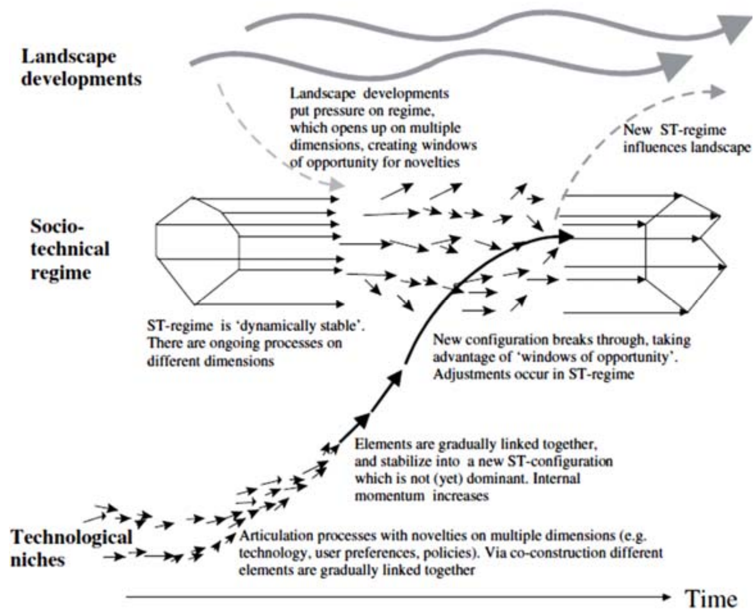
[106] Ibid.

facilitated by modulating of technological niches, i.e. protected spaces that allow nurturing and experimentation with the co-evolution of technology, user practices, and regulatory structures."[107]

3.1.3.5 *Multi-Level Perspective (MLP)*

Geels (2001) claims that MLP as summarized in Figure 3-6, contains all of the approaches in itself.

Figure 3-6. MLP approach of Geels in summary



Source: (Geels 2002)

It tries to sum up theories such as Point-source approaches, the Technology Life Cycle approach, economic path-dependency theories, science and technology studies: Social Construction of Technology (SCOT), Actor Network Theory (ANT) and Large Technical Systems (LTS), Replacement Approaches, Technological and Economic Substitution Approaches, the Punctuated Equilibrium and Technology Cycles approach, Evolutionary economics, Long-wave Theory, Transformation Approaches, Socio-

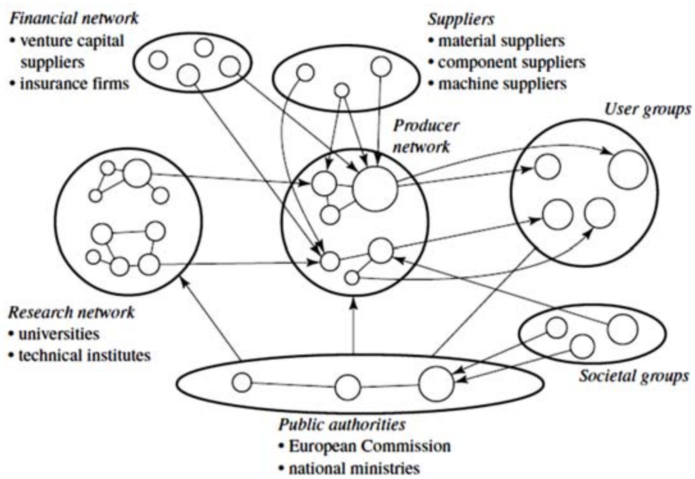
[107] Geels, J. S. a. F. (2008). "Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy." Technology Analysis & Strategic Management.

technical theories together.[108] The MLP is mainly being used to study socio-technical changes over time and emphasizes the historical dimension of the process. Generally, it is not useful for making predictions and the future development of system transitions. However, MLP can successfully be applied to analyze current policies designed to foster transitions[109]. This approach provides the analyst with a holistic picture of the changes of the system under study, from the past until now. By considering influences of macro level factors on the pre-established regime structure and trying to explain external factors at the macro level in combination with innovations at the niche level, changes in the system to the new state can be explained.

3.1.3.6 *Technological Innovation System (TIS)*

Technological Innovation System (TIS) is focusing on the innovation system of a special emerging technology rather than the whole innovation system. The approach emphasizes actors and institutions engaged with the development of technology. The term Technological Innovation System is an attempt to combine the concepts of the technological system and the innovation system. See Figure 3-7 as depicts the scope of multi actor engagement in the technological innovation system.

Figure 3-7. The multi-actor network involved in Technological Innovation Systems



Source: (Geels 2002)

[108] Geels, F. W. (2002). "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study." Research Policy **31**(8–9): 1257-1274.

[109] Kern, F. (2012). "Using the multi-level perspective on socio-technical transitions to assess innovation policy." Technological Forecasting and Social Change **79**(2): 298-310.

In accord with research done by Anna Johnson (2001), the concept of technological systems was used by many authors, at first by Hughes (1983, 1990) as he emphasized how a system tries to solve its problems by introducing innovations while it also needs support from different actors and institutions. Technological innovation systems have three main elements, namely 1) actors, 2) networks and 3) formal and informal institutions[110].

3.1.3.7 *Technological Innovation System Functions*

Notwithstanding the popularity and pervasive implementation of the Innovation System approach, analyses based on this approach are relatively diverse in methodology as well as results and are highly case dependent. Consequently, it is difficult to make a comparative analysis between different innovation systems. To fill these gaps, defining criteria and standard concepts for assessing the performance of the innovation systems rather than insisting on factors affecting the performance can be very useful[111]. Explaining the innovation system by its function provides a helpful insight for defining the borders of the system and can be helpful in defining indicators for analyzing and explaining the current state of the system[112]. From the early development of innovation system theories on, many authors pointed to functions of the innovation system. For example, B.A. Lundvall (1992) insisted on learning as a basic function of every innovation system. Other authors emphasized the role of the institutional framework in reducing transaction costs and incentives for companies. Figure 3-8 shows how different functions interact with each other. It is evident that entrepreneurial activities have many interactions with other functions. One of the main differences between the approaches are the research cost and resources required for implementing a comprehensive research with in-depth analysis.

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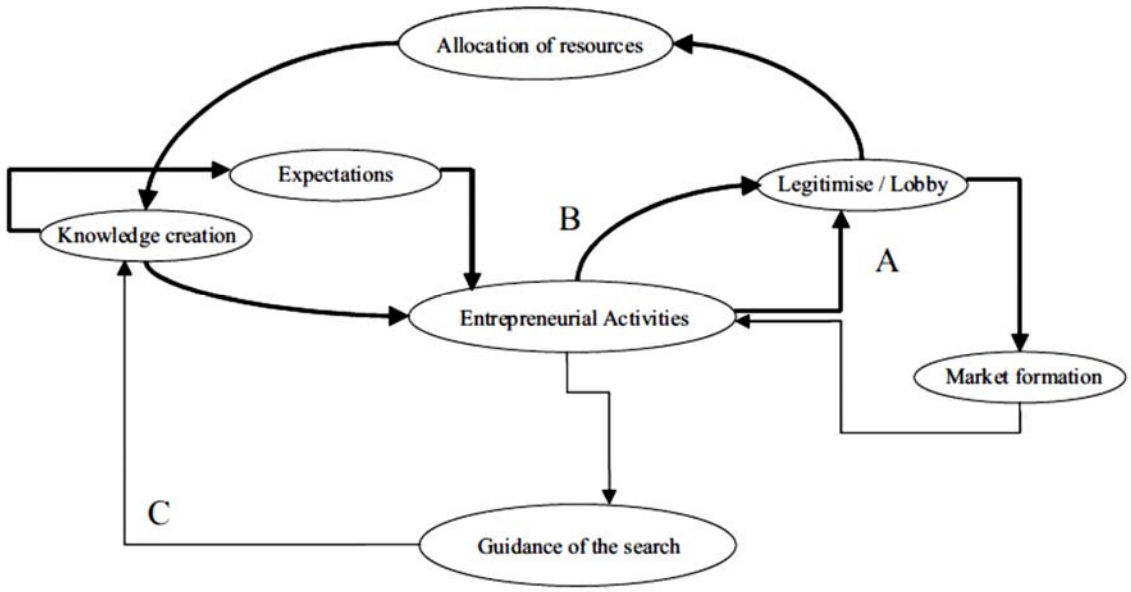
[110] Philip Greenacre, R. G., Jamie Speirs (2012). Innovation Theory: A review of the literature. Imperial College Centre for Energy Policy and Technology.

[111] Anna Bergek, M. H. a. S. J. (2008). Functions in innovation systems: A framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers.

[112] Johnson, A. (2001). Functions in Innovation System Approaches. The DRUID 2001 Nelson and Winter Conference.

Figure 3-8. Interrelation of the innovation system's functions in TIS



Source: (Hekkert, Suurs et al. 2007) p.426.

3.1.3.8 *Other theories related to analyzing innovation activities*

There is a long list of theories that are related to innovation activities and scholars have employed them in order to explain such activities. These theories can be divided into two main categories,

Economic approaches:

- Institutional economics approaches: emphasizing the necessity of institutions for reducing transaction costs and "the importance of internalizing externalities"[113] p.6.
- Industrial economics approaches: changes in contrast with neo-classical economic theory

[113] Swaminathan, A. L. S. (2007). Innovation Theories: Relevance and Implications for Developing Country Innovation, DIW Berlin.

- Replacement approaches: emphasizing competition between technologies based on costs and replacement of more economically efficient products[114] p.22.
- Economic path-dependency theories: according to reinforcement mechanisms of new technologies based on existing institutional paths[115]. (David, 1985; Arthur, 1988).
- Technological and economic substitution approaches

Science and technology studies:[116] p. 22.

- Social Construction of Technology SCOT[117] (Pinch and Bijker, 1987; Kline and Pinch, 1996)
- Large Technical Systems (LTS)
- Actor Network Theory (ANT)

Moreover, many other innovation systems have been developed by authors in order to put the focus of the analysis on specific issues and enabling them to define the borders of the system and its related components in detail. Energy Technological Innovation System (ETIS) and Eco- Innovation System (EIS) are examples of other terms for defining innovation systems. Today it is recommended that the study of innovation systems be as specific as possible, in order to increase the depth of study of specific levels of the innovation system: national systems of innovation, regional systems of innovation or sectorial innovation systems[118].

3.1.4 Defining the borders of research and the analytical framework

As mentioned before, in order to overcome the complexity of innovation system analysis, the concept of innovation system functions was proposed. Still, conducting an in-depth analysis requires focusing on each function of the system individually. Thus, systematic analysis is very costly and requires a multidisciplinary approach as well as the engagement of researchers with expertise in different areas. In the case of energy system

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[114] Elzen, B., et al. (2004). System Innovation and the Transition to Sustainability: Theory, Evidence and Policy, Edward Elgar Publishing Limited.

[115]

[116] Elzen, B., et al. (2004). System Innovation and the Transition to Sustainability: Theory, Evidence and Policy, Edward Elgar Publishing Limited.

[117]

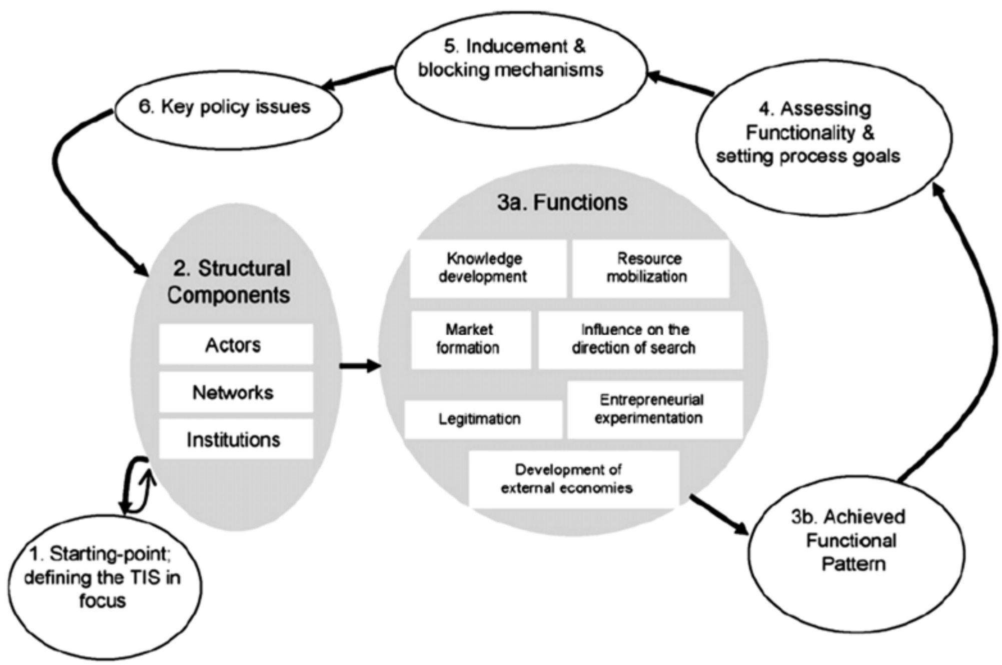
[118] Elzen, B., et al. (2004). System Innovation and the Transition to Sustainability: Theory, Evidence and Policy, Edward Elgar Publishing Limited.

transition and specially micro-CHP, several studies have been conducted until today. However, based on previous research, we conclude that conducting a comprehensive innovation system analysis and emphasizing functions or the historical analysis of technology and using narrative approaches - which is typical in many approaches such as the multi-level perspective analysis - can be useful.

3.1.4.1 *Systematic approach toward technological innovations*

Bergek et al., 2008, formulated the analytical framework based on functions of innovation as a core analysis tool. Figure 3-9 depicts their analytical framework and shows how they suggested the use of TIS functions in a close loop research. As the starting point of analysis, researchers must make a decision about 3 issues: 1) Whether they are going to focus on technology or the knowledge field, 2) the level of aggregation and how much they want to dig to the problem and 3) domains of applications[119].

Figure 3-9. Analytical framework for analyzing TIS



Source: (Anna Bergek 2008) p.411.

[119] Anna Bergek, M. H. a. S. J. (2008). Functions in innovation systems: A framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers.

In the above steps, they propose an analysis of system structures and find the actors, institutions and networks. By looking for innovation system functions, researchers can find out what fosters or hinders them. In this way, the bottlenecks and main blocking policies can be distinguished. At the next step, solutions and suggestions for depressing blocking mechanisms can be proposed to the system of actors and institutions. This loop can be started again.

3.1.4.2 *Is TIS a system of subsystems or System of Systems (SoS)?*

The term system can be defined as a mixture of interacting elements forming a whole, whose behavior and outputs are different from the sum of its elements[120]. "These elements may include people, cultures, organizations, policies, services, techniques, technologies, information/data, facilities, products, procedures, processes, and other human-made or natural entities. The whole is sufficiently cohesive to have an identity distinct from its environment."[121] P.13. If the components of the system are very diverse and interconnected in a complicated manner, the analysis of the system becomes very difficult or even impossible. If we are able to classify (or categorize) components with some common characteristics in groups and analyze the aggregated output of each group, it makes the analysis more effective. In this taxonomy, if the groups of components have the characteristics of a system we have a System of Systems. Therefore, Systems of Systems can be defined as integrated systems, which are heterogeneous and can operate independently. Each system is managed primarily to accomplish its own separate purpose, and there is a network between them for accomplishing a common goal[122]. In fact, since the beginning of the theoretical development of innovation systems, authors have been naturally using the concept of System of Systems. However, emphasizing this concept as an analytical framework for analyzing innovation systems is a new approach. The SoS research area constitutes a relatively new multi-disciplinary approach. SoS can

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[120] White, B. E. (2006.). Fostering intra-organizational communication of enterprise systems engineering practices. 9th Annual Systems Engineering Conference. San Diego CA, National Defense Industrial Association.

[121] Ibid.

[122] Ibid.

generally be defined as large complex socio-technical systems[123]. By looking back at the existing research and approaches for explaining innovation systems, we can now map the innovation system as a SoS. Obviously, the definition of SoS can be applied to the Technological Innovation System as well. Until now, the only direct attempt for defining innovation systems as SoS stems from the work of Mostafavi et al (2011)[124]. As explained before, the concept of SoS is closely related to the theory of evolutionary economics which emphasizes the variation and selection process of innovation that makes the system continuously more complex. The emerging behavior, network-centric, independency characteristics in System of Systems are results of the continuous emergence of innovations and selection of innovations as Beverly Gay McCarter and Brian E. White (2009) suggested. The institutional economic approach insists on the necessity of a fair institutional framework for supporting innovations. We can distinguish the institutional system as one of the SoS systems. Therefore, drawing on the National Innovation System (NIS) approach, we define a selected and limited number of systems and assign them developed concepts of functions. In fact, each defined system may have several functions. The Innovation System Functions approach and analytical framework proposed by Bergek, Jacobsson et al. (2008) is very useful but has some shortcomings. Analyzing it leads to the conclusion that the analytical framework views the innovation system mostly as a monolith[125].

3.1.5 Entrepreneurial system

The Knowledge Spillover Theory of Entrepreneurship insists on the required linkage between produced knowledge in universities and private firms for the commercialization of ideas. As a result, entrepreneurship (with the function of knowledge spillover) is presented as a missing link in the process of economic growth, in the absence

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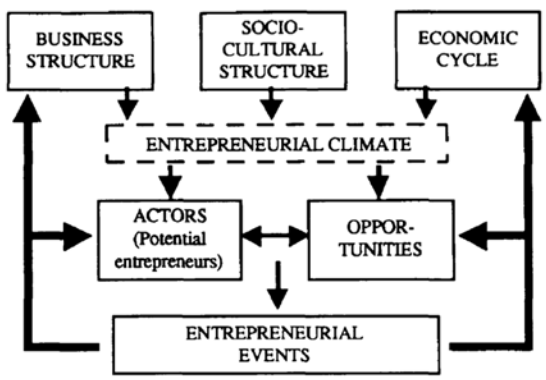
[123] Jamshidi, M. (2009). SYSTEMS OF SYSTEMS ENGINEERING Principles and Applications, Taylor & Francis Group.

[124] Mostafavi, A., et al. (2011). "Exploring the Dimensions of Systems of Innovation Analysis: A System of Systems Framework." Systems Journal, IEEE **5**(2): 256-265.

[125] Ibid.

of which new ideas might not be commercialized[126]. Most theories of innovation consider the starting point to be entrepreneurship and the firm. In such theories, usually firms are considered as exogenous, while knowledge spillover and economic knowledge production are endogenous[127]. The literature also shows that there is a tendency to analyze entrepreneurship mostly in regard to a single person rather than taking into account the system of entrepreneurs. Most authors ignored the fact that only multiple individual entrepreneurial actions and their contribution to the dynamic process of the economy will lead to changes[128]. Birley (1985) and Johannisson (1988) introduced the importance of networks in the success of entrepreneurial activities, which was an evidence of system characteristic of entrepreneurial activities. One of the first attempts for introducing the entrepreneurial system was made by Spilling (1996), who discussed the complexity and diversity of actors and environmental factors that interact in an entrepreneurial system to shape the entrepreneurial performance of a region or a specific area[129]. Figure 3-10 shows the model of the entrepreneurial system developed by Spilling.

Figure 3-10. "Model for interaction between environmental factors and entrepreneurial events."



Source: (Spilling 1996) p.93

[126] Audretsch, D. B. (2005). THE KNOWLEDGE SPILLOVER THEORY OF ENTREPRENEURSHIP AND ECONOMIC GROWTH. The Emergence of Entrepreneurial Economics

G. T. Vinig and R. C. W. van der Voort, Elsevier JAI.

[127] David B. Audretsch, O. F., Stephan Heblich and Adam Lederer (2011). Handbook of Research on Innovation and Entrepreneurship, Edward Elgar Publishing Limited.

[128] Spilling, O. R. (1996). "The entrepreneurial system: On entrepreneurship in the context of a mega-event." Journal of Business Research **36**(1): 91-103.

[129] Ibid.

In the conceptual model of the entrepreneurship system, environmental factors affecting the entrepreneurial system are suggested based on the work of Bruno and Tyebjee (1982) as follows:

- "Availability of Venture capital
- Presence of experienced entrepreneurs
- Accessibility of Technically skilled labor force
- Accessibility of suppliers
- Reachability of customers or new markets
- Favorable governmental policies
- Proximity of universities
- Availability of land or facilities
- Accessibility of supporting services
- Attractive living conditions."[130] p.94.

Technological innovation systems interact with various surrounding systems. From studying theories in this regard, it can be concluded that despite the analysis of many systems, innovation systems can be considered as a single system with several functions or a system of subsystems. The absence of a clear system analysis framework makes the definition of system borders and components more difficult. Despite of the functional definition, due to the absence of clearer research structure, the problem of comparison between different TIS remains. Then a more structured framework is required for conducting analysis. Another problem is that many analyses of several system functions are based on historical data and statistics. For an in-depth analysis, it would be better if researchers focused on entrepreneurship decision-making models and the effect of other factors on the expected functioning of the system. Then we argued that the entrepreneurial system is not a subsystem but rather an independent system, which interacts with its surrounding environment. In order to analyze the effects of surrounding phenomena on the entrepreneurial system, we need a better theoretical framework. In the next chapter, we discuss and choose our theoretical framework for analysis. Furthermore, we try to formulate the relevant factors based on a policy analysis framework required for this research.

[130] Ibid.

3.2 Theoretical framework for analyzing the entrepreneurial activities in the Technological Innovation System of Micro-CHP

In the previous section, we concluded the importance of entrepreneurial activities and we discussed how entrepreneurship contributes introduction of technological innovations into the economy and is essential for economic growth. In this section, we choose an adequate theoretical framework and define the borders and levels of our analysis more precisely. The theoretical framework of the research and research methodology are developed in this section. Different approaches to the analysis of innovation systems are reviewed. In this chapter, we answer the following question:

1- What are criteria for innovative entrepreneurial activities regarding the development of technological innovations in society?

Moreover, we formulate the connection between the theoretical framework and the energy system and especially the development of micro-CHP in Germany. To this end, we explain and discuss the socio-technical aspects of the energy system and the necessity of an integrated approach in the analysis of micro-CHP development in the energy system of Germany.

3.2.1 Definition of entrepreneur

Definitions of what an entrepreneur is can be divided into two main areas. Some authors define entrepreneurs as founders of small or medium-sized firms, which have the potential to grow. On the other hand, some authors focus mostly on the economic function of entrepreneurs rather than individuals[131]. For system analysis and policy design the second approach is more useful while the first is suitable for fundamental research in the fields of cognitive and decision making analysis. The OECD defines entrepreneurial activity, entrepreneurs, and entrepreneurship as follows:

"**Entrepreneurs** are those persons (business owners) who seek to generate value, through the creation or expansion of economic activity, by identifying and exploiting new products, processes or markets.

[131] Casson, M. (2010). Entrepreneurship: Theory, Networks, History, Edward Elgar.

Entrepreneurial activity is the enterprising human action in pursuit of the generation of value, through the creation or expansion of economic activity, by identifying and exploiting new products, processes or markets.

Entrepreneurship is the phenomenon associated with entrepreneurial activity."[132] p.9. The most accepted definition of entrepreneurs has been proposed by Wennekers and Thurik (1999), accordingly, entrepreneurs have three main characteristics: 1) they are innovative and are not only aware of new opportunities but also create them. 2) They act under uncertainty and make decisions on resource utilization to introduce new products to the market. 3) They are running their own business and are constantly competing to gain a bigger share in the market[133].

3.2.2 Theoretical analysis: Economic Theory of Entrepreneurship

One of the recent theories for describing entrepreneurial activities is the Economic Theory of Entrepreneurship, which was proposed by Mark Casson (2010). The theory is based on the economic functions of entrepreneurs by focusing on the interaction between these functions and other parts of the economic system[134]. It is assumed that the judgment about by entrepreneurs is not equal with decision-making process. When the situation is volatile and uncertain, entrepreneurs make judgments under several affecting factors of economics system. The theory analyzes the demand-supply mechanism of entrepreneurs. If the rules of decision-making are clear for everyone, there is no need for entrepreneurs. The assumption is that there is neither a decision-making model for entrepreneurship nor for any other activity of mankind but it is possible to discern which factors and environmental situations and conditions affect decisions and whether their effects are negative or positive. Figure 3-11 shows the concept of entrepreneur's demand that is used in the theory. The demand for entrepreneurs will not necessarily lead to qualified judgments. It is also required that the system provide suitable conditions for increasing the supply of high quality entrepreneurial judgments by both raising their numbers and their quality.

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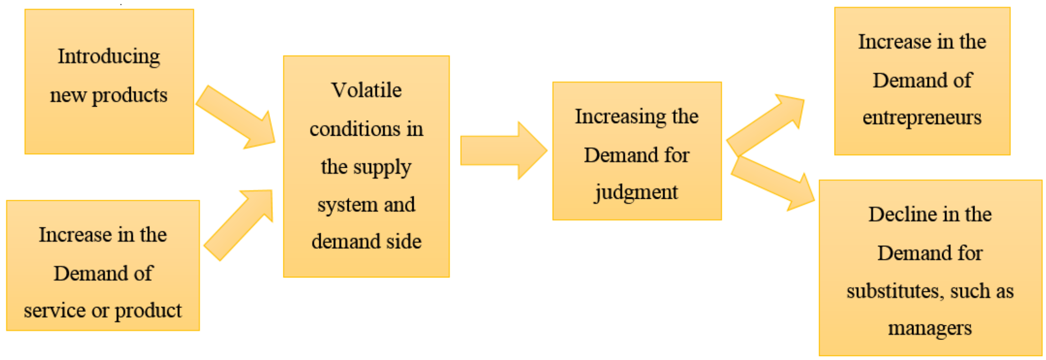
[132] OECD , A., N. R. G. Seymour Defining Entrepreneurial Activity, OECD Publishing.

[133] David B. Audretsch, O. F., Stephan Heblich and Adam Lederer (2011). Handbook of Research on Innovation and Entrepreneurship, Edward Elgar Publishing Limited.

[134] Casson, M. (2010). Entrepreneurship: Theory, Networks, History, Edward Elgar.

Figure 3-11. Increasing the demand for entrepreneurs and decline of managers demand



Source: author, (based on the Economic Theory of Entrepreneurship))

In social science, there are many theories for analyzing the process of decision-making, but because the cognition of different people is not equal, anticipating the decisions of people is very difficult, even impossible. Similarly, entrepreneurs interpret the same information in different ways, which cannot be predicted[135]. This requires a theory, which explains the influencing factors on entrepreneurial judgments, and interpret how it is possible to raise the supply of entrepreneurs. Based on the Economic Theory of Entrepreneurship, raising the supply of entrepreneurs can be implemented in two ways:

- If the quality of judgment is poor: Improvement of the quality of judgment of all individuals in society
- If people are scared to take risks: Increasing the confidence of people to make judgments

The theory argues that encouraging people to judge when their decision quality is poor wastes resources and is not a good idea. Instead, by looking at entrepreneurs as human capital, it would be better to invest in increasing their judgment quality and information processing abilities. As the supply of entrepreneurs can be raised through environmental factors affecting their decision making, in the policy analysis paradigm, understanding such factors and studying them can be more practical than focusing on individual cognition and the decision making model, which is common in other science paradigms. Based on the Economic Theory of Entrepreneurship and the concept of entrepreneurial systems, we are looking for environmental factors in the literature rather

[135] Ibid.

than personal characteristics such as hard work, high incomes, power and education. Authors recognized that several factors could affect entrepreneurial activities. Public policy designers can consider seven factors for increasing entrepreneurial activities: 1) Norms and culture, 2) regulations of entry, 3) taxes, 4) level of economic development, 5) sectors and the stage of firms' life cycle, 6) the institutional framework[136]. Mark Casson (2010) insists on factors for increasing the supply of more entrepreneurs to the economy with more qualified judgements. Economic Theory of Entrepreneurship lists 1) institutional framework, 2) demand for the new product, 3) cultural factors 4) networks and access to networks 5) social capital and trust, 6) entry regulation and financing constrains, 7) physical infrastructure and availability of resources. Many Authors consider the competitors to be negative factors, especially when they have the advantage of monopoly power. However, if the competition occurs in a liberal market, entrepreneurs do not care much about it as a hindering factor. Later, based on the analytical framework and research deign, we explore the analysis for each factor.

3.2.2.1 *Demand for new product and customers*

Besides the consumption patterns of consumers and many other exogenous factors, the demand for new innovative products, can be affected by government and by designing technological policies. Supporting policies not only on the demand side but also on the supply side can affect demand. In the following, a list of policies for the promotion of demand and supply is suggested[137]:

Supply-side policies

- Horizontal measures: "In their most straightforward form, horizontal policies are directed at all firms in the economy that might make investments in productivity-improving technological change."[138] p.1193

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[136] Braunerhjelm, P. (2011). Entrepreneurship, innovation and economic growth: interdependencies, irregularities and regularities. Handbook of Research on Innovation and Entrepreneurship. O. F. David B. Audretsch, Stephan Heblich and Adam Lederer, Edward Elgar Publishing Limited.

[137] Steinmuller, W. E. (2010). ECONOMICS OF TECHNOLOGY POLICY. HANDBOOK OF THE ECONOMICS OF INNOVATION. M. D. I. KENNETH J. ARROW, Elsevier. **2**.

[138] Ibid.

- Thematic funding: “Thematic funding is a general term for a wide range of programs that involve the predefinition of themes under which eligible candidates are invited to propose specific programs of research.”[139] p.119
- Signaling strategies: “programs that aim to make a large number of decision makers aware of emerging technological opportunities or the value of particular techniques for business application and to influence the technological expectations of private decision makers.”[140] p.1195
- Protectionist measures: “aimed at bolstering infant industries or providing an incentive for import substitution have generally been proscribed through international trade agreements.”[141] p.1197
- Financial measures: “aimed at improving the supply of risk, or venture capital or changes in capital markets that are likely to improve the valuation or make intangible (knowledge-related) assets more liquid.” [142]p.1198

“Policies for supply of complementary factors

- Labor supply
- Technology acquisition policy

Demand side designs

- Adoption subsidies
- Information diffusion policies: Policies to increase awareness and educate potential adopters about potential benefits”[143] p.1198-1202.

Analyzing the demand for products on entrepreneurship activities can be accomplished in two ways: first, by analyzing the profit model of entrepreneurs and predicting demand through economical and technical methods and secondly by analyzing the effects of policies on demand and collecting data from target groups or governments.

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[139] Ibid.

[140] Ibid.

[141] Ibid.

[142] Ibid.

[143] Ibid.

3.2.2.1.1 Culture

Conventional neoclassical models suggest that cultural characteristics in some societies can improve economic performance faster and more effective than in other cultures[144]. In this regard, culture is considered not only a public good but also an economic asset and can be defined as shared values and beliefs that can influence the performance of an economy in many ways. The Economic Theory of Entrepreneurship identifies "four major dimensions of culture which influence the performance of a group:

- Individualism versus collectivism,
- Pragmatism versus proceduralism,
- Degree of trust, and
- Level of tension."[145] p.201.

Tension is defined as the enthusiasm for the implementation of goals and the determination to succeed. It is important to keep in mind that culture is not just an instrument for increasing the quality of life by improving the economy and producing better materials but also a "direct source of emotional rewards"p.201. For example, Western culture is based on modern neoclassical economics, promotes competitive individualism and is accompanied by low levels of trust.[146] It requires the government to invest in training of moral leaders such as philosophers, religious leaders and artists[147]. The three components of culture are values, beliefs and forms of expression, culture are shared within a social group such as entrepreneurs. By focusing on those aspects of culture which are likely to influence economic performance, four main dimensions of culture can be derived. In Table 3-2, two example of economic systems with corresponding cultural dimensions are listed. The right side lists the optimum combination of dimensions suggested by theory.

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[144] Casson, M. (2010). Entrepreneurship: Theory, Networks, History, Edward Elgar.

[145] Ibid.

[146] Ibid.

[147] Ibid.

Table 3-1. Four dimensions of culture affecting economic performance

Typical Western competitive individualistic society	Idyllic and closed society	Optimal combination
Individualism	Collectivism	Voluntarism
Pragmatism	Proceduralism	Good judgment
Low- trust and High- tension	High- trust and Low- tension	Warranted trust Warranted self confidence

Source: author (based on (Casson 2010) p.216)

3.2.2.2 *Entry regulation and financing constraints*

Access to adequate amounts of capital is one of the biggest barriers in the way of starting new businesses[148]. Without proper policies for reducing financial constraints, policy makers cannot reach their goal of increasing entrepreneurial activities. Indicators such as the ratio of bank deposits to GDP or stock market capitalization to GDP can show the availability of financial resources for new firms. On the other hand, the regulations for taking out loans from banks and investors must not be very strict. For example, Black and Gilson (1998) argue that "the institutional environment in Germany, which is more bank oriented compared to the USA's market orientation, reduces the ability of German startups to achieve liquidity events via stock listings. Therefore, the Venture Capital community in Germany is less developed, and the flow of risk capital to good projects in Germany is weaker. "[149] P.90. In addition to external financial factors, the business model developed by entrepreneurs plays an important role in the availability of capital. In highly innovative businesses, in which new technologies dominant of the entire business model, convincing the intermediaries in the banking system or other investors, which are not familiar with the technology, is important. The judgement of investors for investing in new technologies is highly influenced by the profit-earning plan described in the business model.

[148] William R. Kerr , R. N. (2011). Financing constraints and entrepreneurship. Handbook of Research on Innovation and Entrepreneurship. O. F. David B. Audretsch, Stephan Heblich and Adam Lederer, Edward Elgar Publishing Limited.

[149] Ibid.

3.2.3 Innovation model of entrepreneurs

The goal of entrepreneurial activities, which policy makers or analyzers expect to observe, is creating more value for the economy and society. Innovation is the central core of this value creation process. Besides, although many theories and approaches describe the influential factors on good decision making by entrepreneurs, there is a shortage in the methodological application of these theories. We need a tool for the implementation of these theories, which clearly focuses on entrepreneurs' innovations. The tool must consider all factors we discussed previously. It should consider: 1) value creation as the aim of entrepreneurial activity, 2) the innovation characteristics of activities, 3) external factors, 4) policies, 5) actors and users. The business model framework fits very well with this theoretical framework. It focuses on value streams and can capture innovative components that evolved in response to new opportunities[150]. Many authors refer to business models as a part of the innovation process and change[151]. Many researchers suggest that business model accurately describes how a business creates value[152].

[150] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

[151] Loock, M. (2011). HOW DO BUSINESS MODELS IMPACT FINANCIAL PERFORMANCE OF RENEWABLE ENERGY FIRMS? The Handbook of Research on Energy Entrepreneurship

R. Wüstenhagen and R. Wuebker, Edward Elgar Publishing Limited.

[152] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

4 Analyzing the general factors and institutional setting on development of entrepreneurial activities of micro CHP in Germany

According to the economic theory of entrepreneurship and culture, the cultural dimension plays a very important role in increasing the supply of more qualified entrepreneurial activities. In this chapter, we discuss the social culture and general infrastructure of Germany and their influence on specific cases of entrepreneurial activities of micro-CHP. The economic theory of entrepreneurship and culture gives us criteria for analyzing the general influencing factors on the entrepreneurial system of micro CHP. The theory proposes a framework for analyzing general factors leading to more qualified judgments, which is a prerequisite for good entrepreneurial activities. In this chapter, we discusses the institutional framework as one of the main general influential factors on the entrepreneurial system of micro-CHP.

For analyzing the institutional setting, it is necessary to look at actors, regulations and technological change from an integrated socio-technical point of view the importance of which we explained in the theoretical chapter. In light of the fact that all the institutional settings related to the entrepreneurial system of micro CHP in Germany are shaped by many external factors at the macro and micro levels, we try to analyze the institutional setting from a multi-level perspective (the theoretical framework of which is explained in the previous chapters). In this research, we define the institutions as formal social and informal rules that control all actions by inserting incentives and penalties, suggesting orientations or prescribing or prohibiting specific behaviors of actors[153]. In the case of micro-CHP, these institutions are electricity market regulations, actors, and the culture of consumption and business in Germany. We divide the institutions into two different parts, the formal and informal institutions. The informal institutions consist of dominant culture in the society and personal values. In the case of technological changes, the interaction between these two institutional settings plays a very important role. Because, if the formal institutional settings such as regulations do not match the informal institutions, the technological changes cannot be sustainable. If the government and other

[153] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

formal institutions on the other hand constantly adjust themselves to society, it promises a better and faster development. A good example of such an adjustment is the German government's decision for phasing out nuclear power because of society's will.

4.1 Culture

As explained previously, from the typological analysis of culture proposed by Casson (in his economic theory of culture), it can be concluded that the most efficient culture from an economic point of view, has individualistic, high trust, high tension and pragmatic characteristics. In the case of entrepreneurial activities, more pragmatism with regards to collective behaviors and high levels of trust facilitate an effective environment for working on ambitious projects with high levels of innovation[154]. The level of tension undermines the level of trust but tension is very essential for entrepreneurs. The culture of Low trust for cooperation can be deducted as lack of leadership. Low level of trust create anti-social behavior and a culture of cheating. As a result, the transaction cost will rise which leads to a low quality of materials and production, which in turn undermines the economy[155]. In order to analyze the situation in Germany, we focus on four major dimensions of culture as explained previously, which influence the economic performance of the society[156]:

- Individualism or collectivism,
- Pragmatism or proceduralism,
- The degree of trust, and
- The level of enthusiasm and determination for reaching the goals.

We use official resources and published data for categorizing countries in these cultural characteristics as well as scientific literature, which points to these characteristics. The level of tension reduces the level of trust but is very essential for

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[154] Casson, M. (2010). Entrepreneurship: Theory, Networks, History, Edward Elgar.

[155] Ibid.

[156] Ibid.

entrepreneurs. Cultures with Low level of trust in cooperation may be resulted from lack of leadership. It is necessary that government set policies for training leadership from early education system. Low level of trust creates anti-social behavior and culture of cheating as a result the transaction cost will raise which can led to low quality of materials and production, which undermine economy.[157] Table 4-1 summarizes the differences in the values, beliefs, and forms of expression between various cultural dimensions.

Table 4-1: differences in the values, beliefs, and forms of expression between various cultural dimensions

	values	beliefs	forms of expression
High trust	honesty, hardworking, loyalty, trust	others are honest, work hard, loyal,	generally keep their promises even when they have little material incentive to do so
Low trust		Others are guided by material incentives;	Often lie, cheat or shirk.
High tensio n	high aiming,		attracted to ambitious projects; ashamed of failure
low tension	is relaxed	Blame any failure on factors outside their control.	prefer easy projects; behave in a spontaneous manner

Source: Author. (extracted from)(Casson 2010) p.217)

4.1.1 Individualism or collectivism

Richter (2013) identified threats and opportunities of distributed PV generation for utilities by conducting several interviews. He analyzed the attitude of German people toward renewable energy and he concluded that besides the supports of the German public for the energy transition, most people express that they do not like to have renewable energy plants close to their living place[158]. The attitude of people about having their own privacy shows a relatively individualistic culture with low levels of collectivism. One of the popular indicators for measuring individualism or collectivism are the "Geert Hofstede cultural dimensions" indexes. Table A-3 in appendix 1, classified the

[157] Ibid.

[158] Richter, M. (2013). "German utilities and distributed PV: How to overcome barriers to business model innovation." Renewable Energy **55**(0): 456-466.

combination of different cultural dimension and shows how each combination can shape a socio-economic system[159].

Table 4 1: Continued

	values	beliefs	forms of expression
Individualism	personal ‘lifestyle	People are autonomous. Information is distributed. Shocks are individual-specific.	Individuals Ownership and control of resources. Only individuals have the information required to take decisions that affect themselves.
collectivism	Uniformity. everyone is the same,	We are all part of the community. Dependent on others for our survival. Shocks have collective impacts.	Group ownership and control of resources. Centralized Information in coordination.
Pragmatism	Intuitive judgments. personal experience	The best decisions are made promptly. Single individual Is ultimately responsible for each decision.	Testing Hunches through informal conversation with other people.
Proceduralists	use of committees,	formal procedures generates good decisions	By theory and which involve the systematic Collection of objective information. ‘get it right’ than to do it too quickly

Source: Author. (extracted from (Casson 2010) p.217)

Hofstede defined this dimension as follows:

“The high side of this dimension, called individualism, can be defined as a preference for a loosely-knit social framework in which individuals are expected to take care of only themselves and their immediate families. Its opposite, collectivism, represents a preference for a tightly-knit framework in society in which individuals can expect their relatives or members of a particular in-group to look after them in exchange for unquestioning loyalty.”[160] This indicator gives each country a score between 1 as the

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[159] Casson, M. (2010). Entrepreneurship: Theory, Networks, History, Edward Elgar.

[160] hofstede, g. (2015). "Long Term Orientation versus Short Term Normative Orientation (LTO)." from http://geert-hofstede.com/dimensions.html.

lowest and 100 as the highest degree of individualism. Based on this index, Germany is ranked 15th with a score of 68, which can be considered as individualistic[161]. (The first country is the USA with a score of 91). Figure 4-1 indicates the Hofstede Individualism Index of different countries. The high level of individualism in Germany explains why people in Germany emphasize personal achievements and rights. Besides the importance of group working, Germans are keen on the idea of liberalism and respecting the rights of everyone to have his/her opinions[162].

4.1.2 Pragmatism or proceduralism

The pragmatism dimension can tell us to which degree society must maintain some procedures from its own past when dealing with present and future challenges[163]. Procedural societies prefer to keep traditions and norms while viewing societal change. Figure 4-2 depicts the list of countries based on the Hofstede Pragmatism Index. In the “Hofstede” country index, the score of Germany is 83, which classifies it as a highly pragmatic country. In such a society (in contrast to ideological societies), people mostly believe that the truth is not the same in different situations[164] and that it depends not only on the situational context but also on the observer. However, such a culture can be highly trustful. People’s judgments about the truth stem from maturity and knowledge rather than selfishness. They are able to adapt traditions to new conditions; also, these societies show a strong attitude toward saving and investing and stamina in achieving results[165].

[161] Cultural, C. (2014). "Individualism." from http://www.clearlycultural.com/geert-hofstede-cultural-dimensions/individualism/.

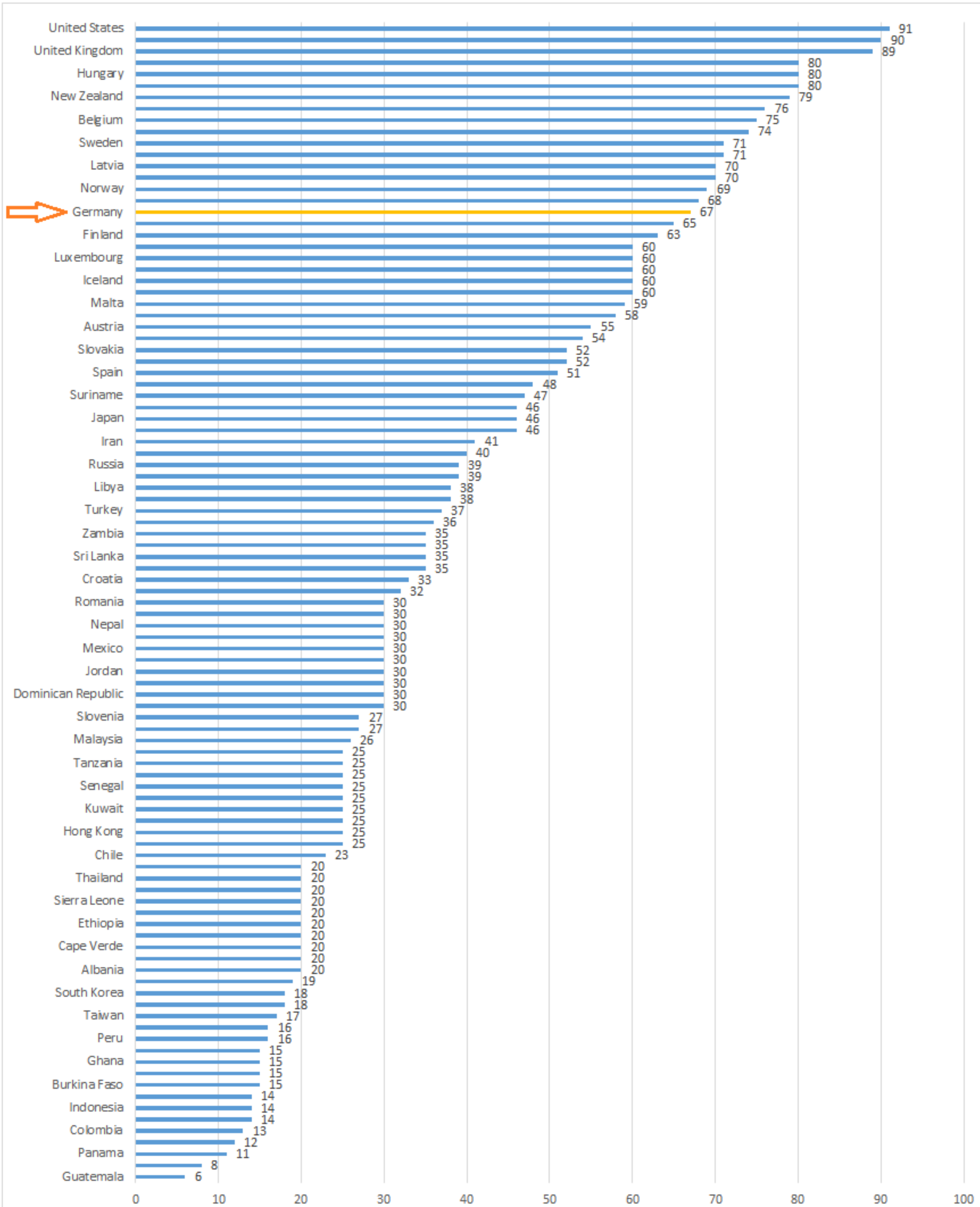
[162] Ibid.

[163] hofstede, g. (2015). "Long Term Orientation versus Short Term Normative Orientation (LTO)." from http://geert-hofstede.com/dimensions.html.

[164] hofstede, g. (2014). "Country Comparison: Germany." from http://geert-hofstede.com/germany.html.

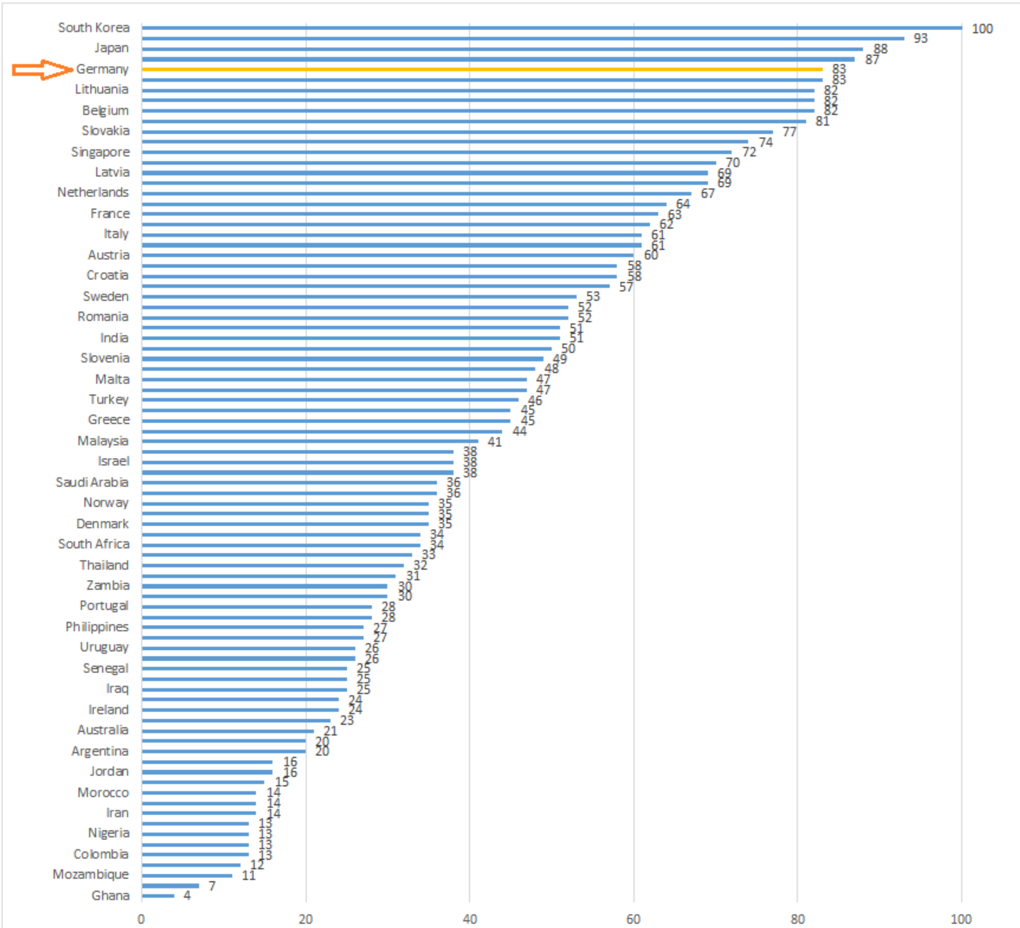
[165] Casson, M. (2010). Entrepreneurship: Theory, Networks, History, Edward Elgar.

Figure 4-1. Hofstede Individualism Index of countries



Source: generated by the author, data gathered and adopted from Hofstede website (hofstede 2015)

Figure 4-2. Hofstede Pragmatism Index of Countries (generated by the author, data gathered and adopted from Hofstede website)



Source: generated by the author, data gathered and adopted from Hofstede website (hofstede 2015)

4.1.3 The level of enthusiasm and determination for reaching goals

Richter (2013) shows in his research that the Germans are relatively Uncertainty avoidance and do not like to enter into long-term contracts with their energy supplier[166]. Another study conducted in 1990 about fifty successful German entrepreneurs indicated they display constant efforts to assess and solve their problems[167]. For measuring this

[166] Richter, M. (2013). "Business model innovation for sustainable energy: German utilities and renewable energy." Energy Policy **62**(0): 1226-1237.

[167] Faltin, G. (2001). "CREATING A CULTURE OF INNOVATIVE ENTREPRENEURSHIP." INTERNATIONAL BUSINESS AND ECONOMY **2**.

factor in Germany, we use different source of cultural analysis. Hodgetts et al (2005) analyzed motivation and enthusiasm across cultures by applying the “Achievement motivation theory” on the Hofstede cultural index[168]. He concluded that uncertainty avoidance and masculinity are well describing high-motivated societies (see Figure 4-3). Hofstede defines masculinity and uncertainty avoidance as follows:

Masculine societies are working with competition and achievement; on the other hand, feminine societies define success as taking care of others and trying to improve the quality of life[169]. On the other hand, the dimension of Uncertainty Avoidance is about how a “society deals with the fact that the future can never be known: should we try to control the future or just let it happen? “[170]. Hodgetts concluded that people in countries with high uncertainty avoidance scores (like Germany) are more conservative and less motivated for changes. But these cultural traits causes the Germans to “prefer to compensate their uncertainty by strongly relying on expertise.”[171]. Moreover, Hofstede rejects the direct effect of uncertainty avoidance on motivation. He argues: “Societal Uncertainty Avoidance values, as found in Germany, Denmark, and China, were positively associated with Team-Oriented, Humane-Oriented, and Self-Protective leader attributes“[172]. Regarding the economic theory of entrepreneurship, Casson (2010) uses the Hofstede index of Masculinity as a direct indicator for the level of enthusiasm and determination, which exists for reaching the goals in the culture. We use the argument of Hodgetts (2014) about the cultural aspect of motivation in the society as a function of uncertainty avoidance and masculinity to produce an index for motivation in societies and modify it by also considering the three additional factors of pragmatism, indulgence and power distance. According to Hodgetts’ argument, whenever uncertainty avoidance in a society is lower and masculinity is higher, motivation is higher. Nevertheless, there are

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[168] Hodgetts, R. M., et al. (2005). International Management: Culture, Strategy and Behavior W/ OLC Card MP, McGraw-Hill Companies,Incorporated.

[169] Hofstede, G., et al. (2010). Cultures and Organizations: Software of the Mind, Third Edition, McGraw-Hill Education.

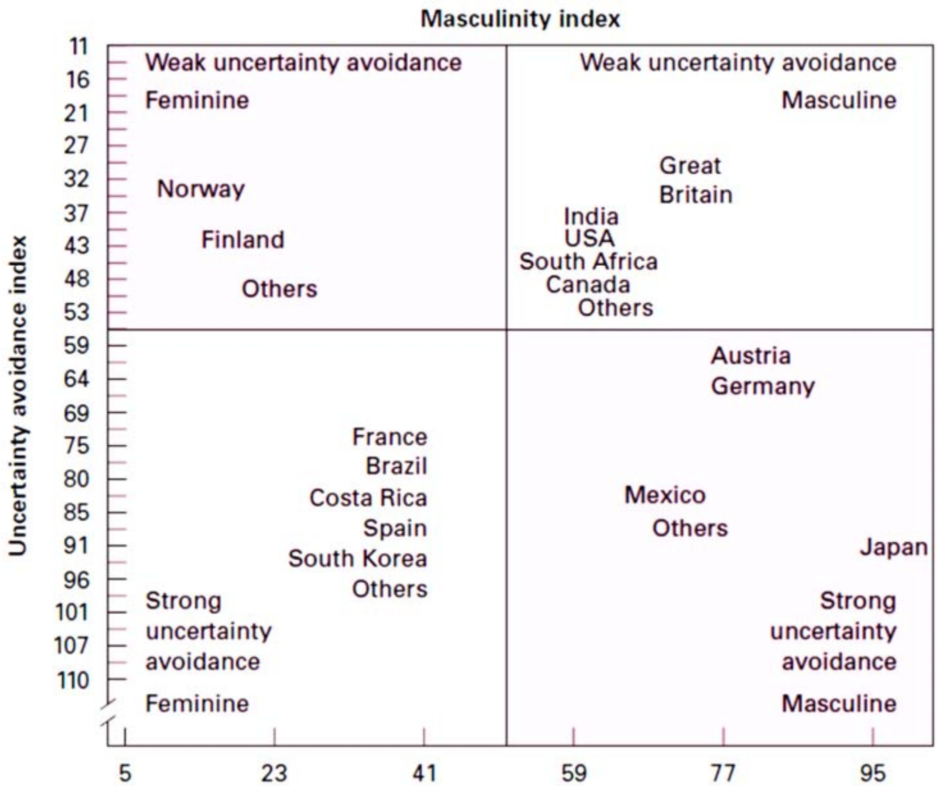
[170] hofstede, g. (2015). "Uncertainty Avoidance Index (UAI)." from http://geert-hofstede.com/dimensions.html.

[171] hofstede, g. (2014). "Country Comparison: Germany." from http://geert-hofstede.com/germany.html.

[172] Cultural, C. (2014). "Individualism." from http://www.clearlycultural.com/geert-hofstede-cultural-dimensions/individualism/.

several exceptions in this regard such as Germany and Japan. For solving this conflict, we considered the effects of other cultural dimensions on motivation.

Figure 4-3. "Selected Countries on the Uncertainty-Avoidance and Masculinity Scales"



Source: (Hodgetts, Luthans et al. 2005)

We know that the feeling and judgment of people in society about equity can increase or reduce their motivation and enthusiasm for reaching goals. Hofstede defined this cultural characteristic as "Power distance" as follows: "This dimension deals with the fact that all individuals in societies are not equal – it expresses the attitude of the culture towards these inequalities amongst us. Power distance is defined as the extent to which the less powerful members of institutions and organizations within a country expect and accept that power is distributed unequally."[173] We concluded that the more people within a culture believe and accept the inequality of power distribution, the less motivation they have for achieving their goals. As a result, we considered and applied the power distance index as a reverse factor in motivation index. In addition, the level of pragmatism in a

[173] hofstede, g. (2015). "Power Distance Index (PDI)." from http://geert-hofstede.com/dimensions.html.

culture directly affects positively the motivation and enthusiasm of the respective society. Then we considered the pragmatism with direct influence on motivation. Another cultural index that can positively affect motivation is the degree of indulgence. Hofstede defines indulgence society as follows: “Societies with a low score in this dimension have a tendency to cynicism and pessimism. In addition, in contrast to indulgent societies, restrained societies do not put much emphasis on leisure time and control the gratification of their desires. People with this orientation have the perception that their actions are, or should be, restrained by social norms and feel that indulging themselves is somewhat wrong.”[174] Now we can produce an Index by dividing masculinity to uncertainty avoidance and power distance and multiply it to indulgence and pragmatism.

$$\text{Cultural Motivation Index} = \frac{Masculinity \times Pragmatism \times Indulgence}{Uncertainty\ avoidance \times\ Power\ distance}$$

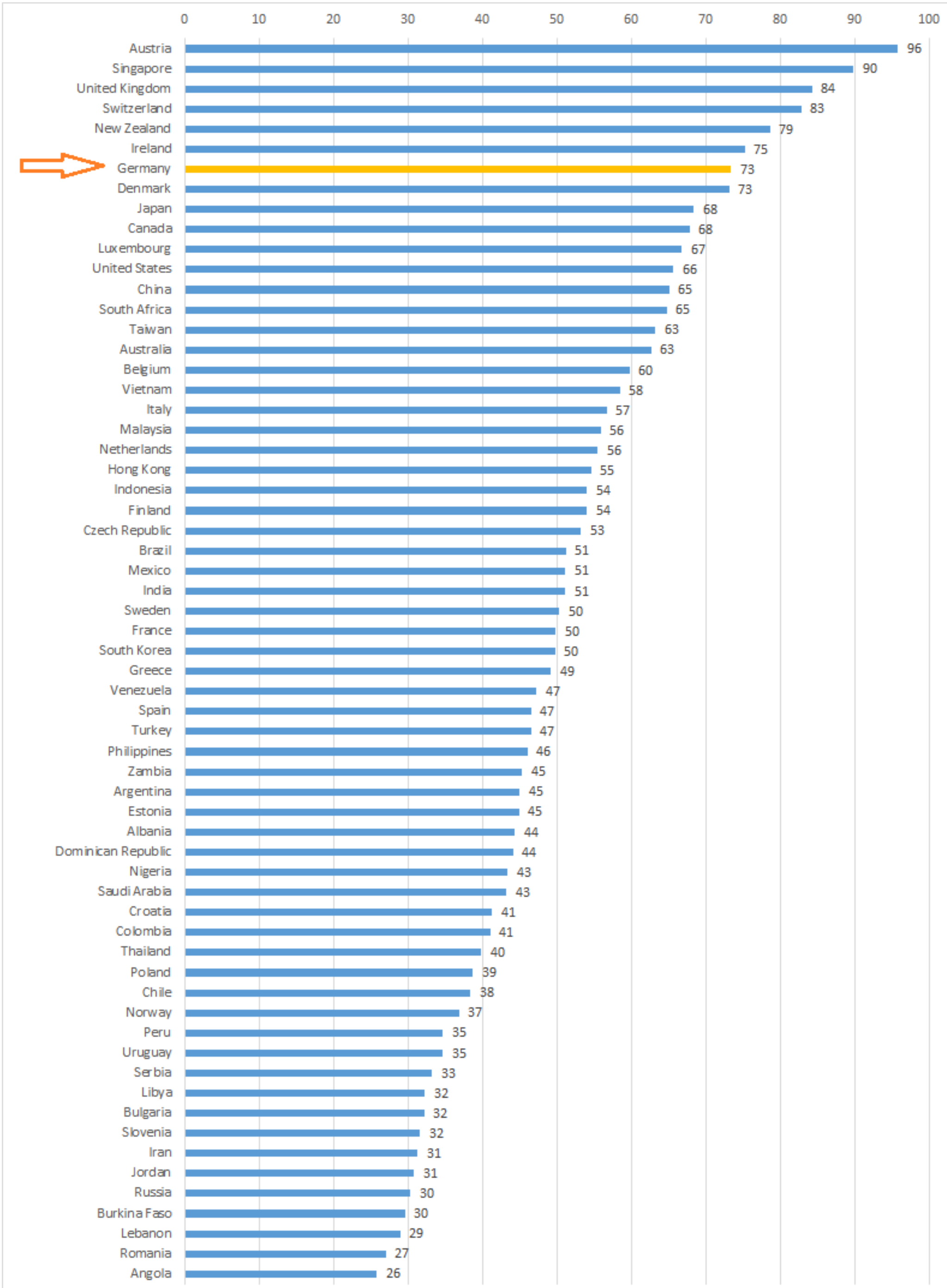
Figure 4-4 shows the list of countries from highest to lowest motivation index.

4.1.4 The degree of trust

For measuring trust and social capital, we use two main sources. The first source is the cultural index published by the OECD and the second one is scientific literatures. As it can be seen in Figure 4-5, Germany is located at rank 12 in the Pro Social behavior Index between OECD countries with six percent anti-social behavior. According to the fact that a low level of trust creates anti-social behavior, by extending this index to include trust, the OECD published the trust index. As Figure 4-6 shows, the rank of Germany between OECD countries is 14, with a 61 percent level of trust expressed by people in society, which is higher than the average level of 59 percent. Another source of data is the World Values Survey (See Figure 4-7), which publishes the results of surveys asking the following question: ‘Generally speaking, would you say that most people can be trusted or that you need to be very careful in dealing with people?’ Possible answers include ‘Most people can be trusted’ or ‘Can´t be too careful’.

[174] hofstede, g. (2015). "Indulgence versus Restraint (IND)." from http://geert-hofstede.com/dimensions.html.

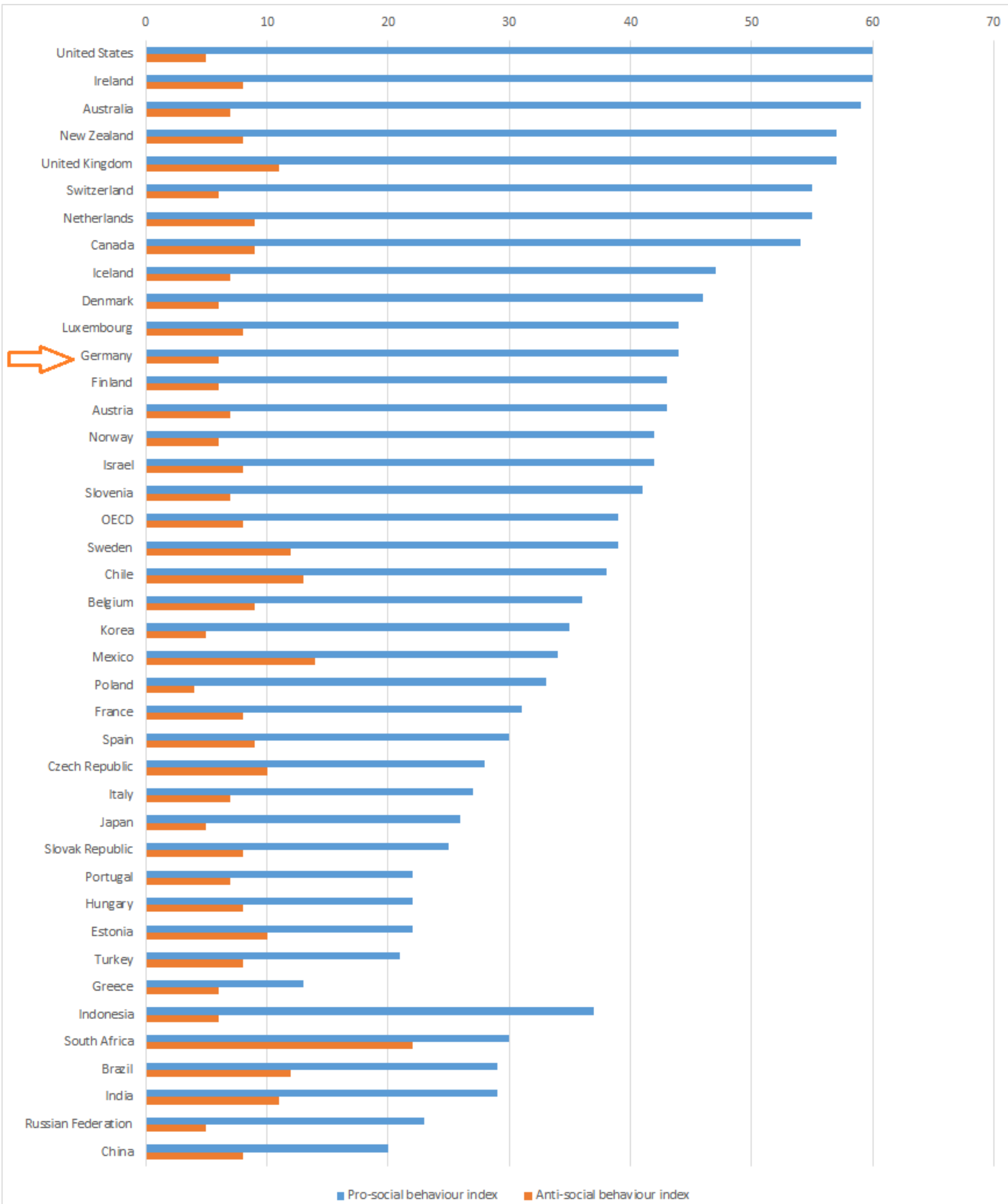
Figure 4-4 Ranking of countries based on the level of enthusiasm and determination for reaching the goals in the culture



Source: author

The survey results shows that 37 percent of Germans believe most people can be trusted which is closer to the results of J. Allik's and A. Realo's (2004) analysis rather than the OECD publication[175].By the way, in this survey Germany ranks 17th in the world. Generally, it can be stated that the level of trust in Germany is relatively higher than average and Germany can be categorized as a medium to high trust culture. The uncertainty avoidance of German culture justifies its rank in trust.

Figure 4-5. Levels of pro-social behavior among OECD countries in 2011



Source: Generated by the author with data extracted from (OECD 2011)

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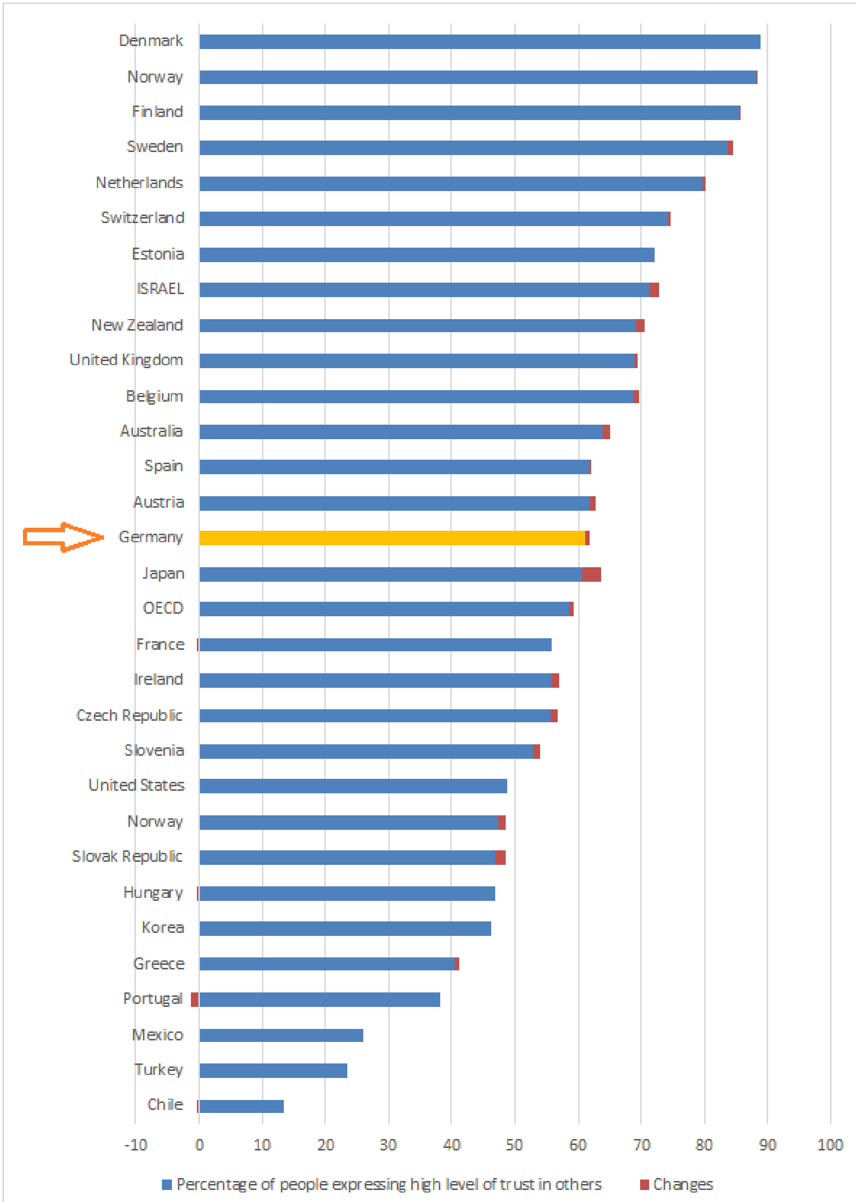
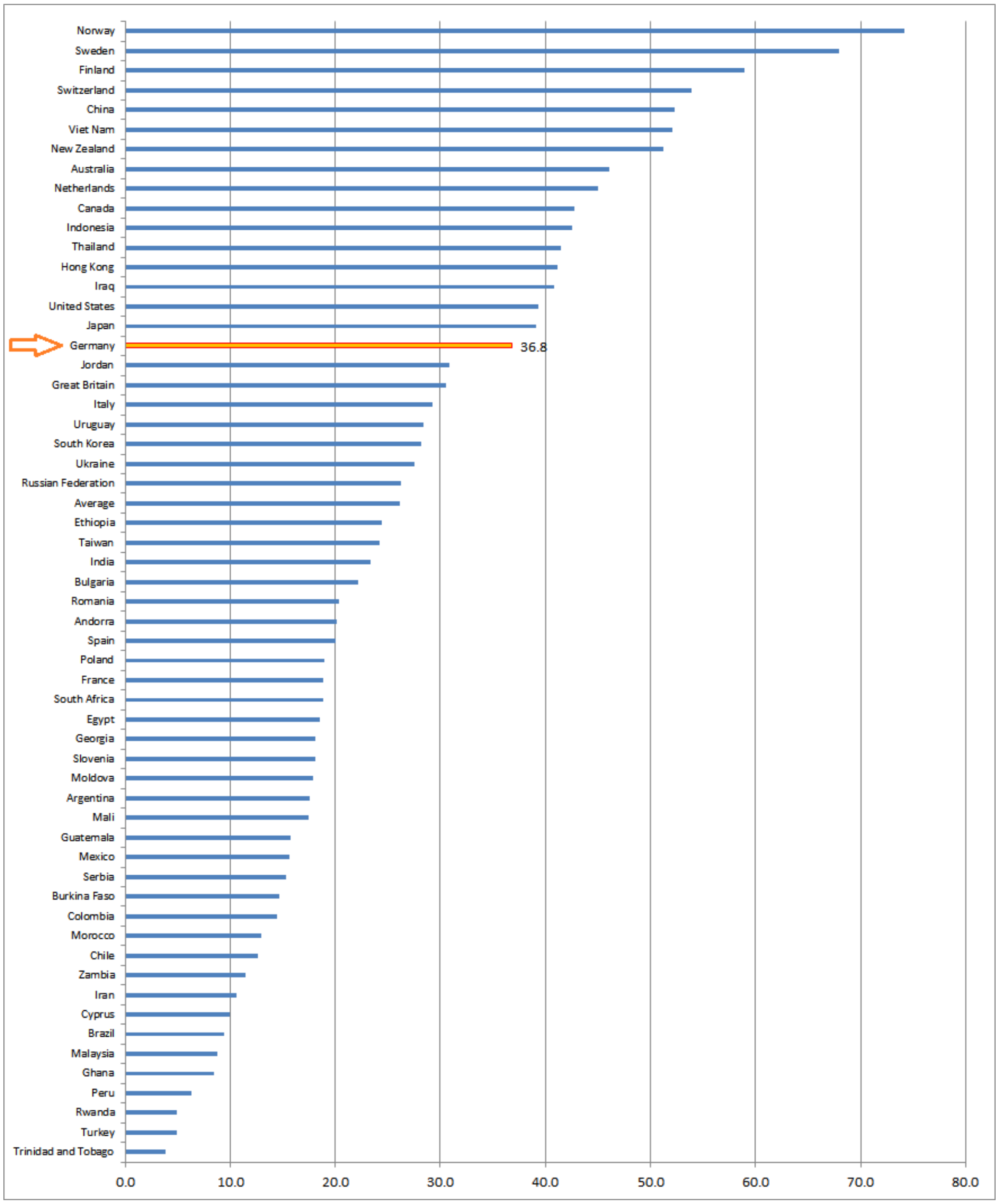
[175] JÜRI ALLIK, A. R. (2004). "INDIVIDUALISM-COLLECTIVISM AND SOCIAL CAPITAL." CROSS-CULTURAL PSYCHOLOGY **35**.

Figure 4-6. Source: Levels of trust among OECD countries in 2008



Source: Generated by the author with data extracted from (OECD 2011)

Figure 4-7. Percent of answers: Most people can be trusted

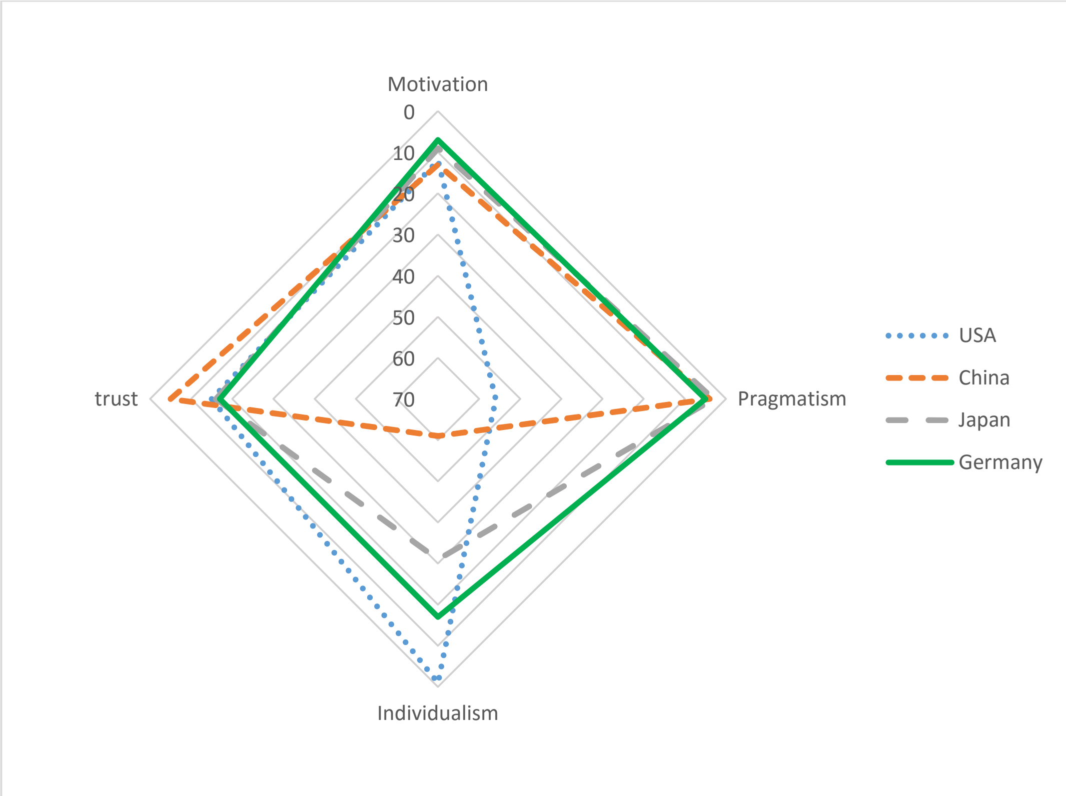


Source: Generated by the author with data extracted from (WorldValuesSurvey 2014)

4.1.5 Summary of cultural dimensions in Germany

In Figure 4-8, the four cultural dimensions for Germany are depicted. We compared the four dimension of culture between the four biggest economic powers in the world. We used the country ranking instead of the country score, because the score sometimes makes little sense.

Figure 4-8. Country rank of four dimensions of culture in the USA, China, Japan and Germany,

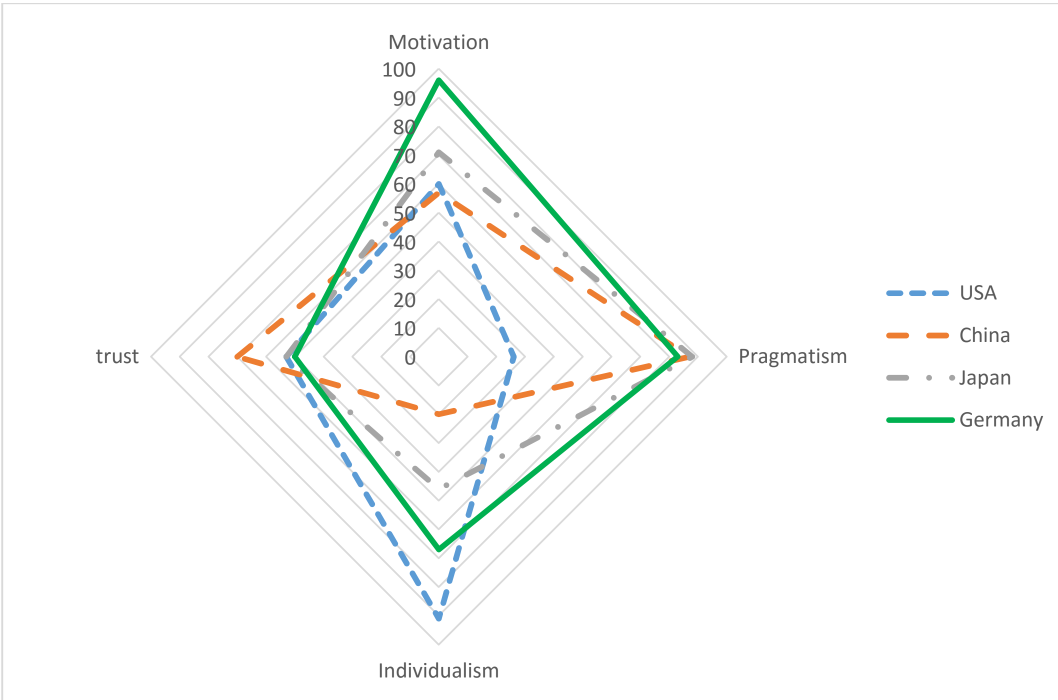


Source: author

In Figure 4-9, we followed the same approach but this time we used the country score instead of country rankings. Both comparisons show that Germany is more balanced and symmetric in the cultural dimensions than others. The cultural dimension of Germany proves relatively suitable for entrepreneurial activities. However, with a higher level of trust, the culture can benefit more from social capital and leadership. In the coming sections and next chapters, we discuss how this cultural dimension affects micro-CHP development in Germany. The cultural characteristics of Germany construct a type of economic capitalist system named alliance capitalism. In contrast to countries like the USA with competitive capitalism, in which the highly individualism dimension of the culture promotes selfishness, alliance capitalism is shaped by a corporate culture of cooperation between industry, banking and insurance. This culture helped establish win-

win economic activities around common goals by collaborative relationships between commercial entities[176].

Figure 4-9. Country score of four dimensions of culture in the USA, China, Japan and Germany.



Source: author

4.2 General factors influencing entrepreneurial activities in Germany

Several international sources of information published indexes for ranking the competitiveness of countries concerning economic development. The World Competitiveness Center of the Institute for Management Development (IMD) occasionally publishes the World Talent Report, which ranks 60 countries based on their ability to develop[177]. In addition, the World Economic Forum publishes the Global

[176] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

[177] IMD (2014). IMD World Talent Report. Institute for Management Development, Lausanne, Switzerland.

Competitiveness Report for 148 countries[178]. In these reports (which are among the main references for this research), the physical infrastructure, institutions and countries' human assets (without considering natural resources) have been analyzed. In this ranking, Germany stands in the third position in IMD[179] report and ranks fourth in the report by the World Economic Forum (See Table A-1 in Appendix 1). However, there are some strengths and weaknesses, which can affect the development of new energy technologies such as micro-CHP more than other aspects. The framework for indexes is summarized in Figure A-1 of Appendix 1.

Despite the fact that the number of small and medium-sized enterprises in Germany are twice the EU average, the contribution of entrepreneurship and micro-enterprises to employment is 19% in comparison to the 30% EU average[180]. The advantages of German entrepreneurs and start-ups are that the levels of innovation and innovative activities are much higher than in other EU countries[181]. Since 2007, the government supported young entrepreneurs through consulting programs with a budget of up to 4500 euros. The federal government started the "Gründerland Deutschland" program for promoting start-ups and motivating and teaching young entrepreneurs from high school and universities[182]. Another study by the World Economic Forum categorizes countries in four different economic types. Germany is categorized as an innovation-driven economy with several advantages and disadvantages. Figure 4-10 shows the score of Germany in different economical indexes and compares it with the average score of innovation-driven economics. The rank of Germany in each index is shown inside a small red square next to each index. In the global competitiveness report, Germany stands in 4th place among 148 countries in the world after Switzerland (1st place), Singapore (2nd place) and Finland (3rd place) (For more information, see Table A-1 in Appendix 1[183]). Despite of the fact that Germany has better scores in all pillars than average innovation-driven economies, it

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[178] WorldEconomicForum (2013). The Global Competitiveness Report 2013–2014 Full Data Edition World Economic Forum Geneva.

[179] IMD (2014). IMD World Talent Report. Institute for Management Development, Lausanne, Switzerland.

[180] EuropeanCommission (2010). Member States competitiveness performance and policies. Brussels,.

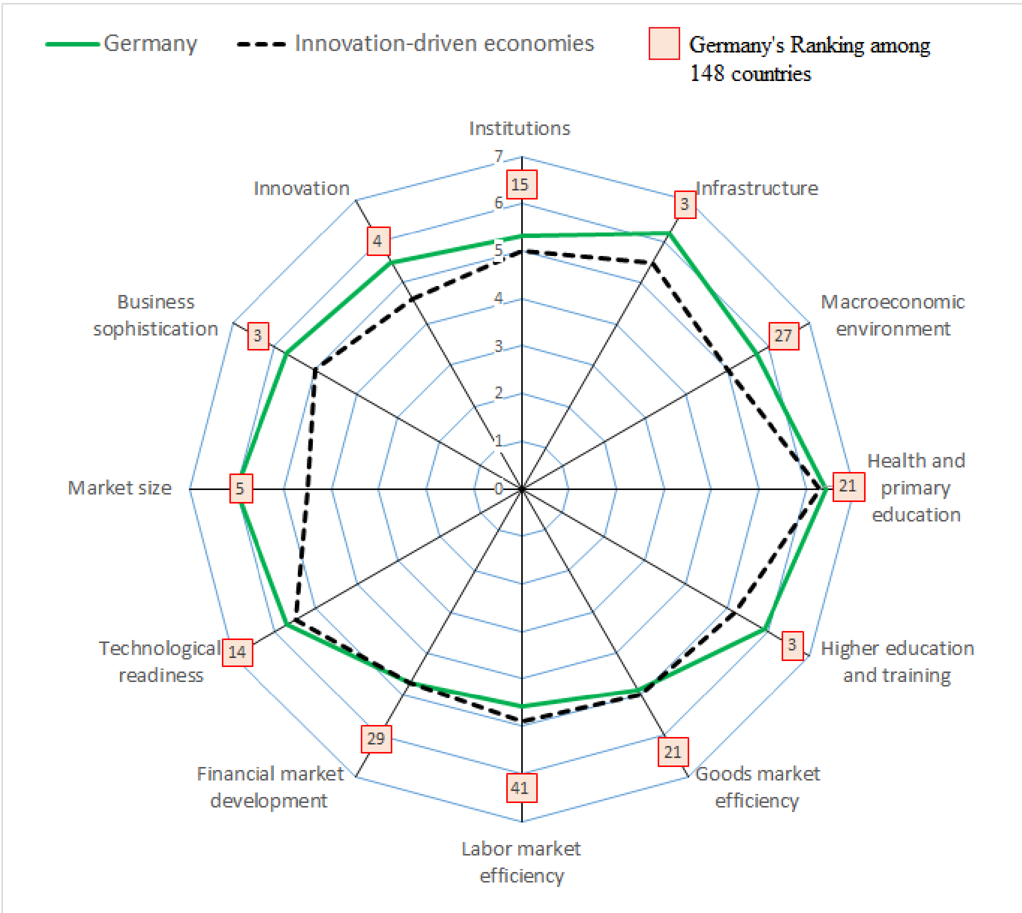
[181] Ibid.

[182] Ibid.

[183] WorldEconomicForum (2013). The Global Competitiveness Report 2013–2014 Full Data Edition World Economic Forum Geneva.

has weaknesses in labor market efficiency (with a rank of 41) and in financial market development (with rank of 29).

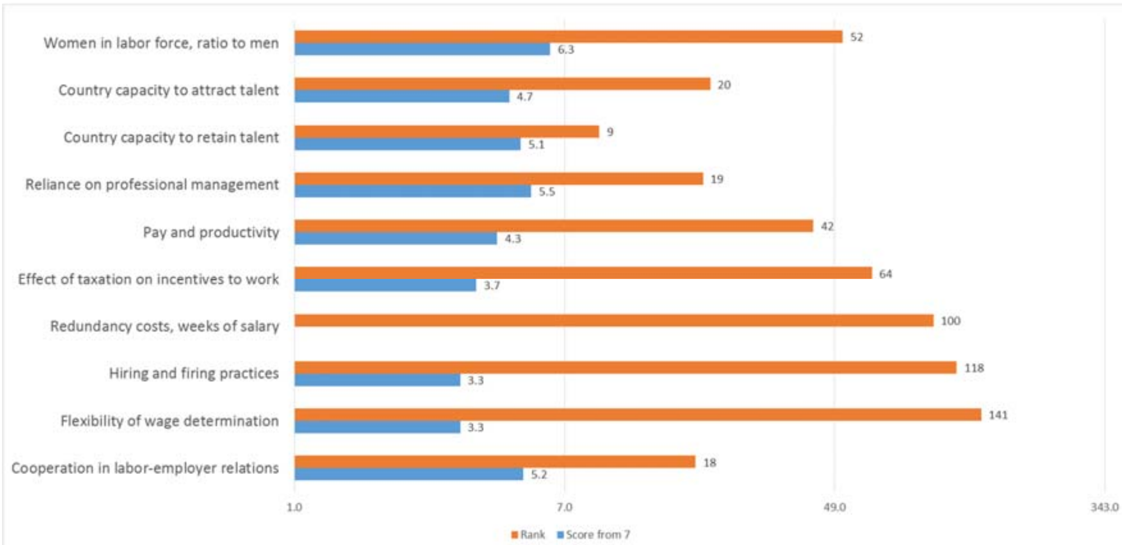
Figure 4-10. Comparison of Germany in different economical indexes with average scores of innovation-driven economics



Source: Generated by the author with data from (WorldEconomicForum 2013)

Figure 4-11 provides more insights into the details of the labor market efficiency index in Germany. The worst scores for Germany in this index are "Flexibility of wage determination" with a rank of 141 and "Hiring and firing practices" with a rank of 118. Germany has a low score and rank in several other indexes. The number of procedures to start a business in Germany is 9 which ranks it 104th among other countries. The low score of financial market development in Germany is related to the soundness of banks, which is ranked 64th among 148 countries. Germany has a medium score of 3.2 when it comes to the availability of venture capital with a rank of 33 and a score of 3.2 in ease of access to loans with a ranking of 46[184]. Better conditions exist for the availability and affordability of financial services and in this field Germany is ranked among the top 20 countries. The institutional setting in Germany is ranked 15th among 148 countries.

Figure 4-11. The ingredients of the labor market efficiency index in Germany



Source: Generated by the author with data from (WorldEconomicForum 2013)

Among different institutional indicators, property rights and protection, judicial independence and reliability of police services have the highest scores and are ranked 15th among all countries. The worst institutional score is 5 out of 10 and relates to the strength of investor protection with a ranking of 84 in the world. Germany has strengths in some critical areas. It is ranked 3rd in infrastructure, higher education and training and business sophistication. Germany is ranked 4th in innovation and 5th in market size among 148 countries which provides its economy great advantages in comparison with big economies like China and the USA[185]. (For more information, see Table A-2 in Appendix 1[186]). In a survey by the World Economic Forum, experts in different sectors of the economy selected the five most problematic factors for doing business in Germany. They were asked to rank their answers between 1 (which means the most problematic)

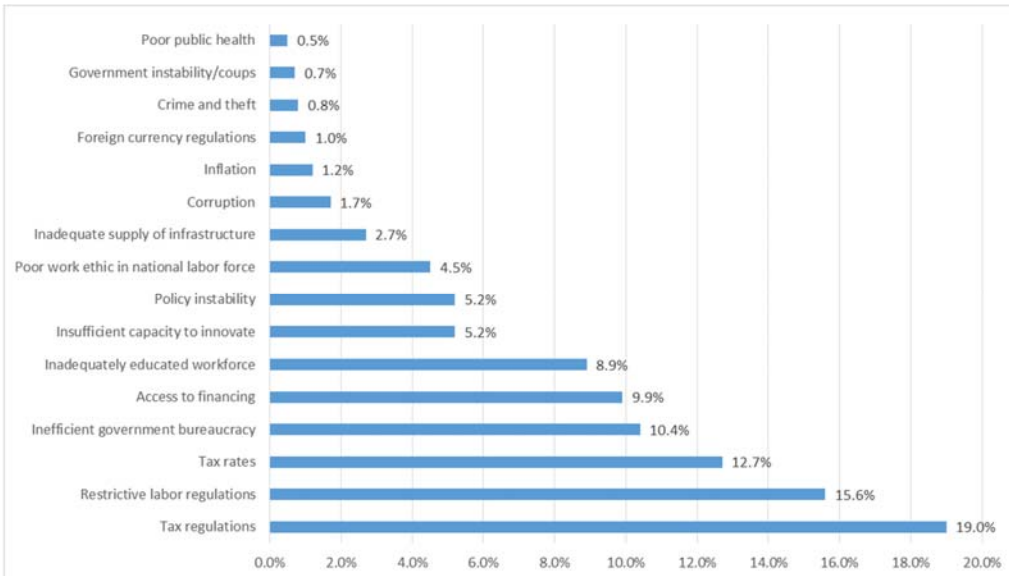
[184] Ibid.

[185] Ibid.

[186] Ibid.

and 5 (as the least influential factor). Figure 4-12 indicates the result of the survey as percent of answers about most problematic factors for doing business in Germany.

Figure 4-12. Percent of answers about most problematic factors for doing business in Germany



Source: Generated by the author with data from (WorldEconomicForum 2013)

4.3 Institutional framework in multi-level perspective

In previous section, we discussed the culture in Germany and its influences on entrepreneurial activities of micro CHP development. The institutional framework determines the choice of activities and extends of rewards entrepreneurs receive from their activities. Some entrepreneurs can change the institutional characteristics of the current situation and serve other entrepreneurs by modifying the institutional framework. They can be labelled as Mega- entrepreneurs. Lobbying, seeking and using rent are common behaviors of entrepreneurs.[187] Advocacy coalitions between several entrepreneurs in the market are the result of activities aimed at changing the institutional framework. On the other hand entrepreneurs naturally seek rent and try to use innovation to create rent for privileging themselves from monopoly position and earning more

[187] David B. Audretsch, O. F., Stephan Heblich and Adam Lederer (2011). Handbook of Research on Innovation and Entrepreneurship, Edward Elgar Publishing Limited.

profit[188]. The legal and institutional framework in this regard can provide two environments: first by providing conditions for entrepreneurs to form advocacy coalitions and establish their market against other bigger and stronger competitors and in contrary, establishing liberalized market by preventing strong lobbies[189]. The character of rent-seeking behavior of entrepreneurs necessitates policy makers to consider both the advantages of advocacy coalitions and the danger of jeopardizing current entrepreneurial profits and shaping the new monopolies by entrepreneurs. In addition, it is important that the regime of regulations and laws allows people to carry out experiments and that the rules of the game be designed by the people not just by elites[190]. The institutional framework should be in place, clear and welcoming to micro CHP investors[191]. With regard to the institutional framework of micro CHP, we examine the existence of advocacy coalitions and the liberalization or monopoly structure of the system. Finally, we study the institutional changes in a multi-level perspective analysis. We are trying to answer the question: If institutional architecture gives momentum to the micro CHP technology and if it stimulates firms to develop micro-CHP technology?

The energy policies define the structure of the institutional setting. Therefore, having a general perception about the actors in the process of energy policy design is necessary for analyzing the institutional setting. "In the Federal Republic of Germany energy policy traditionally was a part of overall economic policy and belonged to the portfolio of the Federal Minister of Economics and Technology. Energy policy is formulated by the Federal Government in cooperation with the federal states."[192] After the Federal and state governments, there are the electricity and natural gas industries and their constituent companies, which are the most important players in shaping German

[188] Ibid.

[189] Ibid.

[190] Casson, M. (2010). Entrepreneurship: Theory, Networks, History, Edward Elgar.

[191] UN (2011). Sustainable Energy for All: Opportunities for the Utilities Industry North America Clean Energy Lead Accenture.

[192] Mez, L. (2007). On the Role of the Mass Media in German Energy Policy. Berlin, Environmental Policy Research Centre.

energy policy[193]. In Germany the following institutions are responsible for or shape the country's energy policy:

The Parliament

The German parliament includes the federal parliament (Bundestag) with representatives from general elections and state parliaments (Bundesrat) consisting of the representatives of state governments. The Committee of Environment, Protection of Nature and Reactor Safety as well as one on Economy and Technology are responsible for the supervision on energy issues. But they play no significant role in designing energy policy[194] .

Government

Before 2013, the responsibility for energy issues was divided between the Ministry of Economy and Technology (BMWi) and the Ministry of Environment, Protection of Nature and Reactor Safety (BMU). In addition, the Ministry of Traffic, Construction and Housing plays an important role in implementation of the energy policies[195] [196].

Ministry of Economy and Technology (BMWi)

The sub-institutions of BMWi monitor and coordinate the energy market and implement the energy programs[197]. The Federal Office of Economics and Export Control (Bafa), which is a subordinate of (BMWi), leads some programs for BMU. Bafa is responsible for support programs in the fields of energy efficiency and development of renewables[198].

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[193] Ibid.

[194] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

[195] Ibid.

[196] Claudia Kemfert, J. H. (2013). Good Governance of the Energiewende in Germany: wishful thinking or manageable?, Hertie School of Governance.

[197] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

[198] Claudia Kemfert, J. H. (2013). Good Governance of the Energiewende in Germany: wishful thinking or manageable?, Hertie School of Governance.

The Ministry of Environment (BMU)

The Ministry of Environment started its activity in 1986 and always played an important role in Germany's energy policy. All of BMU's ministers, for example Walter Wallmann (1986-87) Klaus Töpfer (1987-1994) (heading the Ethics Commission) and Angela Merkel (1994-1998) (Chancellor since 2005), were among Germany's top politicians[199]. The renewable energies (except bioenergy), environment conservation, and safety of nuclear power plants and their waste are in the domain of BMU's responsibility. However, the legal authority of BMU has overlap with the BMWi in many areas like renewable energy development and the emissions trading system (ETS) in Germany[200].

Local level (State Governments)

The local governments have partial responsibility for implementation of energy policies approved by the federal government. In some areas, they have more autonomy for their own energy policies, for example some southern states are more developed with regards to solar energy and some states in the north have mostly developed wind energy[201]

Municipal Level

"At the municipal level the implications of Energiewende are addressed in the frame work of the local responsibility mainly for traffic and housing but also for local energy distribution and last but not least as owners or shareholders in the local or regional utilities. Many municipalities explicitly address the issue of Energiewende."[202]

Other Institutions

There are three main organizations, which play an important role in policy design and implementation in Germany. The Federal Network Agency (Bundesnetzagentur)

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[199] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

[200] Claudia Kemfert, J. H. (2013). Good Governance of the Energiewende in Germany: wishful thinking or manageable?, Hertie School of Governance.

[201] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

[202] Ibid.

(BNetzA) is responsible for supervising regulations for grid access in Germany. Prior to 2005, it was responsible for the telecommunications grid and later it took over the responsibility of regulatory issues of gas and electricity grids. The grid expansion, reliable supply of power and supervising renewable energy financial stream are another main task of BNetzA[203]. The Cartel Office (Bundeskartellamt) is an organization in Germany which is responsible for anti-competitive behavior in the energy market. It plays an important role in the liberalization of the energy market[204]. The implementation of policies by managing projects and providing technical aids are responsibilities of dena (Deutsche Energie Agentur) which was established in 2000. With an ownership structure of 50% belonging to the federal government, 26% KfW, 8% Deutsche Bank and 8% DZ Bank, its central role is promotion of energy efficiency, renewable energy and intelligent energy systems by supporting pioneer projects, analysis of energy technologies and markets and provision of advice to politicians and other actors[205] .

4.3.1 Actors related to development of micro CHP

The main target of all regulations and incentives are customers in residential and commercial buildings. Depending on many parameters, installing micro-CHP can provide profit by self-generation of electricity or Reduction of costs in comparison with traditional ways of energy supply. However, there are other actors which the development of micro CHP has generated costs and benefits for. Among them are the large electricity producers and local energy companies, which may lose benefits by reduction in electricity sales and a decline in their number of customers. Technology developers are among the promising winners of more micro CHP development. "It is interesting to note that originally independent technology developers like Senertec and Power Plus, along with a number of fuel cell developers, have been purchased by other boiler or CHP technology manufacturers."[206]. The distribution network operators (DNOs) can gain from micro-CHP

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[203] Ibid.

[204] Ibid.

[205] Claudia Kemfert, J. H. (2013). Good Governance of the Energiewende in Germany: wishful thinking or manageable?, Hertie School of Governance.

[206] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

but if they belong to the big utilities, they lose out because of lower benefits for their parent companies due to more micro CHP. There are opportunities for mediation between final users and technology developers and other actors. For example, the planning and energy management of the building and installing and operation and maintenance of micro-CHP plant can provide opportunities for small energy servicing companies. Some incentives such as KfW programs directly encourage small energy servicing companies to be active in this area. The KfW confirms the payments of loans only if the loan applicant uses the expert advice for energy efficient construction and micro CHP plants. Moreover, due to the fact that most of the micro CHP technologies use natural gas as an input fuel, gas companies also enjoy more gas sales through micro CHP development. Accordingly, in the German market, some big electricity companies try to acquire natural gas import and long-distance transport companies. For example, E.ON, "acquired the Ruhrgas and pursues a strategy to gain access to the gas grid and the local heating market."[207] Because the regulations are not stable and in fact the German government tries to reduce the subsidies and helps the technology to leave the niche level and enter the market to stand independently. Consequently, the regulations support the technology until it survives. Many changes in the regulations have negative effects on the micro-CHP market, which increases the risks for investment. We can view society as another actor, which benefits from more micro-CHP development in Germany. The aggregate awareness of the society about the benefits of micro-CHP can increase its development. In addition, the dominant public view about sustainability and new technologies plays a very important role in the behavior of all other actors.

If the big utilities acquire the gas companies or technology developers it is possible to acquire profits from micro CHP development. Another way to make profits from micro-CHP, is to act as a mediator between other actors, for example energy servicing companies. However, such activities require innovation and flexibility, which is difficult for big utilities. In fact, it is not because of a lack of "creativity and ability to invent new things, but it is 'the inertia of past actions, the stifling effects of bureaucracy, and the

[207] Ibid.

inflexibility of collective mind-sets that inhabit large firms"[208] p. 172. The situation is a two-sided complex for government, which on one hand is responsible for public interests by securing electricity supply to households at a reasonable price and on the other hand must support big utilities in the market against other competitors[209]. There were several major threatening institutional conditions against micro-CHP: first, the traditional monopoly in the energy supply chain of Germany, secondly, advocacy coalitions in other competing technologies, and thirdly complicated regulations for contracting and ownership of new plants along low financial incentives for users and investors[210].

We analyze these changes in different intervals of time. For a specific period, we focus on the pressures from technological innovations or niche level on the regime. The niche level points out the changes at the micro level, which have limited effects on the system and mostly consist of technological breakthroughs or the introduction of new micro CHP. The importance of the niche level is that government must protect it continuously by funding programs and providing incentives for pioneer users. Moreover, new technologies provide options about the possible future of the energy system. Other influencing factors are global phenomena that put pressures on the system at the macro level. We assumed the regulations at the EU level, and the public's view about energy issues as influential factors on the macro level. By conducting a multi-level perspective analysis, it is possible to summarize the whole process of system transition. Period prior to 1990

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[208] Wüstenhagen, R. and R. Wuebker (2011). The Handbook of Research on Energy Entrepreneurship, Edward Elgar Publishing Limited.

[209] Torsten Brandt, W.-u. S. I. W. (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

[210] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

4.3.2 The period before 1990

4.3.2.1 *Phenomena at the macro level prior to 1990*

The economic shock from the oil crisis in the 1970s affected the energy policies of not only Germany but also all industrial countries and energy efficiency became very important. Moreover, concerns about climate protection changed the public viewpoints towards low-carbon and renewable resources of energy. The most recent global phenomena before 1990 were the Chernobyl disaster, and unified 70 percent of German society against nuclear energy[211].

4.3.2.1.1 Oil crisis 1973 and 1980

In the 1960's, European nation-states were dependent on energy imports from OPEC and the oil crisis showed that their economies were highly vulnerable to external factors beyond their influence .The oil crisis was a warning signal for Europe[212]. The oil crises lasted 10 years and started when the Arab world instituted a ban on oil sales in 1973 in reaction to the Arab–Israeli War. Again, after the Islamic revolution in Iran in 1980, the oil price rose quickly. These oil crises promoted arguments regarding the importance and necessity of alternative sources of energy[213]. In Germany, the unemployment increased from 273,000 in 1973 to more than a million in 1975[214]. Many industrialized countries which were dependent on oil, substituted it with coal[215]. Three changes in German energy policy happened as the first measurable reaction to the oil crisis. First, the coalition of Social Democrats and the Liberal party (1969-1982) promoted a shift in energy policy towards nuclear power and coal. Germany's next reaction to the oil crisis

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[211] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

[212] Jones, L. E. (2014). Renewable Energy Integration: Practical Management of Variability, Uncertainty, and Flexibility in Power Grids, Elsevier Science.

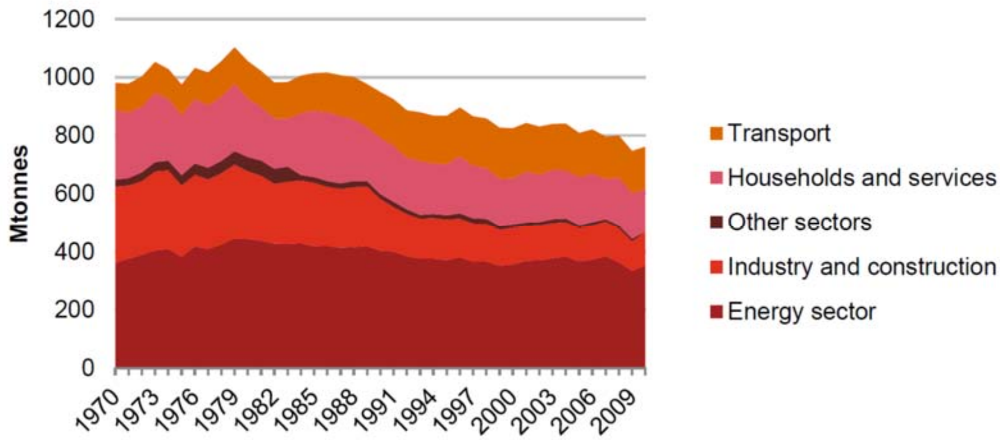
[213] Wüstenhagen, R. and R. Wuebker (2011). The Handbook of Research on Energy Entrepreneurship, Edward Elgar Publishing Limited.

[214] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[215] Bach, W., et al. (1980). Interactions of energy and climate: proceedings of an international workshop held in Münster, Germany, March 3-6, 1980, D. Reidel Pub. Co.

was increasing the import of natural gas from the Soviet Union[216]. The substitutions of oil with coal lead to increase of CO2, which were much higher than had oil been used as an energy source[217]. Figure 4-13 shows the CO2 increase in Germany.

Figure 4-13. "CO2 emissions per sector (1970-2010)"



Source: (Advisory 2013)

In order to avoid the problem of high CO2 emissions, exploitation of new technologies such as renewable energies and high efficient technologies became important. In the 1980s, the European Community (now European Union (EU)) started the development of policies aimed at reducing oil consumption and greenhouse gas emissions by encouraging the use of renewable energies for electricity, heating/cooling, and transport[218]. Concerns about the fossil-based energy system in Germany and the country's dependence on oil imports promoted discussions about the inclusion of renewable energies in the German energy mix[219]. At that time, Germany started programs for research on renewable technology development. Consequently, Germany introduced

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[216] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[217] Bach, W., et al. (1980). Interactions of energy and climate: proceedings of an international workshop held in Münster, Germany, March 3-6, 1980, D. Reidel Pub. Co.

[218] Jones, L. E. (2014). Renewable Energy Integration: Practical Management of Variability, Uncertainty, and Flexibility in Power Grids, Elsevier Science.

[219] Wüstenhagen, R. and R. Wuebker (2011). The Handbook of Research on Energy Entrepreneurship, Edward Elgar Publishing Limited.

the feed-in tariff mechanism for renewables in 1979[220]. Although nuclear energy was non-fossil fuel and produced no CO2, after the mid-1970s, German society demanded more changes in the energy system and the issue of nuclear energy became more controversial[221]. Civil society started campaigning against the rapid growth of nuclear power plants in Germany, which caused much violence, and demonstrations[222].

4.3.2.1.2 Chernobyl nuclear disaster

In 1986, the nuclear reactor number 4 of the Chernobyl power plant exploded and a huge amount of radioactive material was released into the atmosphere, including a lot of radioactive CO2 from the burnt graphite moderators of the reactor. The accident had a deep impact on German public opinion about nuclear energy, which was divided after the oil crisis[223]. German society turned against nuclear energy[224]. The Social Democrats and Green party formed a coalition (Conservatives and Liberals – 1982-1990) against nuclear energy[225]. Moreover, the idea of the municipaliation of electricity supply was widely discussed and welcomed by local activists[226]. In the second half of the 1980s and due to acid rains and forest degradation, the German government introduced restrictive air pollution regulation for big combustion plants[227]. A work group established by the

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[220] Jones, L. E. (2014). Renewable Energy Integration: Practical Management of Variability, Uncertainty, and Flexibility in Power Grids, Elsevier Science.

[221] Wüstenhagen, R. and R. Wuebker (2011). The Handbook of Research on Energy Entrepreneurship, Edward Elgar Publishing Limited.

[222] Kitschelt, H. P. (1986). "Political opportunity structures and political protest: anti-nuclear movements in four democracies." British Journal of Political Science **16 (1)**: 57–85.

[223] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

[224] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[225] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

[226] Ibid.

[227] Lutz Mez, M. J. H. W. (1995). "Reduction of Exhaust Gases at Large Combustion Plants in the Federal Republic of Germany." Successful Environmental Protection: 173-186.

German government recommended a 30 percent CO2 and methane reduction by 2005 based on levels of the year 1987 and first measures for market development proposed[228].

4.3.2.2 *Regime level 1973-1990*

At the regime, level several decisions made by politicians in response to the pressures from the macro level lead to many changes. An immediate reaction to the economic pressures from the oil crisis was a significant review of Germany's energy policy. Germany tried to improve its energy security by 1- diversifying its energy sources and 2- more self-reliance by increasing the domestic production of energy. In order to diversify its energy sources Germany increased its gas imports from the Soviet Union and replaced part of its requirements for oil by replacing it with natural gas[229]. On the other hand, Germany was very advanced in the field of nuclear energy and has the sixth largest coal reserves in the world. As a result, the German government, a coalition of Social Democrats and the Liberal Party (1969-1982), increased the research budgets for the development of nuclear energy and coal power plants. (See Figure 4-14). However, pressures from society caused the new German government (which was shaped by a coalition of Social Democrats and FDP) changed its policy toward nuclear energy and coal. Investments in and research budgets for renewable sources were increased. The first actions for market creation took place in the early 1980s and the feed-in tariff mechanism was proposed in 1987[230]. Prior to 1990, the concept of micro CHP started to catch attentions of energy experts but there was not any significant technology at niche level. From an institutional point of view, the electricity sector of Germany never was a broad government monopoly (contrary to examples of other industrial countries like the "Central Electricity Generating Board" of England or "Electricité de France" in France[231].

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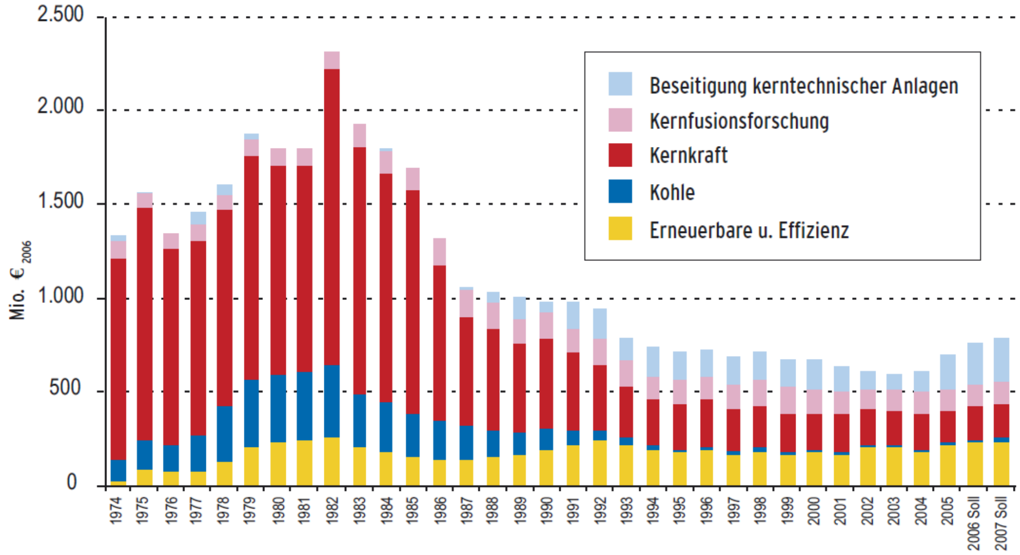
[228] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

[229] Bach, W., et al. (1980). Interactions of energy and climate: proceedings of an international workshop held in Münster, Germany, March 3-6, 1980, D. Reidel Pub. Co.

[230] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

[231] Hans-Böckler-StiftungBrandt (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

Figure 4-14. German government research budgets for research in energy technologies



Source: (Bundesministerium für Umwelt 2007) (p. 36)

On the other hand, "the electricity market of Germany is shaped traditionally by a coexistence of public, private and mixed-economy enterprises"[232] p.3. The "territorial monopolies" system in Germany shaped the electricity market from the beginning. After the First World War, each distribution area was allowed only to be active inside its established area, which was defined by contracts between energy supply companies[233]. After the National Energy Act of 1935 ("Gesetz zur Förderung der Energiewirtschaft vom 13.Dezember 1935"), this system of territorial monopolies became even stronger and by investments from municipalities in the respective local or regional energy supply companies, various connections between municipal utilities and energy supply companies were established[234]. The municipalities benefited via shared profits of electricity sales to their citizen while electricity producers benefited from a guaranteed contingent of customers. "Generally speaking this system, which had been stabilized by exceptions of the electricity economy from the Anti-Trust Law of 1953, ensured security of supply and

[232] Torsten Brandt, W.-u. S. I. W. Ibid.

[233] Ibid.

[234] Ibid.

profits for energy supply companies and municipal utilities and functioned for almost one century in Germany" [235]p. 3. It was in the 1970s that a component regarding environmental protection was also added to the regulatory framework. The regulation of the electricity market in Germany before 1990 has the following main characteristics:

- The federal states control investment in the electricity sector and also supervise and control the electricity price
- Apart from the federal states, municipals control the amount of electricity that came to their territory.

In 1976, in order to reduce the dependency on imported energy, the German government passed the Energy Saving Act (Energieeinsparungsgesetz). Later the "German Blue Angel Program" was issued in 1977. In this program, energy label were introduced to help consumers find the most energy-efficient products and buildings[236]. The energy saving act followed by other measures such as the Thermal Insulation Ordinance of 1977 and 1982, Heating Installation Ordinance of 1978/1982, KfW Environmental Protection Programme (1984), Small-Scale Combustion Plant Ordinance (1987)[237]. The period from the mid-1970s until the beginning of 1990 can be seen as a formative phase for the development of distributed generation technologies such as renewables and high efficiency CHPs. In this period, high R&D budgets and subsidies were assigned for technology development. Moreover, the institutional setting such as several environmental organizations and regulatory frameworks for supporting technologies on the niche level were set up. Public concerns about climate change and environmental degradation found their way into the policy system, led to the first National Climate Protection Programme (NCPP) in Germany, and forced politicians to establish a strategic roadmap for reducing emissions. All led to the market niche formation in the

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[235] Ibid.

[236] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[237] Barbara Schlomann, W. E., Edelgard Gruber, Nicola Kling, Wilhelm Mannsbart, Friedemann Stöckle (2001). Evaluating the Implementation of the Energy Consumption Labelling Ordinance, Fraunhofer Institute for Systems and Innovation Research (ISI), GfK Marketing Services GmbH & Co. KG.

late 1980s for renewables, which has been developed as a model for micro CHP a decade later[238].

4.3.2.3 *Niche level (prior to 1990)*

Today's idea of structured decentralization with micro generators did not catch attentions until 1970s and early 1980s[239]. However, like all technologies, the development of micro CHP technologies has a long history but the most direct technology development started in the 18th century. Robert Stirling invented a “heat economizer” as an idea of today’s Stirling engines. In 1838, Christian Friedrich Schönbein discovered the principle of fuel cells[240]. It was in 1876 that Nikolaus A. Otto invented the reciprocating internal combustion engines, which is another base for CHP technologies. Finally, Thomas Edison in the Pearl Street station (1882) accomplished the conversion of mechanical energy to electricity[241]. In the early 1960s, Thomas Grubb and Leonard Niedrach in General Electric (GE) made a significant breakthrough in fuel cell technology, which was the invention and development of the first polymer electrolyte membrane (PEM) fuel cell[242]. In the 1970s, an alkaline fuel cell for NASA’s Space Shuttle. Prior to the 1990s, many other scientists worked and developed fuel cell technologies to make it cheaper for daily use which was very expensive and only been used in space shuttles[243]. Japan, USA, Italy and two German companies were the pioneers in developing the Organic Racking Cycle

[238] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[239] Jan-Peter Voß, C. F. (2006). Dynamics of Socio-Technical Change: Micro Cogeneration in Energy System Transformation Scenarios. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

[240] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

[241] Ibid.

[242] Cook, B. (2001). AN INTRODUCTION TO FUEL CELLS AND HYDROGEN TECHNOLOGY. Canada.

[243] Ibid.

(ORC) technology between the 1960s and 1990s. Several plants with putout powers from a few kW to hundreds of kW were introduced[244].

4.3.3 Period 1990-2000

Until the late 1980s, a few small firms and environmentalist pioneers shaped the micro generation sector of Germany. Their activities mainly consisted of installing photovoltaic panels at small scale[245]. In the early 1990s, the two German states were unified and many East German coal power plants were purchased by West German utilities. After a small fluctuation in CO2 emission (because of high CO2 emission by before 1990s energy sector of East German), the carbon emission reduced and less utilization of coal accelerated during 1990-1995[246].

4.3.3.1 *Phenomena at macro level (1990-2000)*

4.3.3.1.1 Reunification of East and West Germany 1990

A peaceful revolution in East Germany, in 1989, led to the reunification of East and West Germany in 1990. The unification at its beginning caused a rapid growth in the West German economy, by 5% in 1991 and a reduction of the unemployment rate by 15% from 2 million to 1.7 million. Nevertheless, shortly after first economic boom, Germany's economy entered a recession in 1993. GDP declined by 2.2 % and unemployment increased by about 600,000 compared to the level of 1990[247]. The situation affected the energy system development in various ways. As Figure 4-15 shows, the share of some

[244] J. Larjola, L. (2011). Organic Rankine cycle (ORC) based waste heat/waste fuel recovery systems for small combined heat and power (CHP) applications. Small and Micro Combined Heat and Power (CHP) Systems: Advanced Design, Performance, Materials and Applications

R. Beith, Elsevier Science.

[245] Barbara Praetorius, M. M., Raphael Sauter, and Jim Watson (2012). Microgeneration in the UK and Germany from a Technological Innovation Systems Perspective. Sustainability Innovations in the Electricity Sector

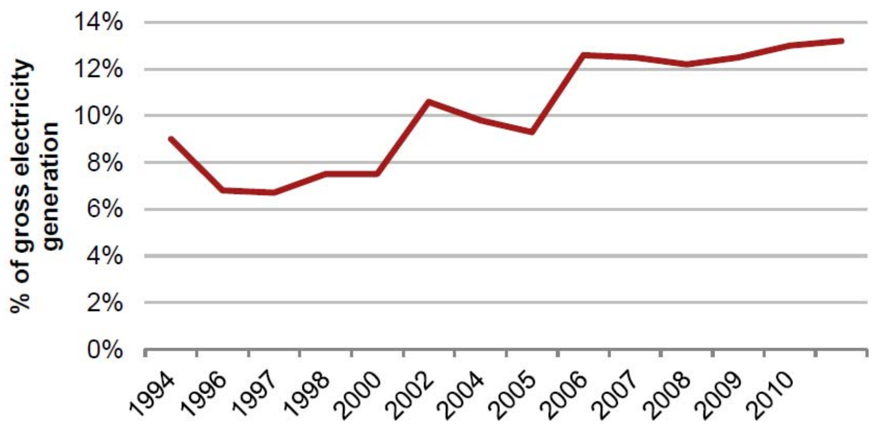
E. Feess, J. Hemmelskamp, J. Huber et al.

[246] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[247] Grömling, M. (2008). Reunification, Restructuring, Recessions and Reforms – The German Economy over the Last Two Decades Bayerische Julius-Maximilians-Universität Würzburg, Wirtschaftswissenschaftliche Fakultät

more efficient technologies like CHP power plants decreased in the first period of the 1990s.

Figure 4-15. Electricity generation from cogeneration in Germany, 1994-2010.



Source: (Advisory 2013) P. 77

The reason of such a decline is that, after the unification of East and West Germany, many industrial plants in East Germany were closed, which lead to a lower demand for power. Alongside of high GHG emission, some coal power plants in East Germany also were shut down. These power plants were replaced by nuclear ones or renovated for better efficiency[248]. Another major shock to the electricity market of Germany was the market liberalization plus the climate protection regime in the 1990s[249].

4.3.3.1.2 Council Directive 92/75/EEC

Directive 92/75/EEC approved on 22 September 1992 intended for labeling and mentioning the product information about energy and other resource consumption of the product in standard format for consumers[250]. Later the EU commission revised the

[248] Anja Hartmann, J. R., and Thomas Vahlenkamp (2008). "Cutting carbon, not economic growth: Germany’s path." McKinsey & Company.

[249] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

[250] COMMISSION, E. (2009). implementing Council Directive 92/75/EEC with regard to energy labelling of household washing machines, EU COMMISSION

directive to cover products, which may not use energy but have an impact on energy efficiency.

4.3.3.1.3 First EU electricity and gas liberalization directive 1996 and 1998

The EU directive 96/92/EC obliged all EU members to assure free entrance of all energy supply companies to the transport segment by different regulation modes of regulated or negotiated third party access[251]. Germany approved the European Union Directive of 1996 in 1998 as the National Energy Act ("Energiewirtschaftsgesetz von 1998). After this law and until 1999, Germany's electricity sector was completely liberalized and "Territorial monopolies" became extinct. In 1996, the European Union tried to revise the energy sector and fostering competition by unbundling of the energy supply chain from production to transmission and distribution. However, the EU could not stop the merging of new monopolies and the process of acquisition of small energy companies by big energy utilities[252]. The directive (96/92/EC) had the following main characteristics:

1- The big electricity supply companies must have separate accounts for their accounting process in generation, transmission and distribution of electricity. It means when there is single buyer; it must not exchange information with other parts and must operate independently. However, there is no need for separate companies[253].

2- For organizing the access to the transmission and the distribution network, Member States can choose different models of negotiated or regulated third party access or the single buyer model. The public service obligation to provide

[251] Bruns, E., et al. (2010). Renewable Energies in Germany's Electricity Market: A Biography of the Innovation Process, Springer Netherlands.

[252] Torsten Brandt, W.-u. S. I. W. (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

[253] Hall, D. (2000). EU Electricity Directive: does not require separation of vertically integrated utilities into separate companies; does not require privatisation. University of Greenwich, Public Services International Research Unit (PSIRU).

service for all customers can be used to choose between different models to balance the competition and act based on the general interests of society[254].

3- Contrary to the initial idea of the directive for promotion of completion and hindering the monopoly of big public companies and their discrimination against private ownership, the essence of privatization, was not mentioned in the directive[255].

Directive 98/30/EC “Gas Directive” was prohibit any discrimination between users by transmission, storage and LNG operators.

4.3.3.1.4 Kyoto protocol, adopted in 1997

The first international institutional framework for controlling the global climate change was set up by the United Nations in 1997 through the Kyoto Protocol. The United Nations Framework Convention on Climate Change (UNFCCC) and its 1997 Kyoto Protocol was an international reaction to the calls for immediate action (which awareness originally were raised from series of national reports)[256]. In the Kyoto protocol, 37 industrial countries and Europe obliged themselves to set targets for the reduction of greenhouse gas (GHG) emissions[257]. The first target was a 5% reduction of GHG below the levels of 1990. They agreed to reach this target by allowing developing countries to develop their economies but reducing the GHG emissions with the help of industrialized countries’ investments in clean technologies. For this purpose the three mechanisms of “an emissions trading market, the clean development mechanism (CDM), and joint implementation (J I)” have been designed[258]. Germany set a more ambitious target of 21% reduction from the 1990 emissions level and committed to reach it in 2008[259].

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[254] Ibid.

[255] Ibid.

[256] Praetorius, B., et al. (2008). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica Verlag.

[257] Sadr, F. (2014). "Heat Pump or CHP – which one is greener?" REHVA Journal.

[258] Sioshansi, F. P. (2013). Energy Efficiency: Towards the End of Demand Growth, Elsevier Science.

[259] Lutz Mez (2005). RENEWABLE ENERGY POLICY IN GERMANY – INSTITUTIONS AND MEASURES PROMOTING A SUSTAINABLE ENERGY SYSTEM. Freie Universität Berlin, Environmental Policy Research Centre.

4.3.3.2 *Regime level 1990-2000*

"In the German parliamentary election year of 1998, the legal underpinnings of the energy industry were fundamentally changed. In April 1998, the Christian Democrat-Liberal coalition government had significantly amended the EnWG and, in a stealth operation, completely opened up the electricity and gas markets in Germany – at least on paper."[260] At the regime level of Germany's energy system, restructuring occurred in the 1990s due to the external pressures from the EU level and public will. Regarding the development of micro generation, the most influential institutional changes were the liberalization of the electricity market, which destabilized the incumbent system of large-scale electric power plants and provided space for decentralized private producers[261]. The National Climate Protection Programme plus several tax reforms and energy related regulations and programs provided more motivation for the private sector and society to go after decentralization and new technologies. By the lobby from renewable energy associations, the conservatives in the German Parliament cooperated with Conservatives and Liberal government (1990-1998) and initiated the electricity feed-in law[262]. In addition, it was in 1998 that the Social Democrats/Greens coalition decided to phase out nuclear energy by outlawing the construction of new nuclear power plants[263].

4.3.3.2.1 1990 Start National Climate Protection Programme (NCPP)

Due to concerns about climate change, the German government initiated the National Climate Protection Programme in 1990 which later led to the feed-in tariff law in 1991 ("Stromeinspeisungsgesetz"). "Since 1994 Germany has been obliged to prepare, publish and regularly update national emission inventories of greenhouse gases."[264]. In

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[260] Mez, L. (2007). On the Role of the Mass Media in German Energy Policy. Berlin, Environmental Policy Research Centre.

[261] Praetorius, B., et al. (2008). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica Verlag.

[262] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[263] Ibid.

[264] Umweltbundesamt (2005). German Greenhouse Gas Inventory 1990 - 2003 Berlin, Federal Environmental Agency.

1995, the government of Germany promised to reduce the CO_2 emission level in 2005 to a level 25 percent lower than in 1990. A reduction of about 18 to 20 percent was achieved until 2000 by reducing 180 to 200 million tons of CO_2[265].

4.3.3.2.2 1991 Electricity Feed-In Law (StromEinspG)

Based on the electricity Feed-in law, the utilities, which at that time were the owner of the distributed network, were obliged to facilitate access of renewable energy generators to the grid[266]. In addition, they were obliged to buy electricity at the feed-in tariff price that was based on 65 to 90 percent of the average market price per kWh. The feed-in law provided low marginal benefits[267]. On the other hand, the big incumbent utilities started to complain against the feed-in tariff law. For example in 1996 the association of electricity producers (Verband der Elektrizitätswirtschaft (VDEW)) "lodged a complaint with DG Competition (a subdivision of the European Commission) invoking violation of state-aid rules."[268]

4.3.3.2.3 1997 Energy Consumption Labelling Act (EnVKG)

After the initiation of Council Directive 92/75/EEC in 1992 and later the Energy Consumption Labelling Act directive 96/57/EEC at European level, member states were obliged to change the national law for labelling and mentioning product information of the consumption of energy and other resources by household appliances in a standard format.[269] The Federal Ministry of Economics of Germany adapted the concept as Energy Consumption Labelling Ordinance (Energieverbrauchskennzeichnungsverordnung) on

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[265] Lutz Mez (2005). RENEWABLE ENERGY POLICY IN GERMANY – INSTITUTIONS AND MEASURES PROMOTING A SUSTAINABLE ENERGY SYSTEM. Freie Universität Berlin, Environmental Policy Research Centre.

[266] Torsten Brandt, W.-u. S. I. W. (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

[267] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[268] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

[269] Barbara Schlomann, W. E., Edelgard Gruber, Nicola Kling, Wilhelm Mannsbart, Friedemann Stöckle (2001). Evaluating the Implementation of the Energy Consumption Labelling Ordinance, Fraunhofer Institute for Systems and Innovation Research (ISI), GfK Marketing Services GmbH & Co. KG.

30 October 1997 and energy consumption labelling became mandatory from 1998[270] onwards.

4.3.3.2.4 1998 German Energy Act, Liberalization

A liberalized market can potentially cause technological competition, which led to promotion of innovation and diversification in better services and products[271]. Before the German Energy Act of liberalization in 1998, the conventional electricity producers protected their benefits by shaping a strong coalition of actors. In addition, the Federal Economics Ministry, which was responsible for reforms, struggled by frustrating attempts for modernization and liberalization of the German Energy Industry Act (EnWG)[272]. However, the EU common market directive and EU electricity and gas liberalization directive of 1996 put pressure on Germany for changes. The German Energy Industry Act (EnWG) which had not been changed since 1935, adapted to the directive 96/92/EC in 1998 and the electricity market of Germany became 100% liberalized for all segments[273]. In addition, the feed-in law has been modified and provided new income mechanisms for electricity producers[274].

The German public and politicians were focusing more on the unbundling process rather than the emergence of new monopolies and during the adaption of directive 96/92/EC, Germany voted for a “Negotiated third party access” instead of “Regulated

[270] IEA (2012). "Energy Consumption Labelling Act (EnVKG)." from http://www.iea.org/policiesandmeasures/pams/germany/name-21390-en.php.

[271] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

[272] Bruns, E., et al. (2010). Renewable Energies in Germany’s Electricity Market: A Biography of the Innovation Process, Springer Netherlands.

[273] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

[274] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

third party access"[275]. The problem was that the "Negotiated third party access" led utilities to avoid the obligation in grid access to the third parties, which was a barrier in the way of liberalization[276]. It was about 1997, that for the first time, electricity suppliers such as "Badenwerk" and "Energieversorgung Schwaben (EVS)" combined and established the new network energy supply company "Energie Baden-Würtemberg AG". In fact, the merging of the large network energy supply companies was a reaction to the liberalization process[277].

"In Germany energy supply companies are classified in either "network energy supply companies", "regional energy supply companies" or "municipal utilities". They are active at municipal, regional or at supra-regional level. "[278]p. 3.

Before the liberalization, the antitrust authority and the ministries of economics at the federal and state level and municipalities at municipal level were the main regulating actors, which were regulating the price to guarantee supply security and protect the interests of customers. After the liberalization, Negotiated third party access was introduced and played an important role on the federal and state levels for giving grid access to other energy suppliers[279]. Moreover, courts were playing important regulating roles by "proceedings of civil courts and antitrust authorities due to discriminations concerning net entry and net prices for new competitors"[280] p. 13. In fact, the network energy supply companies influenced the legislation of the National Energy Act of 1998 and put many obstacles in the way of the liberalization by lobbying and using their relations with politicians and lawmakers[281]. After the Ministry of Economic Affairs proposed a draft for third party access to the grid and more supervision of the electricity

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[275] Torsten Brandt, W.-u. S. I. W. (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

[276] Ibid.

[277] Ibid.

[278] PIQUE ibid.

[279] Ibid.

[280] Ibid.

[281] Ibid.

price in 1993, municipalities and "opposition signaled by the upper chamber of the German parliament started to be against it. The government proposed the second draft with heavy modifications in 1996[282]. In 1999, new producers entered to the market[283]. The immediate effect of liberalization for the customers was the reduction of the electricity price by 35% for three years until 2001. Due to the price drop, the liberalization amendment became against the DG development at the beginning[284]and was an anti-innovation legislation.

4.3.3.2.5 Ecological tax reform 1999

For improving the energy efficiency of industry, a tax reform was passed[285]. The tax reform was designed to increase the use of electricity instead of mineral oils in industry and target energy improvement. This reform can be seen as the first initiative by new government coalition of Democrats and Greens concerning the environment[286]. The revenue from this tax reform was mostly used for reducing the retirement insurance of employees, which also reduced the costs of employers and led to lower production costs. A small part of revenues from tax reform (about 102 million Euro) was dedicated to the renewable energy subsidies[287].

4.3.3.3 *Niche level (1990-2000)*

Institutional conditions in 1990s were mostly designed around the promotion of renewable energy. As a result, at technology and market niche level renewable energy

[282] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

[283] PIQUE (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

[284] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

[285] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[286] Lutz Mez (2005). RENEWABLE ENERGY POLICY IN GERMANY – INSTITUTIONS AND MEASURES PROMOTING A SUSTAINABLE ENERGY SYSTEM. Freie Universität Berlin, Environmental Policy Research Centre.

[287] Ibid.

technologies developed more than other technologies such as cogeneration for household applications. However, research into other technologies continued, which could be useful for developing micro CHP in household sector. Especially after the Kyoto protocol, many companies developed energy saving technologies for industrial applications such as Organic Ranking Cycles and Micro Turbines, which are based on the same technological concept as micro CHP for household applications. The German Society for Engines and Power Plants (Gesellschaft für Motoren und Kraftanlagen GMK GmbH) which was founded in 1994, started to produce comercialized ORC systems for heat recovery in industries and also geothermal and biomass plants[288].

Other technologies like the Fuel cell were further developed. In 1990, NASA developed the first "Direct Methanol Fuel Cell (DMFC)" which later became one of the options for micro CHP[289]. In 1994, Daimler Benz introduced the first example of a fuel cell powered car[290]. As a first steps in the market of micro CHP, the "Senertec" company (later belonging to British Baxi Group) in 1996 founded and later started to manufacture reciprocating micro and mini CHP systems. It was in 1999 that Power Plus (now a Vaillant subsidiary) introduced the first micro CHP unit based on reciprocating engines to households[291]. In 1999, E.ON founded EFC (European Fuel Cell) for developing fuel cell technology for the household sector[292]. Technological changes at niche level were not limited only on energy conversion technology. Other technologies like Information Technology (IT) played an important role in the development of micro CHP. On one hand, IT provided solution for handling challenges in the way of liberalization by easing the analysis of complex technical information and on the other hand, Improved options

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[288] J. Larjola, L. (2011). Organic Rankine cycle (ORC) based waste heat/waste fuel recovery systems for small combined heat and power (CHP) applications. Small and Micro Combined Heat and Power (CHP) Systems: Advanced Design, Performance, Materials and Applications

R. Beith, Elsevier Science.

[289] Eduardo I. Ortiz-Rivera, R.-H., Rey A. Febo (2007). "Understanding the History of Fuel Cells " IEEE.

[290] NYSERDA (2005). HYDROGEN FACT SHEET History of Hydrogen.

[291] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

[292] Ibid.

for market analysis [293]. In the 1990s, the idea of using the micro turbines for cogeneration purposes in households led to first commercial prototypes prior to 2000 (Beith 2011). In 1999, the consultancy EA Technology decided to introduce the micro CHP based on the Solo sterling engine to the market[294].

4.3.4 Period 2000-2010

4.3.4.1 *Exogenous phenomena at macro level (2000-2010)*

Between 2000 and 2010, 3 main external phenomena at the macro level influenced the regime level and development of decentralized micro energy such as micro cogeneration. The EU directive (2003/54/EC) for liberalization in 2004 and an emission trading scheme in 2005 and the adoption of the 20-20-20 goals by the EU Council in 2007 continued pressure for changes on the European Union policy level. The financial crisis of 2008 was a pressure from global level for some changes and like in the past, the public will about energy systems, put constant pressure on the system for changes. What was in the past a reaction to the oil crises now is a response to climate change caused by emissions of CO2[295].

4.3.4.1.1 EU Directive on Energy Performance of Buildings (2002/91/EC) and Directive (2010/31/EU)

The Directive on Energy Performance of Buildings (EPBD) was passed by the EU commission in 2002 to affect energy performance in EU building sector (Anne Power 2011). This Ordinance and its new version in 2010 (Directive 2010/31/EU), were

[293] Praetorius, B., et al. (2008). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica Verlag.

[294] Beith, R. (2011). Small and Micro Combined Heat and Power (CHP) Systems: Advanced Design, Performance, Materials and Applications, Elsevier Science.

[295] Wüstenhagen, R. and R. Wuebker (2011). The Handbook of Research on Energy Entrepreneurship, Edward Elgar Publishing Limited.

Legislative-Informative policies (Barbara Schlomann 2012). They were the main motivational force for energy efficiency in buildings[296].

4.3.4.1.2 EU Acceleration directive (2003/54/EC) and directive (2003/55/EG)

For increasing the competition in the EU's energy, sector and specifically targeting distributed generation as a grid stabilizer[297], the EU modified the previous liberalization directive (96/92/EC) and obliged changes for regulated third party access to the grid through a regulatory agency (which was previously negotiated access in countries like Germany)[298]. Another main target of this directive was accelerating the implementation of a Single Market in the EU. Therefore, the EU Commission adopted the Acceleration Directive 2003/54/EC in 26 June 2003[299]. In Germany, the implementation was postponed until 2005, which the German Energy Industry Act has been, modified[300]. Besides the electricity market, the EU tried to liberalize the gas market through an EU directive (2003/55/EG), similarly called for competition in the gas market, and regulated access to the gas grid[301]. Both directive 2003/54/EC and directive 2003/55/EG provided more chances for micro CHP development in Europe and Germany.

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[296] European Commission, E. (2014). Progress Report on the application of Directive 2006/32/EC on energy end-use efficiency and energy services and on the application of Directive 2004/8/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market.

[297] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

[298] Torsten Brandt, W.-u. S. I. W. (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

[299] code-project (2009). European Potential for Cogeneration, Progress against the Directive's at European level.

[300] Bruns, E., et al. (2010). Renewable Energies in Germany's Electricity Market: A Biography of the Innovation Process, Springer Netherlands.

[301] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

4.3.4.1.3 European Energy Taxation Directive, ETD (2003/96/EC)

In order to change the behavior of customers to use both more energy efficient technologies and renewables technologies, the EU Commission decided some modifications and new regulations in taxation. As a result, for ensuring the proper implementation without adverse effects on the functioning of the internal market key aspects of energy taxation had been proposed at the EU level under Council Directive 2003/96/EC in October 2003, restructuring the Community framework for the taxation of energy products and electricity[302]. Based on this directive, member states can implement tax exemptions for fuels used for CHP and for electricity production and household sectors[303].

4.3.4.1.4 European CHP Directive (EC 2004)

Five years after proposing a strategy for the promotion of CHP (COM (1997) 514 final), in 2002 the EU send out the final draft of the European Directive on CHP[304]. The goal in this strategy was a non-binding benchmark to double the share of CHP from nine to 18 % by the year 2010. After discussions and improvements from the European Commission, Parliament and Council, the CHP directive (EC 2004) was initiated on 11 February 2004[305]. Directive 2004/8/EC was designed for promotion of cogeneration based on a heat demand in the European energy market. It aimed to make the installation and operation of cogeneration facilities easier and consequently facilitate more energy saving and less climate change. Renovation of the existing CHP plants in the short term is part of the CHP directive and makes it possible to promote new plants. Less GHG emissions and combating climate change were at the core of the CHP directive (not

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[302] European Commission, E. (2011). Proposal for a COUNCIL DIRECTIVE amending Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity. E. COMMISSION. Brussels.

[303] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

[304] LÖFFLER, P. (2002). "THE DRAFT EUROPEAN CHP DIRECTIVE welcome but needs strengthening." James & James **3**.

[305] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

economic benefits), so the creation of a framework for fostering the development of high efficiency CHP systems was another goal of the CHP directive in long-term.[306].

4.3.4.1.5 Emission Trading Directive 2003/87/EC and Introduction of the EU ETS 2005

For reaching the targets set by the European Union in the Kyoto Protocol, the EU proposed the Emission Trading Directive 2003/87/EC in 2003[307]. The directive provided a legal framework for creating a market for trading GHGs in the EU[308]. For influencing the energy efficiency and CO2 emission in EU member states, the EU Emission Trading System (EU ETS) was initiated in 2005 in 25 Member States. EU ETS was an indirect support for micro CHP[309]. In the end, the ETS was responsible for reducing 8% of GHGs from 2008 until 2012 (compared to the level of 1990)[310]. In this regards, the emission trading system directive provided more space for the development of new modern decentralized technologies such as micro CHP, which have higher efficiency in comparison with large power plants fired by fossil fuels[311].

4.3.4.1.6 Incident at the Forsmark nuclear power plant 2006

On 25 of July 2006, due to a sudden electric power loss, the control room of the nuclear power plant at Forsmark Sweden erupted in chaos and the reactors went out of control. The backup systems failed to start. However, after about 23 minutes, the personnel took back control. The main concerns were that without electrical power, the cooling systems would stop and the core of the reactor could heat up to the point of an

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[306] European Commission, E. (2014). Progress Report on the application of Directive 2006/32/EC on energy end-use efficiency and energy services and on the application of Directive 2004/8/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market.

[307] Bruns, E., et al. (2010). Renewable Energies in Germany's Electricity Market: A Biography of the Innovation Process, Springer Netherlands.

[308] Ibid.

[309] Gores, S. J., W.; Harthan, R. (2012). KWK-Ausbau: Entwicklung, Prognose, Wirksamkeit der Anreize im KWK-Gesetz unter Berücksichtigung von Emissionshandel, Erneuerbare-Energien-Gesetz und anderen Instrumenten.

[310] Jansen, D., et al. (2011). Sustainability Innovations in the Electricity Sector, Springer.

[311] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

explosion, similar to what happened in Chernobyl[312].The International Atomic Energy Agency rated the Forsmark incident as a level 2. Which means it was seriously dangerous, but "without consequences to people or to the surrounding environment". The incident led to the temporary shutdown of three other nuclear plants in Sweden for more investigation and precaution and the whole story attracted considerable attention in Germany[313].

4.3.4.1.7 The EU directive on energy efficiency and energy services (Directive 2006/32/EC)

The first energy saving regulation by the EU was introduced in 2002 by reducing the energy intensity level of buildings by 30 % and included some prescriptions for old buildings with weak insulation[314]. Later, in 2006, the European Parliament and Council of the EU initiated a directive for "energy end-use efficiency and energy services" (Directive 2006/32/EC), which had to be ratified by EU governments within two years.[315] Based on the directive, the members should prepare a second national Energy Efficiency Action Plan (EEAP)[316]. The directive emphasized providing information to end customers to make a better decision on their energy consumption[317].

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[312] Philip Bethge , S. K. (2006). Nuclear Scare: How Close Did Sweden Come to Disaster? SPIEGEL ONLINE, SPIEGELnet GmbH.

[313] foratom.org (2006). "orsmark incident rated as a Level 2." from http://web.archive.org/web/20060907111808/www.foratom.org/content/view/295/341/.

[314] Lutz Mez (2005). RENEWABLE ENERGY POLICY IN GERMANY – INSTITUTIONS AND MEASURES PROMOTING A SUSTAINABLE ENERGY SYSTEM. Freie Universität Berlin, Environmental Policy Research Centre.

[315] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

[316] European Commission, E. (2014). Progress Report on the application of Directive 2006/32/EC on energy end-use efficiency and energy services and on the application of Directive 2004/8/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market.

[317] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

4.3.4.1.8 EU Council adopts 20-20-20 goals in 2007

In June 2006, the EU Council renewed the sustainability strategy on renewable energy and climate protection. At the EU Council meeting and under Germany's presidency, in 2007, the targets for climate protection were set[318]. The measure consisted of three main targets to be reached by 2020: the first target was reducing the GHGs by 20 % compared to the 1990s level. The second pillar was increasing the share of renewables to 20% until the year 2020 and the third target was increasing the energy efficiency by 20%, the last one of which was not a binding target[319]. The European member states were requested to formulate national action plans and lay out targets systemically for each energy sectors[320].

4.3.4.1.9 Global financial crisis 2008

The 2008 financial crisis caused lower progress in the EU countries than expected and some energy intensive industries faced decreases in output[321]. Due to the financial crisis, the GDP of Germany was reduced by more than 5%[322]. However, it could not stop progress in the energy sector. On the other hand, the energy intensity increased by 2% during the period from 2009 to 2010, which was also due to the cold weather[323]. The investment from independent investors in green energy technologies in Germany had been reduced due to the crisis[324] . (See figure 4-16)

[318] Bruns, E., et al. (2010). Renewable Energies in Germany's Electricity Market: A Biography of the Innovation Process, Springer Netherlands.

[319] Jones, L. E. (2014). Renewable Energy Integration: Practical Management of Variability, Uncertainty, and Flexibility in Power Grids, Elsevier Science.

[320] Bruns, E., et al. (2010). Renewable Energies in Germany's Electricity Market: A Biography of the Innovation Process, Springer Netherlands.`

[321] European Commission, E. (2014). Progress Report on the application of Directive 2006/32/EC on energy end-use efficiency and energy services and on the application of Directive 2004/8/EC on the promotion of cogeneration based on a useful heat demand in the internal energy market.

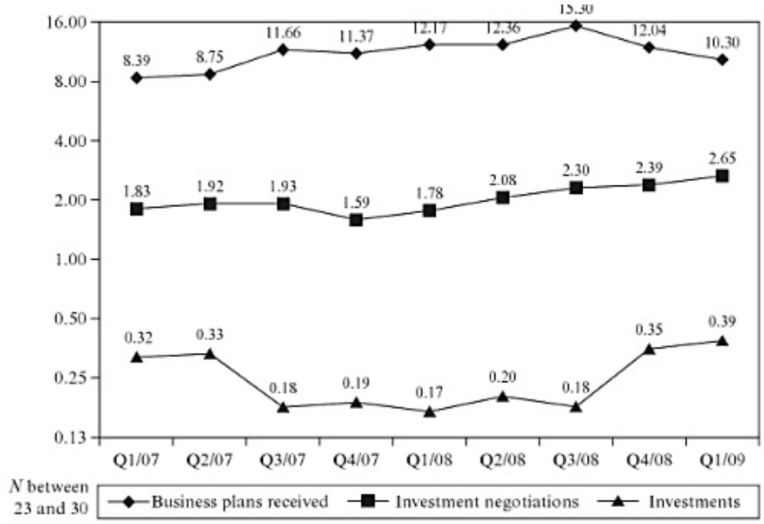
[322] Barbara Schlomann , W. E., Peter Fritzen, Matthias Reuter ,Tobias Schrader (2012). Energy Efficiency Policies and Measures in Germany , ODYSSEE- MURE 2010, Monitoring of EU and national energy efficiency

targets.

[323] Anne Power, M. Z. (2011). Cutting Carbon Costs: Learning from Germany's Energy Saving Program, What Works Collaborative.

[324] Dietmar Grichnik , C. K. (2011). BUSINESS ANGELS AND ENERGY INVESTING: INSIGHTS FROM A GERMAN PANEL STUDY. The Handbook of Research on Energy Entrepreneurship. R. W. Wüstenhagen, R., Edward Elgar Publishing Limited.

Figure 4-16. Effect of Global Financial Crisis on investment in Germany



Source: (Dietmar Grichnik 2011)

4.3.4.1.10 EU Directive 2009/142/EC on Appliances Burning Gaseous Fuels (GAD)

The EU decided to design an operational procedure for ensuring a consistent operational performance and testing for appliances which use gas as fuel. It was an instruction for safety, regulating and controlling devices and sub-assemblies for commercial products, including a range of gas burning appliances that operate up to a temperature of 105 degrees Celsius. On 1 January 1996 Directive 90/396/EEC came into force for gas appliances, particularly those used domestically. Later in 2009, the Directive 90/396/EEC was replaced by Directive 2009/142/EC on Appliances Burning Gaseous Fuels (GAD). The micro CHP systems are included in GDA. In this regard, the GDA caused more innovation in micro CHP development by insisting on combustion standards and installing sensors in appliances for better operation[325].

4.3.4.1.11 Public view 2000-2010

After the technical problems of the Swedish Forsmark nuclear power plant, the Ministry for the Environment (BMU) surveyed public opinion about nuclear energy in

[325] Risk&Policy-Analysts-Limited (2011). EX-POST EVALUATION OF THE GAS APPLIANCES DIRECTIVE.

Germany. The result of the survey (in August 2006) demonstrated that the majority of the German public is against the continuing of nuclear power plants and requested faster phase-out of nuclear power plants[326].

The answers indicated that 71% of people found that the incident had a potentially very high risk. 18% of those surveyed indicated that the incident was as dangerous as Chernobyl in their mind. 53% answered in spite of Germany having the highest safety standards in nuclear power plants worldwide, they still evaluated the risks as too high and unacceptable. Only 2% answered that nuclear energy is safe[327]. Another survey conducted by the soko Institute examined people's opinions about different subsidies paid by the German government. The results of the survey showed the public in Germany disagreeing with subsidies for coal power plants and that there is disagreement about the issue of renewable subsidies[328]. The result is shown in table 4-2. The interviewed persons answered with numbers between -3 (completely disagree) and +3 (completely agree).

Table 4-2. "Survey by the soko Institute 6/2004: Would you welcome or reject a phase-out of subsidies and tax advantages in the following areas?

Item	Mean
Phase-out of hard coal subsidies	2.15
Phase-out of tax advantage for jet fuel	1.82
Phase-out of subsidies for the new Federal states	1.34
Phase-out of agriculture subsidies	1.29
Phase-out of trade fair subsidies	1.24
Phase-out of railway subsidies	1.22
Phase-out of shipbuilding subsidies	1.18
Phase-out of tax exemptions connected to ecotax (electricity and mineral oil tax)	1.08
Phase-out of the feed-in tariff for renewable energies	0.72
Phase-out of subsidies for medium-sized businesses	- 0.88
Phase-out of benefits for the marginally employed (€400 - €800 monthly salary)	-1.24
Phase-out of innovation subsidies	-1.3

Source: (Mez 2007) p. 16

[326] Mez, L. (2007). On the Role of the Mass Media in German Energy Policy. Berlin, Environmental Policy Research Centre.

[327] Ibid.

[328] Ibid.

4.3.4.2 *Regime level 2000-2010*

In 1998, the Conservative-Liberal government was replaced by a coalition of the Social Democratic party and the Green party. The new government spent considerable attention to energy issues and agreed on several policy measures such as an eco-tax reform, improvement of the Feed-in Law and phase-out of nuclear power plants and more supports for renewables and CHP power plants[329]. despite of liberal and conservative's government without the green party in 2005, The coalition government of SPD and CDU, did not change the nuclear policy but it passed a new Integrated Climate and Energy Program (IEKP: Integriertes Energie- und Klimaprogramm) and continued to support renewable energy and energy efficiency policies by increasing support for CHP[330]. The share of CHP in Germany in 2003 was 14.2 % and increased to 16.2% in 2013[331]. Another important factor in the development of micro CHP was the second effort for liberalization. In 2005, the "German Electricity Association" was accused by the "Federal association for renewable energy" for the manipulation of electricity prices. Later, the European Commissioner for Competition accused electricity supply companies of intentionally shutting down power plants in order to reduce the electricity supply and as a result increase the electricity price. In 2006, the European Commission initiated an investigation against E.ON and RWE about corruption of politicians and market manipulation[332]. Such incidents pushed Germany to change the regulations against monopoly and led to better opportunities for independent electricity producers of micro CHP.

[329] Lauber and Mez, L. (2004). "Three decades of renewable electricity policies in Germany." Energy and Environment **15**: 599-623.

[330] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

[331] ProjektIC4-42/13 (2014). Potenzial- und Kosten-Nutzen-Analyse zu den Einsatzmöglichkeiten von Kraft-Wärme-Kopplung (Umsetzung der EU-Energieeffizienzrichtlinie) sowie Evaluierung des KWKG im Jahr 2014.

[332] Torsten Brandt, W.-u. S. I. W. (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

4.3.4.2.1 2000, the Renewable Energy Act (EEG)

The Social Democrats/Greens government argued that the amount of incentives in the Electricity Feed-In Act was not sufficient for the promotion of RE. Then the government replaced the 1991 Feed-In Law with the Renewable Energy Act (EEG) in 2000 for better support of PV, wind and biomass[333]. The key feature of the Renewable Energy Act (EEG) was that it obliged the network operators to buy produced electricity by RE in a fixed feed-in tariff which was much higher than wholesale prices at that time. Moreover, the incentive was guaranteed for 20 years[334]. It provided security for investors. So it protected the RE technologies from the consequences of liberalization in 1998. In the case of micro CHP, a good opportunity was opened because micro CHP plants were using biogas[335].

4.3.4.2.2 CHP Act of 2002

After the first liberalization Act in 1998, the price of electricity was reduced and many CHP plants faced severe problems[336]. A successful advocacy coalition was formed in favor of CHP by the trade union ver.di, NGOs, researchers, some politicians with numerous industrial associations in Germany such as AGFW, B.KWK, and VKU, and with the active support of some international associations such as COGEN Europe[337]. Due to pressures from the advocacy coalition of CHP owners and for both supporting CHP plants and reduction of CO2, the German government approved the first CHP act in 2002[338]. The first CHP act aimed to accelerate the modernization of CHP plants and to

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[333] Bruns, E., et al. (2010). Renewable Energies in Germany's Electricity Market: A Biography of the Innovation Process, Springer Netherlands.

[334] Ibid.

[335] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

[336] Lutz Mez (2005). RENEWABLE ENERGY POLICY IN GERMANY – INSTITUTIONS AND MEASURES PROMOTING A SUSTAINABLE ENERGY SYSTEM. Freie Universität Berlin, Environmental Policy Research Centre.

[337] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

[338] Lutz Mez (2005). RENEWABLE ENERGY POLICY IN GERMANY – INSTITUTIONS AND MEASURES PROMOTING A SUSTAINABLE ENERGY SYSTEM. Freie Universität Berlin, Environmental Policy Research Centre.

help them survive in the market. For this purpose, the Act obliged the network operators to connect CHP plants and to buy electricity from them[339]. he industrial sector in Germany was disagreeing with the first CHP act[340]. Moreover, they started to lobby against it. As a result, the setting of targets and the obligatory approach were abandoned and "replaced by a combination of i) a voluntary agreement between the German government and industry on the reduction of CO2 emissions and the promotion of CHP and ii) a bonus model"[341] p. 190. The changes in the first CHP act initiated the modernization and extension of Combined Heat and Power systems. At that time more than 80% of the micro CHP market was dependent on the replacement of old house boilers. Both the complicated regulations and technical procedures of the installation and use of micro CHP caused customers to not choose micro CHP. The simple plug and play and quick installation of micro CHP was another challenge for the technology, besides it high investment costs[342].

4.3.4.2.3 Energy Saving Ordinance (EnEV 2002 and 2009)

The energy-saving decree (Energieeinsparverordnung, EnEV) was introduced in 2002 as a replacement for the ordinances of insulation in 1995 and heating installations in 1994[343]. For the implementation of the first European Directive on Energy Performance of Buildings (2002/91/EC) the Energy-saving decree (EnEV 2002) was revised in 2007 and forced to action in 2009[344]. The EnEV was an important part of the energy and climate program "Integriertes Energie- und Klimaprogramm (IEKP) by the German government

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339 Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

340 Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

341 Ibid.

342 code2-project (2013). CODE2 Cogeneration Observatory and Dissemination Europe,First draft of final CHP roadmap GERMANY.

343 Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

344 BBSR, B. f. B. S. u. R. (2013). "Energy Saving Ordinance (EnEV)." from http://www.bbsr-energieeinsparung.de/EnEVPortal/EN/EnEV/enev_node.html.

for regulating energy certifications and energy efficiency of new buildings[345]. The new energy efficiency highlighted the importance of other ways for energy supply like micro CHP in buildings. There were standards for designing new building with floor areas above 1000 m^2, forcing planners to consider all alternatives for energy efficient technologies (as well as micro CHP) before construction[346].

4.3.4.2.4 National Energy Act of 2005

Five years after the German Energy Act of liberalization in 1998, the intended level of competition in the electricity market of Germany had not been reached. Three "associations 'agreements" were conducted to modify the energy act but these modifications did not achieve the desired effects[347]. In Table 4-3, the changes in the electricity market before the German Energy Act of liberalization in 1997 and after 2004 are summarized. After the first liberalization act, the monopoly of big utilities increased in the generation sector from 79% to 95% by a reduction in the number of producers from 8 to 4 big utility companies. In the transmission sector, the four electricity producers owned 100% of transmission. In the distribution sector (low voltage), several companies merged. Moreover, the four big producers increased their share in sales to 72% in 2004, which stood at less than 60% prior to the first liberalization in 1997. After the Acceleration Directive 2003/54/EC, the pressures from the European Committee on Germany increased and the second amendment to the Energy Industry Act was initiated in 2005[348]. Based on the new amendment, Germany decided to change the system of negotiated access to the grid with the regulated access[349]. After the second amendment, the situation started to improve. Monopoly power decreased and improved competition

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[345] buildup.eu (2012). German Energy Saving Ordinance 2009 (EnEV 2009), http://www.buildup.eu/.

[346] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

[347] Torsten Brandt, W.-u. S. I. W. (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

[348] Bruns, E., et al. (2010). Renewable Energies in Germany's Electricity Market: A Biography of the Innovation Process, Springer Netherlands.

[349] Hans-Böckler-StiftungBrandt (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

in the market. Figure 4-17 compares four dimensions of the liberalized market after the second liberalization act in 2005 and before it in 1998. There was a 22% reduction in the number of municipal utilities between 1998 and 2005, from 900 to 700[350]. However, after the liberalization process in 2005 the ownership structure of more than 50% of municipal utilities changed to a private form[351].

Table 4-3. Electricity market of Germany before first and before the second liberalization act

	Before the process of liberalization 1997	**After the process of liberalization in 2004 and before 2005 liberalization amendment**
Generation (not capacity)	8 network energy supply companies with 79% of electricity production, regional energy supply companies with 10%, municipal utilities with 11%	Network energy supply companies with 95.6% : RWE: 38.7% E.ON: 26.5% EnBW: 13.8% Vattenfall Europe: 16.2%
Transmission	8 network energy supply companies with 100% in their territories	100% share by 4 network energy supply companies
Distribution (at low voltage power supply)	80 regional energy companies - 900 municipal utilities	50 regional energy supply companies - 700 municipal utilities
Sales to end consumers	5 network energy supply companies (50%-60%), Distribution (at low voltage power supply) (40%- 50%)	Companies with 72.8%: RWE: 16.8% E.ON: 22.1% EnBW: 19.5% Vattenfall Europe: 14.4%) - 700 municipal utilities - regional producers

Source: (Hans-Böckler-StiftungBrandt 2006)

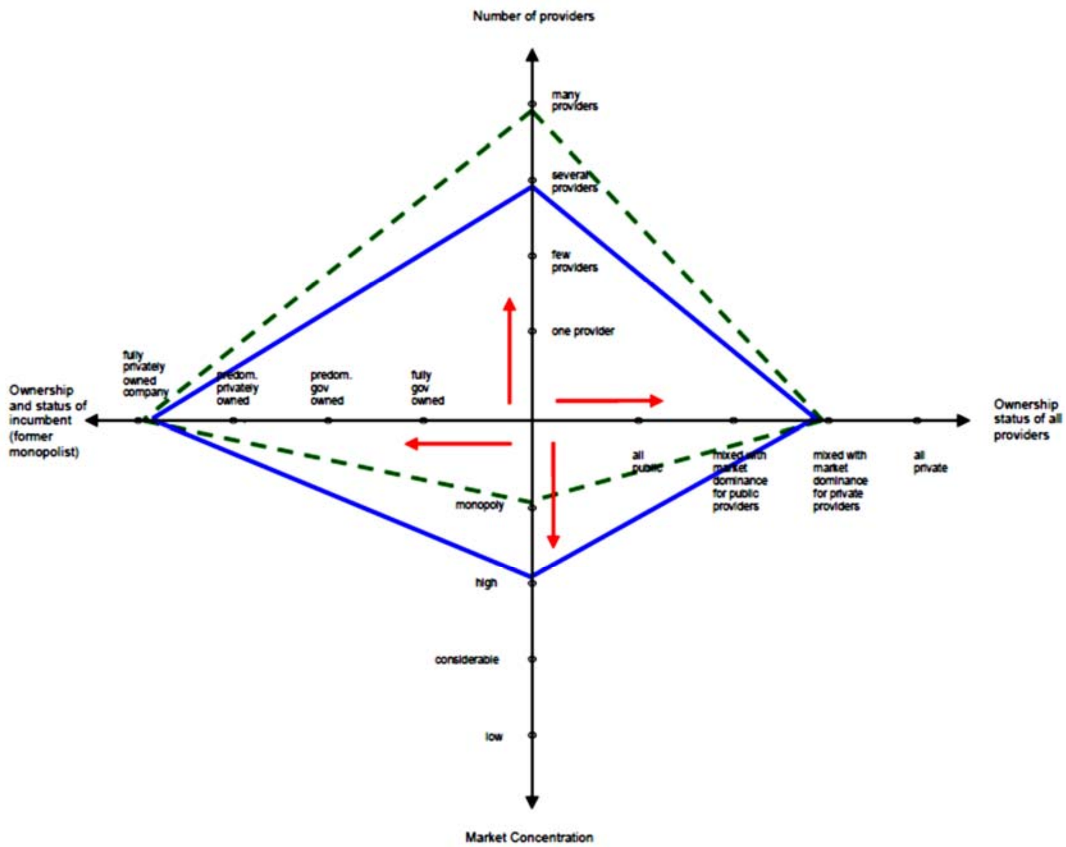
After the National Energy Act of 2005, many municipalities and energy companies that had more than 100,000 customers were obliged to unbundle their retail sector from their distribution activities. They had to accomplish this by establishing two separate

[350] PIQUE ibid.

[351] Ibid.

companies or letting other investors or companies operate the separated part[352]. The obligation for energy companies to unbundle their generation and network activities and the replacement of negotiated access with a regulated mechanism, helped to relieve the discrimination against micro CHP operators for access to the network[353].

Figure 4-17. "Electricity Germany (generation and supply) Green dashed line before liberalisation, blue full line after liberalisation."



Source: (pique 2007) p. 37

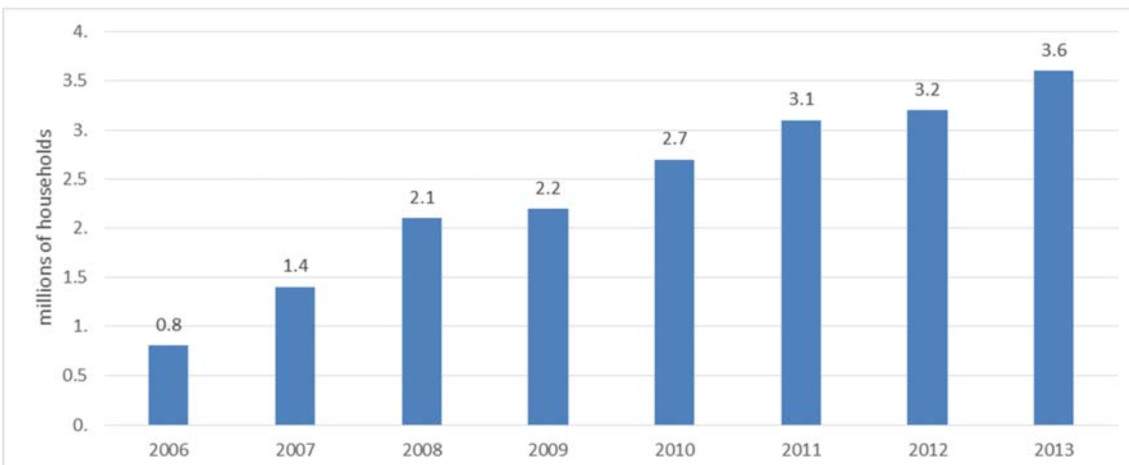
In 2005 the "Federal association for renewable energy" for electricity price manipulation criticized the "German Electricity Association" and later, the European Commissioner for Competition accused network energy supply companies of

[352] Julian, C. (2014). Creating Local Energy Economies: Lessons from Germany.

[353] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

intentionally shutting down power plants in order to reduce the electricity supply and as a result increasing the electricity price. In 2006, the European Commission initiated an investigation against Eon and RWE about corruption of politicians and market manipulation[354]. One indicator for liberalization is the number of households, which changed their electricity provider. Because when households have many options for choosing a service provider, more of them make a decision to change it. As a result, the more diverse suppliers are, the higher the probability of households changing their electricity provider. Figure 4-18 shows the trend of electricity supplier change by households in Germany. After the liberalization, the number of households who changed their supplier increased by 75% and increased from 800 thousand in 2006 to 3.6 million households in 2010.

Figure 4-18. Number of Households (in Million) changed their electricity provider



Source: (BUNDESKARTELLAMT 2014)

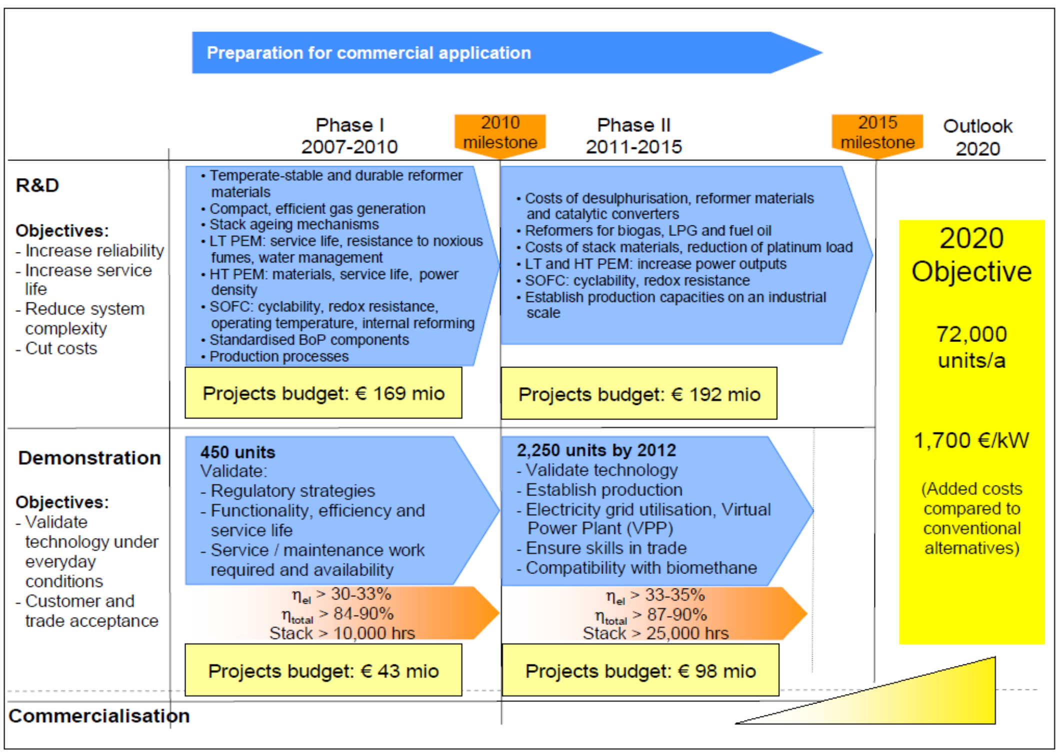
4.3.4.2.5 National Hydrogen and Fuel Cell Technology Innovation Programme 2006

In order to promote the fuel cell technology from a niche technology to the market level and helping it toward market maturity in Germany, the "National Innovation Programme" (NIP) of Hydrogen and Fuel Cell Technology was initiated in 2006. The German government and the private sector provided 1.4 billion euros in funding over a

[354] PIQUE (2006). Liberalisation, privatisation and regulation in the German electricity sector. Country reports on liberalisation and privatisation processes and forms of regulation, Hans-Böckler-Stiftung.

ten year period. the Federal Ministry of Transport and Digital Infrastructure (BMVI) and the Federal Ministry of Economic Affairs and Energy (BMWi) are responsible for an amount of 700 million euro and the rest is provided by industrial partners[355]. 9% of the budget is spent for the development of stationary household fuel cell technology and the rest dedicated to industrial and transport applications[356]. In the roadmap for market introduction of stationary household fuel cell technology, two main phases predicated. In The first phase, (from 2007 to 2010), 450 units predicted for demonstration, with a total budget of 45 million euro. In the second phase, from 2011 to 2015, 2500 units are planned. The project aimed to fill market demand for stationary household fuel cell in 2020 with 72000 units per year and the price of 1700 euro per kWe [357](See figure 4-19).

Figure 4-19. roadmap for development of stationary application both for industrial and household



Source: (Brennstoffzellen 2007)

[355] Now_GmbH (2013). ANNUAL REPORT, National Organisation Hydrogen and Fuel Cell Technology.

[356] Ibid.

[357] Brennstoffzellen, S. W. (2007). National Development Plan Version 2.1 for the “Hydrogen and Fuel Cell Technology Innovation Programme”, National Organisation Hydrogen and Fuel Cell Technology.

4.3.4.2.6 The Renewable Energy Heat Act (EEWärmeG 2009)

In order to reinforce the development of renewables, the German government decided to increase the share of renewable energy use for heating and cooling by 14% until 2020. To this end, the government introduced a new law to oblige new buildings to supply at least 50% of their heating and cooling from renewable sources of energy[358]. The Renewable Energy Heat Act (EEWärmeG) was initiated in 2009 and allowed buildings to use district heating and energy recovery from waste for covering their 50% share[359].

4.3.4.2.7 Integrated Energy and Climate Programme of the German Government 2007

For implementation of its Kyoto Protocol commitments (to reduce 21% GHG emission between 2008 and 2012 from the 1990 level), in 2007, the German government integrated its strategies as "Integrated Energy and Climate Programme"[360]. To this end, the government set targets for industrial sectors. power plants obliged to reduce their emission by 15% of the level years 2000-2002. The CHP plants and other industries asked for 1.25% emission reduction[361].

4.3.4.2.8 First National Energy Efficiency Action Plan (NEEAP) 2007

Germany has its own ambitious target for energy saving by increasing energy efficiency by 100% until 2020 based on the 1990 level. However, in accordance with the EU Directive on "energy end-use efficiency and energy services" (2006/32/EC), EU member states must reduce 9% of the average annual consumption of all energy users covered by Directive 2006/32/EC during the last five years before 2005. Germany paid more attention to the electricity sector as it represents 61% of the total available potential. The Federal Ministry of Economics and Technology (BMWi) took responsibility for NEEAP[362]. Within the framework of NEEAP, the German Energy Agency has supported

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[358] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[359] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

[360] Kerr, T. (2008). CHP/DHC Country Scorecard: Germany. France.

[361] Ibid.

[362] BMWi (2011). Second National Energy Efficiency Action Plan (NEEAP) of the Federal Republic of Germany Pursuant to the EU Directive on Energy End-use Efficiency and Energy Services (2006/32/EC).

the financing of programs in the housing sector for the use of electricity and information technology for implementation of more cogeneration and renewables. Many other stimulus programmes for Mini CHP plants in the context of the CHP Act of 2002 and the Ecotax law of 2003 can be seen as a part of the National Energy Efficiency Action Plan (NEEAP)[363].

4.3.4.2.9 An amendment of the CHP act from 2008

The CHP act of 2000 has been modified in 2008 in order to promote a higher CHP share in the German energy system. The new amendment aimed for 25% of cogeneration share in the energy system in 2020 and proposed more incentives by introducing CHP bonus and avoiding the usage of grid bonuses[364]. The extra bonus was set to 5.11 cents per kWh for micro CHP operators[365]. Observers saw a general ambiguity and confusion of processes and procedures, which increased the transaction costs by involvement of many administrators. The lack of a comprehensive and consistent national policy regarding micro CHP urged the German government to initiate programs for providing specific investment and subsidies targeted at micro CHP[366]. Prior to 2005, the share of micro CHP in total electricity supply was less than 1 percent and reached 3.2% in 2010 (see Figure 4-20). Nevertheless, the share of heat from micro CHP was always less than 1% of total heat supply in the residential sector until 2010.

4.3.4.3 *Niche 2000-2010*

The Federal Government of Germany assigned 4.4 billion euro in subsidies for combined heat and power (CHP) stations with an electricity output of less than 2 MW as well as micro CHP technologies such as fuel cells and other cogeneration technologies. 100 million euro was spent by the Federal Ministry of Economics and Labour, the Federal

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[363] BMWI (2007). National Energy Efficiency Action Plan (EEAP) of the Federal Republic of Germany, in accordance with the EU Directive on “energy end-use efficiency and energy services” (2006/32/EC).

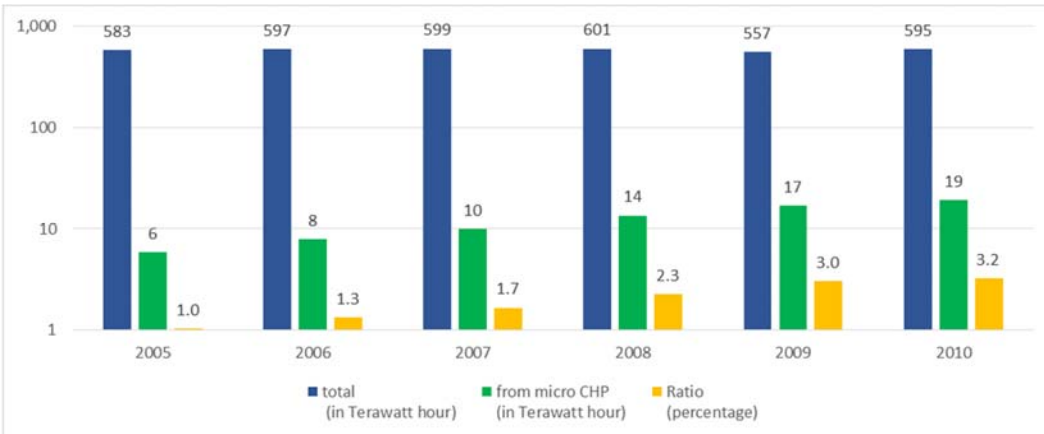
[364] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[365] Boehnke, J. (2007). Business Models for Micro CHP in Residential Buildings. School of Business Administration, St Gallen,. **PhD**.

[366] ELEP (2005). Interconnection of decentralised electricity generation: a review of standards, technical requirements and procedures in the EU-15.

Environment Ministry, and the Federal Ministry of Education and Research for the development and demonstration of fuel cell projects between 2001-2003[367].

Figure 4-20. The share of micro CHP in final electricity supply and its ratio with Total supply of electricity in Germany



Source: data adapted by Author from (StatistaGmbH 2014)

Boiler and big CHP technology manufacturers and some big utilities (like Eon) purchased several dependent micro CHP technology developers like Senertec and PowerPlus and later developers of other technologies however, the micro CHP played little role in the whole energy system of Germany[368].

4.3.4.3.1 Reciprocating and Stirling engine micro CHP

Until 2008, the micro CHP market was dominated by plants based on reciprocating engines which were the only technology in the niche market. The German market was dominated by products of Senertec and Power Plus, development of whose products started in 1990s[369]. The Sterling micro CHP systems were still in a technology niche until the mid-2000s. A linear free piston Stirling engine (LFPSE) micro CHP was developed by the BG Group from a US (Sunpower) design which was intended for wall-mounting.

[367] EuropeanCommission (2005). Assessing the International Position of EU's Research and Technological Development and Demonstration (RTD&D) on Hydrogen and Fuel Cells EUR, Institute for Prospective Technological Studies.

[368] Praetorius, B., et al. (2008). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica Verlag.

[369] Ibid.

Later a 1 kWe was developed by MEC, a consortium of gas boiler companies (Viessmann, Baxi, Vaillant, Remeha) and Sunpower intended for marketing before 2010. Two UK boiler companies started to market the same technology in 2010. In Japan, the Rinnai in collaboration with Ariston (formerly MTS), Bosch and Enatec started to produce 1000 units planned to be sold from 2008–2010 on the European market[370]. In 2003, the Japanese car producer Honda introduced a 1 kW reciprocating micro CHP unit to the Japanese market. In 2004, the British energy supply company Powergen (E.ON UK) decided to install 80.000 Whisper Tech Stirling micro CHP systems in the UK until 2020. In 2006, Senertec announced that it produced more 15,000th "Dachs" micro CHP unit and at the same year, the German company PowerPlus Technologies (Vaillant) sold more than 2000 Ecopower micro CHP systems[371]. In 2007, the German company Sunmachine GmbH introduced the first wood pellet Stirling engine with 1.5 to 3 kWe output power[372].

4.3.4.3.2 Fuel cell micro CHP

Between 2000 and 2010, Japan, Germany and South Korea were pioneer countries in the demonstration and commercialization of small and micro fuel cell technologies in the world[373]. The years 2000 to 2010 can be seen as the take up period for fuel cell micro CHP technologies. Thousands of prototypes have been sold and many projects implemented in the household sector at the technology niche level. Many technologies for fuel cell application in houses were developed by increasing the lifetime of the plant and its efficiency and costs. In fact, one of the biggest technological barriers for fuel cells was their very short lifetime, which was less than a year. Figure 4-21 shows how the

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[370] Harrison, J. (2011). Stirling engine systems for small and micro combined heat and power (CHP) applications. Small and Micro Combined Heat and Power (CHP) Systems: Advanced Design, Performance, Materials and Applications

R. Beith, Elsevier Science.

[371] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

[372] bhkw-prinz.de (2014). BAFA-Förderung für Mini-KWK-Anlagen inkl. Tabelle, bhkw-prinz.de.

[373] Iain Staffell, R. G. (2012). The cost of domestic fuel cell micro-CHP systems, Imperial College Business School, Imperial College London, UK.

lifetime of PEFC (Proton Exchange Fuel Cells) which is the best technology for home applications improved until 2010 and provides opportunities for shaping a market niche. Three companies, Baxi Innotech (PEMFC), Hexis and Vaillant (both SOFC) started to manufacture FC micro CHP in Germany in 2008 and installed 100 units[374]. Between 2001 and 2010, the average price of PEFC micro CHP systems with output power less than 5 kWe, decreased from more than 80,000 euro to about 20,000 euro. These were introduced by Japanese companies, mainly by Panasonic[375]. The boiler manufacturer Boxi developed two fuel cell micro-CHP units Beta 1.5 in 2005 and Beta 1.5 PLUS in 2008. The Japanese EneFarm in cooperation with Panasonic, Tokyo Gas Co., Ltd and Kyocera developed a 1 kWe PEMFC micro-CHP system that runs on natural gas and planned for its marketing by installing 50 units between 2003 and 2005 and the demonstration of 3000 units until 2009[376]. The real creation of a market niche for fuel cells started in 2009 after the first plants from a mass production line were introduced by EneFarm which intended to sell 10000 units and planned to double sales in 2011[377]. In Table 4-4 the targets of world leading manufactures are summarized and it is shown how the micro CHP market planed for dominance of FC technology after 2010. The South Korean government paid subsidies with an amount of 80% of the purchasing price to support the 500 residential power generators in 2004. Later, four Korean companies (GS Fuel Cell, FuelCell Power, HyoSung and LS) introduced FC micro CHP for households and with 18 million dollars supports from the government 210 units had been installed between 2006 and 2009[378]. most of FC micro CHP demonstrations were from Germany. More than 90% of all patents

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[374] D. J. L. Brett, N. P. B., et al. (2011). Fuel cell systems for small and micro combined heat and power (CHP) applications. Small and Micro Combined Heat and Power (CHP) Systems: Advanced Design, Performance, Materials and Applications

R. Beith, Elsevier Science.

[375] Ibid.

[376] Riffat, T. E. a. S. B. (2014). State of the Art Review: Fuel Cell Technologies in the Domestic Built Environment. Progress in Sustainable Energy Technologies Vol II: Creating Sustainable Development

I. Dincer, A. Midilli and H. Kucuk, Springer International Publishing.

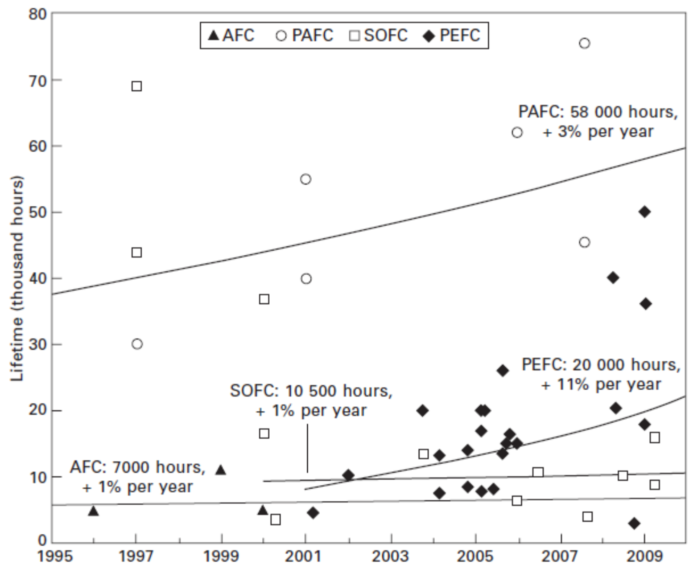
[377] D. J. L. Brett, N. P. B., et al. (2011). Fuel cell systems for small and micro combined heat and power (CHP) applications. Small and Micro Combined Heat and Power (CHP) Systems: Advanced Design, Performance, Materials and Applications

R. Beith, Elsevier Science.

[378] Gangi, S. C. a. J. (2014). 2013 Fuel Cell Technologies Market Report. Washington, D.C. , Breakthrough Technologies Institute, Inc.

in the EU came from Germany. The majority of FC micro CHP demonstrations were from Germany.

Figure 4-21. Improvement of the fuel cell lifetime from 1995 to 2010



Source: (D. J. L. Brett, A. D. Hawkes et al. 2011) p.252

More than 90% of all patents in the EU came from Germany. Germany, after the Japan, is the leader of micro CHP in the EU and also in the world[379]. Until 2005, Germany placed number one in the EU with 350 organisations and 2800 employees in the FC industry and with more than 34% of total activities in the industry of FC (See figure 4-22)[380]. In 2008, Germany started its biggest project for developing residential FC micro CHP in Germany by investing 1 billion euros. The project was named Callux by the Federal Ministry of Transport, Building and Urban Development and facilitated the cooperation of nine industries as part of the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP).

[379] EuropeanCommission (2005). Assessing the International Position of EU's Research and Technological Development and Demonstration (RTD&D) on Hydrogen and Fuel Cells EUR, Institute for Prospective Technological Studies.

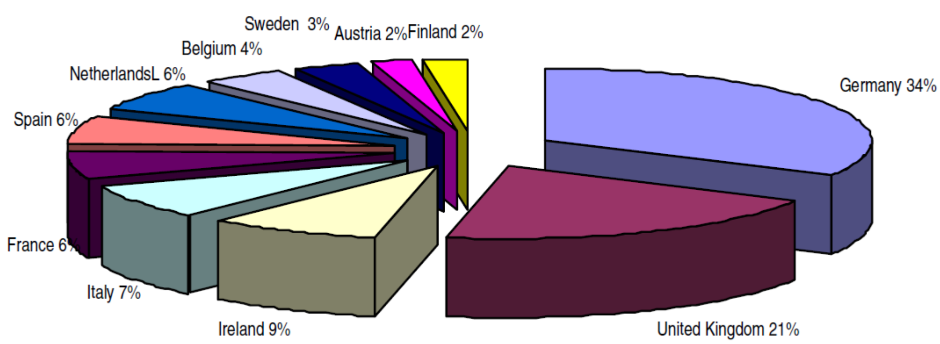
[380] Ibid.

Table 4-4“Expectations and targets given by the manufacturers and government bodies involved with world-leading fuel cell demonstrations”

Technology / Region		Year for projection	Production volume	Price (2010 USD)	Description
PEMFC	South Korea	2010		$15,500	Target cost stated in the 2008 Korean national action plan.
		2012	10,000 cumulative	$10,500	Target price set in 2008 by the Ministry of Knowledge Economy.
		2012		$20,000	Targets set out in the KOGAS roadmap for small stationary fuel cells.
		2030		$3,000–5,000	
	Japan	2010	10,000 p.a.	$20,250	Estimated manufacturing cost for EneFarm systems made by the manufacturers.
		2012	50,000 p.a.	$6,000–10,500	The METI technology roadmap for production cost of residential cogeneration systems.
		2015	500,000 p.a.	$4,500–6,000	
		2015	100,000–200,000 p.a.	$4,250	Target prices announced by Panasonic in 2008 and ENEOS in 2011.
		2020-2030	“widespread dissemination”	$3,500	The METI technology roadmap for production cost of residential cogeneration systems.
SOFC	Japan	2015	50,000 p.a.	$4,000	Target price announced by JX Nippon for the launch of EneFarm-S in Germany.
		2015	“several thousand” p.a.	$8,500 / kW	The METI technology roadmap for production cost of residential cogeneration systems.
		2020-2030	“widespread dissemination”	$3,500 / kW	
		–	“mass production”	$5,000	Osaka Gas and Kyocera’s expectation for retail price under full dissemination.
	Australia	–	“mass production”	$5,500–7,000	Statements from CFCL on the eventual price of the BlueGen when mass produced.

Source: (Iain Staffell 2012) p. 12.

Figure 4-22. “Distribution of EU fuel cell industry”



Source: (EuropeanCommission 2005) p. 21

Four boiler manufacturers, BAXI INNOTECH, Hexis, Vaillant and Viessmann plus five energy suppliers, EnBW, E.ON Ruhrgas, EW, MVV Energie and VNG Verbundnetz

Gas gathered together to form a partnership[381]. Development of ICT and smart grid provided to be the fundamental infrastructures for distributed generation and further development of micro-CHP. According to Table 4-5, Germany stands in rank six among the top ten countries by supporting Smart Grid.

Table 4-5. Top Ten Countries by Smart Grid Stimulus in 2010

Country	Rank in net Stimulus	amount in million US $	Rank in Stimulus Per Capita
China	1	7,323	6
US	2	7,092	1
Japan	3	849	5
South Korea	4	824	3
Spain	5	807	2
Germany	6	397	7
Australia	7	360	4
UK	8	290	8
France	9	265	9
Brazil	10	204	10

Source: (CABA 2010)

There are 40 million households in Germany, but in 2006 only 21,600 Micro cogeneration units with a total capacity of 38 MW had been globally installed, which was 23% more than in 2005 but still not an impressive number[382].

4.3.5 Period 2010-2014

4.3.5.1 *Macro level 2010-2014*

4.3.5.1.1 Energy performance of Buildings Directive (2010/31/EU)

In the directive 2010/31/EU, micro-CHP systems are considered as part of energy efficiency policies for improving the energy efficiency in building[383].

[381] Callux (2008). Callux: Field tests on fuel cells for single-family homes, Callux.

[382] Praetorius, B., et al. (2008). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica Verlag.

[383] Santarelli, M. (2014). European-wide field trials for residential fuel cell micro-CHP, Politecnico di Torino.

4.3.5.1.2 Nuclear disaster in Fukushima 2011

On 11 March 2011, an earthquake with magnitude of nine on the Richter scale hit the east coast of Japan. A 15-meter tsunami created by an earthquake killed more than 19,000 people. After 3 days, due to the power loss and lack of cooling, the core of three nuclear reactors was damaged and melted down[384]. A huge amount of radioactive materials leaked out. In Germany, the government is responsible for the safety of nuclear power plants, the safety review of reactors and the shut-down of old reactors[385].

Prior to the disaster in Fukushima, the government tends to keep nuclear power plants. in one hand it intended to increase nuclear tax earn at least 2.3 billion Euros per year and on the other hand to use the flexibility of nuclear power plants for compensation of renewable fluctuations in the electricity grid. Because nuclear power plants are able to work between 10% of their maximum load and change their output power with a rate of 100 MW per hour (for a 1000 MW power plant), this flexibility made them ideal for dealing with instabilities caused by renewables in the electricity grid[386]. The Germany political regime was deeply influenced by the Fukushima disaster and due to the huge amount of required investment for nuclear safety, a turnover in energy policy took place in the country. Germany decided to accelerate the phase out of nuclear power plants and put more emphasis more on the use of natural gas, coal and renewable resources[387] (Josef Auer 2012).

4.3.5.1.3 EU Energy Efficiency Directive EED (Directive 2012/27/EC)

The Energy Efficiency Directive 2012/27/EU (EED) is obligatory for EU Member States by June 2014. Directive 2012/27/EU led to many improvements for cogeneration in the European legislative area and had positive effects for the development micro-CHP

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[384] WorldNuclearAssociation (2015). "Fukushima Accident (Updated February 2015)." from http://www.world-nuclear.org/.

[385] Schneider, L. (2006). Economics of Micro Cogeneration. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

[386] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

[387] Josef Auer, E. H. (2012). "Germany's energy turnaround :Challenging for municipalities and municipal utilities." DB Research Management.

technologies as well[388]. Based on Directive 2012/27/EC, member states intended to assess the potential and implementation of District Heating and Cooling (DHC) integrated with CHP systems and cogeneration units with a maximum capacity below 50 kWe. Moreover the European members were encouraged to eliminate the institutional barriers for the connection of micro-CHP systems to the grid and simplifying the installation procedures as a simple plug and play[389].

4.3.5.1.4 European Parliament Micro generation Resolution (adopted on 12th September 2013)

The European Parliament Micro Generation Resolution in 2013 emphasized the potential of micro-CHP for energy saving in buildings.[390]

4.3.5.1.5 The Situation in winter 2011–12 and 2012–13

At the end of December 2011, an extremely cold weather hit Eastern and Central Europe including Germany. For about two weeks in early 2012 (27 January - 10 February 2012), temperatures climbed below -40°C. Hundreds of people were killed and energy demand increased rapidly[391]. As a result, a tense electricity supply situation occurred in Germany, which could have led to a blackout[392]. In addition to the tight situation for the electricity grid, the unexpected shortage in supply of natural gas led to some gas-fired power plants being unable to work at their full capacities. After these problems, construction of new power capacity and a capacity market became important[393]. To prevent this situation from happening again, Germany kept itself ready for the next winter with enough power capacity. However, the winter 2012/2013 was not as cold as during

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[388] COGENEurope (2014). COGEN Europe Position Paper: Micro-CHP delivering energy savings in the framework of Energy Efficiency Directive.

[389] Santarelli, M. (2014). European-wide field trials for residential

fuel cell micro-CHP, Politecnico di Torino.

[390] Ibid.

[391] Forecasting, I. (2012). February 2012 Global Catastrophe Recap, Impact Forecasting.

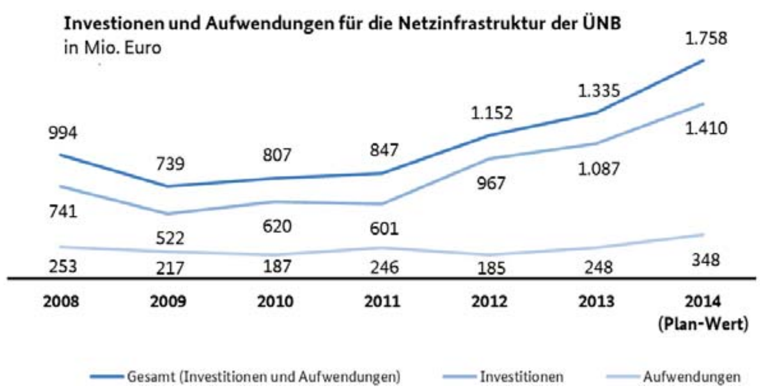
[392] BNetzA (2012,). Bericht zum Zustand der leitungsgebundnen Energieversorgung im

Winter 2011/12.

[393] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

the previous year and even more renewable resources like sun and wind were available. Because of oversupply of electricity, the market price in the exchange market first became zero and then negative[394]. Some technical problems occurred in the grid. The new power lines between north and south became more necessary and new debates regarding renewables have been started[395]. Some ideas regarding the management of produced electricity from renewable sources when it is not required, such as converting the excess electricity to hydrogen or even methane (power to gas) became prominent in the debate[396]. After the incident, the German government and electricity suppliers increased the investments in grid infrastructure on both high and low voltage levels (See Figures 4-23 and 4-24).

Figure 4-23. The investment and costs in Germany for distribution system operators' (DSOs) grid infrastructure



Source: (BUNDESKARTELLAMT 2014)

Besides those incidents, as Figure 4-25 shows, the supply failure time reduced constantly which is a sign of good preparation of the supply system.

4.3.5.1.6 Public view 2010-2014

The Fukushima disaster led to a higher demand for green energy. In April 2011, Süddeutsche Zeitung, published the result of a survey by Verivox about the opinion of German people in different states (Länder) about green energy before and after the

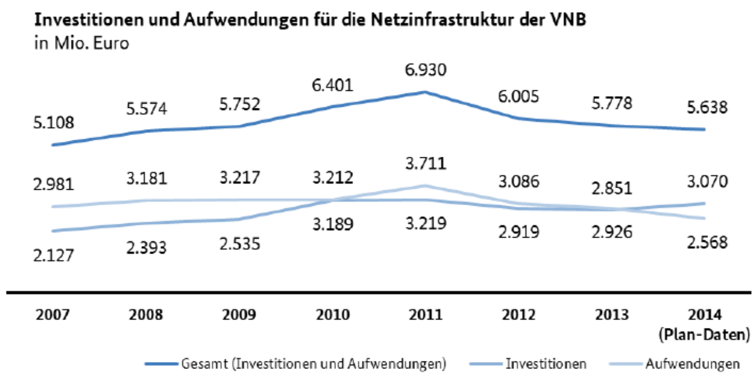
[394] BNetzA (2013). Bericht zum Zustand der leitungsgebundenen Energieversorgung im Winter 2012/13. Bundesnetzagentur.

[395] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

[396] Agora-Energiewende (2013). 12 Insights on Germany's Energiewende. Berlin, Agora Energiewende.

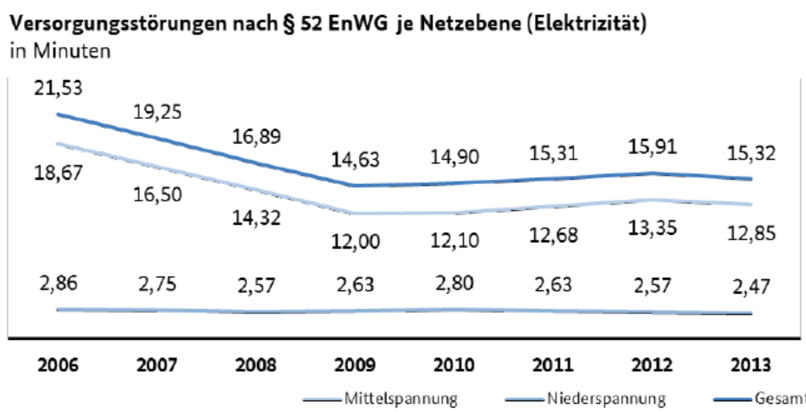
Fukushima disaster (See Figure 4-26). The survey showed a big influence of the incident on the public opinion in favor of green energy technologies.

Figure 4-24. The investment and costs in Germany for transmission system operators grid infrastructure



Source: (BUNDESKARTELLAMT 2014)

Figure 4-25. Supply failure in Germany's high voltage grid in minutes



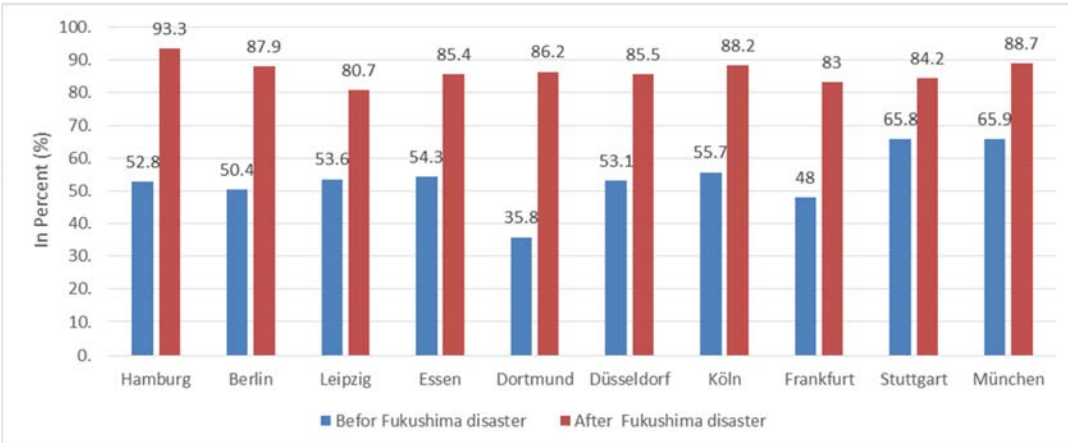
Source: (BUNDESKARTELLAMT 2014)

Despite of more support for green energy from the German public, the drastically increase of electricity prices for household (the highest relative to purchasing power in the world) made green technologies less popular than in the past[397]. Another survey by TNS Emnid in 2011 from 1.000 person above 14 years old showed that 33% of questioned people in Germany are not in favor of electricity from green sources if this led to any

[397] IEA (2012). ELECTRICITY INFORMATION. IEA STATISTICS.

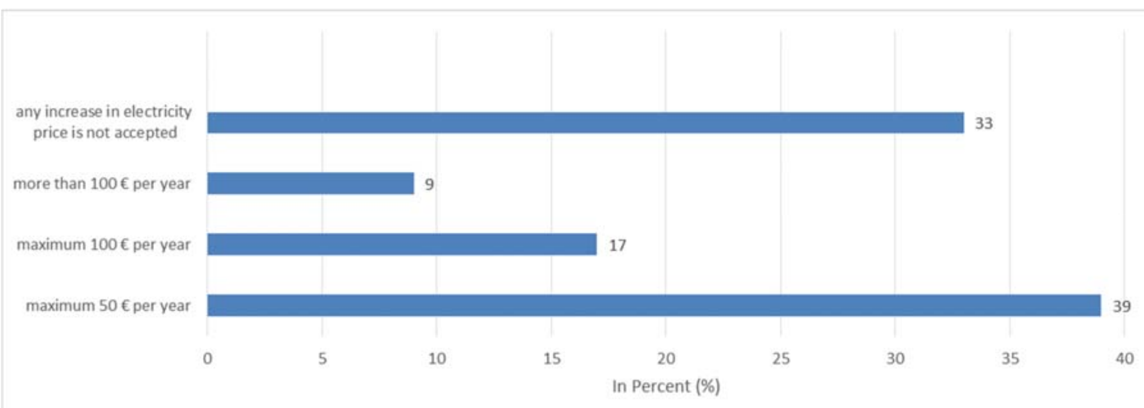
increase in the electricity price. Also only 9% answered that they would accept an increase of more than 100 euro per year in their costs for more green energy. The majority of 39% answered that they would at most accept 50 euros of additional costs per year for electricity from green resources as well as micro-CHP[398]. (See Figure 4-27)

Figure 4-26. Percent of answers regarding the change to green energy sources before and after the Fukushima disaster



Source: (StatistaGmbH 2015)

Figure 4-27. Do you agree to pay more for green energy?



Source: (StatistaGmbH 2015)

[398] StatistaGmbH (2015). Wären Sie prinzipiell bereit, für Ökostrom mehr zu bezahlen?, StatistaGmbH.

4.3.5.2 *Regime level 2010-2014*

In 2010, the government of Germany decided to keep nuclear power plants operational, but after the Fukushima nuclear disaster, this decision had been changed and the eight oldest nuclear power plants in Germany were shut down[399]. The cold winter of 2011 and the negative price of electricity in the next year showed how the development of renewables could be risky for the economy. On the one hand, the low price of CO2 emission certificates in the European Emissions Trade System (ETS) and on the other hand, the dilemma of energy security led to more conservative policies regarding the phase-out of carbon intensive coal power plants in Germany. In 2012, the Government road map indicated that the goal of reducing emissions to 40% below the 1990 level by 2020 could not be reached[400].

In the market, still the four big utilities of Eon, RWE, EnBW and Vattenfall produce 80% of electricity. However, development of distribution power generation like renewables and small CHPs provides a brighter future for liberalization. Moreover the cooperatives energy company model (Stadtwerk) has become more common in recent years and about 450 new energy cooperatives have been formed both to provide generation and a local grid in the 5 years before 2012[401]. Another structural change at the governmental level was changing the previous institutional setting for managing the energy transition and initiating a new ministry of energy. Prior to 2010, most responsibilities for the Germany energy transition were concentrated at the Ministry of Economy in cooperation with the Ministry of Environment and the Ministry of Traffic. Later, the name of "Ministry of Economy and Technology" was changed to "Ministry of Economy and Energy". Responsibilities regarding the Energiewende such as renewables and climate change policies were transferred from the Ministry of Environment to the new Ministry of Energy. Moreover, the Ministry of Environment became responsible for housing and urban planning which previously was the responsibility of the Ministry of

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[399] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[400] OECD (2014). OECD Economic Surveys GERMANY.

[401] Buchan, D. (2012). The Energiewende – Germany's gamble, Oxford Institute for Energy Studies.

Traffic[402]. One of the main objectives of the coalition agreement between the CDU, CSU and SPD after the formation of a new government in 2013 was strong support for the reduction of energy consumption in Germany. The coalition government enforced a further increase in the CHP bonus by 0.3 cents per kWh. The increased funding for CHP is financed by a levy on electricity prices[403].

4.3.5.2.1 Energy Concept for an Economically Sound, Reliable and Affordable Energy Supply 2010

In 2010, the German government approved the "Energy Concept for an Economically Sound, Reliable and Affordable Energy Supply" and submitted it to the parliament. This document mapped Germany's energy policy until 2050. In 2011, the government adopted a supplementary package including measures for faster implementation of the "Energy Concept"[404]. In 2010, the German government submitted the energy concept to the parliament. The most controversial parts were the following issues:

- Extending the lifetime of nuclear power plants by 14 years for power plants, which went to operation after 1980, and 8 years for plants with starting dates earlier than 1980[405].
- Subsidizing renewables and other climate protection programs by earning required funds from the profits of the prolongation of nuclear power and earning tax from nuclear fuel for 2.3 billion euro per year[406].

The submitted energy concept in 2010 raised criticism among opposition groups; mostly the SPD and five SPD-governed states submitted their complaints to the Germany Constitutional Court in 2011. They claimed that the new law violated the rights of the

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[402] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

[403] senertec (2015). "KWK-Wochenende: Kraft-Wärme-Kopplung live erleben." from http://kwk-wochenende.de/2014/01/kwk-wochenende-kraft-waerme-kopplung-live-erleben/.

[404] Germany, F. g. o. (2010). The Federal Government's energy concept of 2010 and the transformation of the energy system of 2011.

[405] Jahn, J. (2011). Länder reichen Klage gegen Atomlaufzeiten ein Frankfurter Allgemeine Zeitung.

[406] Ibid.

states[407]. Table 4-6 shows the other targets in the Energy Concept (2010). A survey indicated that a large majority of Germans prefers more expensive electricity prices without nuclear power, 80% want all nuclear power plants to close and only 10% rejected to pay the additional costs due to a phase-out[408]. After the Fukushima disaster, the energy concept was amended. The amendment changed the previous law of prolonging nuclear plants' lifetime and proposed a plan for the faster phase-out of nuclear power plants. As a result, in 2011 more than 40% of nuclear power plants were shut down. Gas power plants and a higher share of renewables replaced their capacity. (See Figure 4-28).

Table 4-6. Quantitative targets in the energy concept submitted to parliament in 2010

	2011	2020	2030	2040	2050
Greenhouse Gas Emissions					
Greenhouse Gas Emissions (in contrast to 1990)	26.40%	40%	55%	70%	80% to 95%
Efficiency					
reduction in Primary energy use (in contrast to 2008)	6.00%	20%			50%
Energy productivity (final energy use)	2.0% per year (2008-2011)	2.1% per year			
reduction in Gross electricity consumptior	2.10%	10%			25%
Share of CHP-generated electricity	15.4% (2010)	25%			
Buildings					
Heating demand reduction		20%			
Primary energy demand reduction					in the order of 80%
Refurbishment rate	1% per year	doubling 2% per year			
Transport					
Final energy use reduction	around 0.5%	10%	40%		
Number of electric vehicles	ca. 6600	1 millon	6 million		
Renewable energy sources					
Portion of gross electricity consumption	20.30%	at least 35%	at least 35%	at least 50%	at least 80%
Portion of gross final energy consumption	12.10%	18%	30%	45%	60%

Source: (BMWi. 2012)

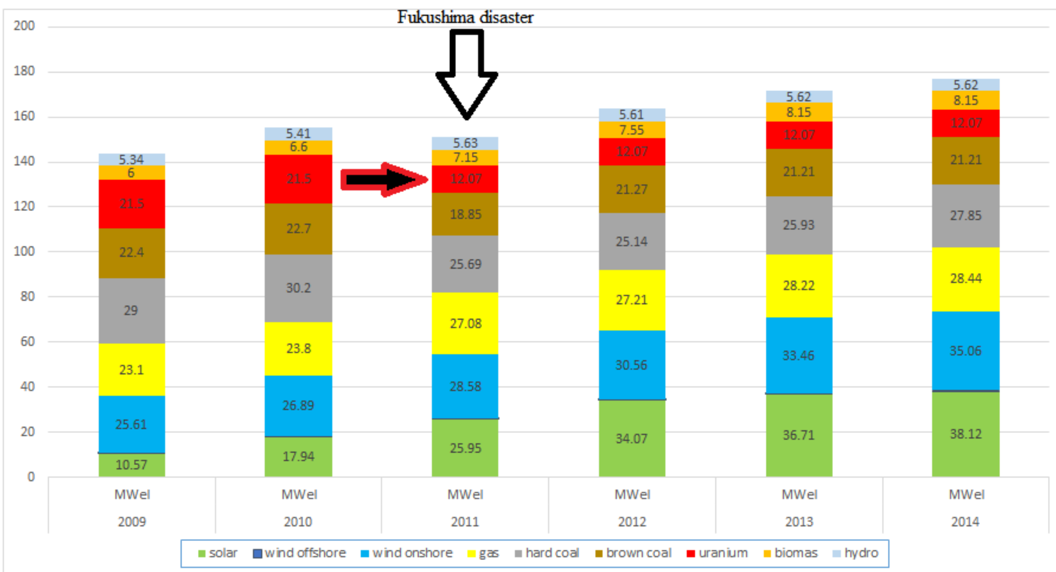
In general, it can be concluded that the phase-out of nuclear power opened more space for other technologies like renewables and high efficient technologies such as micro-CHP and fuel cells. "The Energy Concept of 2010 was the first policy document presented to parliament to give a comprehensive compilation of energy targets (derived

[407] Ibid.

[408] rp-online (2011). "Umfrage: Deutsche akzeptieren höhere Strompreise für Atomausstieg." from http://www.rp-online.de/wirtschaft/umfrage-deutsche-akzeptieren-hoehere-strompreise-fuer-atomausstieg-aid-1.2002006.

from an 80% plus reduction target for GHG) as well as a comprehensive list of instruments and measures to achieve the targets based on scenario evaluation. To make the 80% target more manageable and avoid postponing decisions into the future it is broken down into decennial steps. At the same time a review every three years is introduced to oversee the effectiveness of the measures taken and if necessary correct them."[409] p. 38. Moreover, after the Energy Concept of 2010 and its amendment in 2011 for the shutdown of nuclear power plants, the liberalization accelerated. As Figure 4-29 shows, despite the big share of 4 big producers, the trend of changes is positive and shows a 10% shift of supply from four big utilities in 2010 to other suppliers in 2014.

Figure 4-28. Installed electricity production capacity in German according to the fuel type



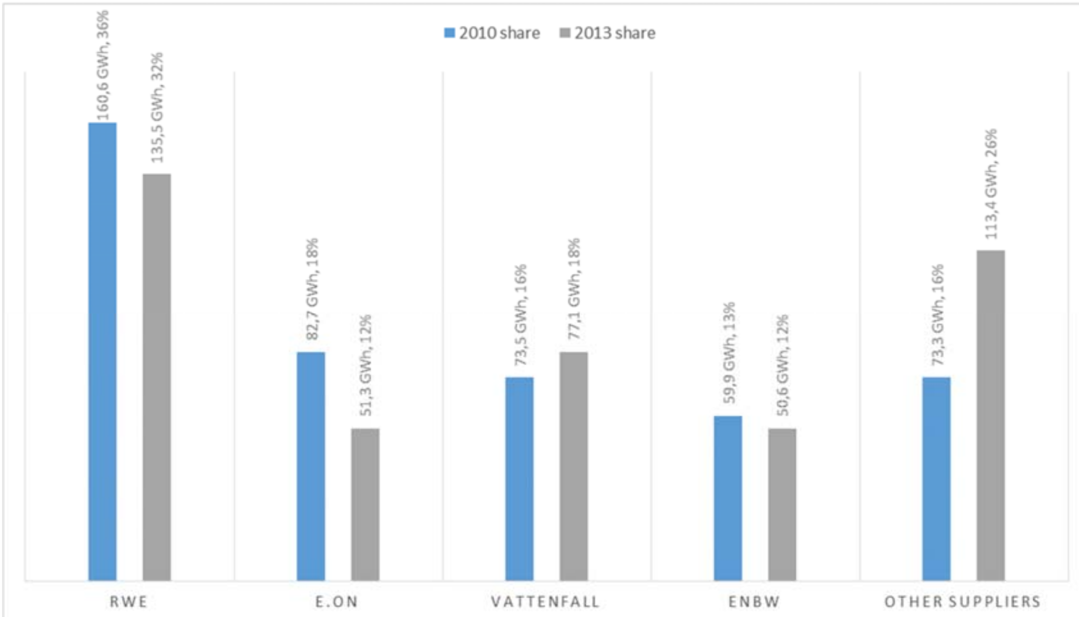
Source: Author (adapted data from (FraunhoferISE 2015))

4.3.5.2.2 The second and third National Energy Efficiency Action Plan (NEEAP) (2011 and 2014)

The first NEEAP was introduced in 2007 and based on the EU Directive on Energy End-use Efficiency and Energy Services (2006/32/EC). In 2011, the Federal Ministry of Economics and Technology submitted the second National Energy Efficiency Action Plan (NEEAP) of Germany.

[409] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

Figure 4-29. Comparison of the share of four big utilities in the German energy supply in 2010 and 2014



Source: (BUNDESKARTELLAMT 2014)

In a top-down approach, the second German NEEAP used aggregated statistical data and energy efficiency indicators (published by the European Commission in 2010) and showed significant improvements in energy efficiency in all consumption sectors since the first NEEAP[410]. Based to the NEEAP, Germany achieved the target of a 9% energy efficiency increase in 2016 compared to the average of energy efficiency in the years 2001 to 2005. The monitoring report in 2011 pointed to the importance of new contracting, the awareness of the public about energy efficiency and support of small

[410] Barbara Schlomann , W. E., Peter Fritzen, Matthias Reuter ,Tobias Schrader (2012). Energy Efficiency Policies and Measures in Germany , ODYSSEE- MURE 2010, Monitoring of EU and national energy efficiency

targets.

cogeneration as well as micro-CHP technologies[411]. In 2014, the Federal Republic of Germany approved the 3rd NEEAP following the EU Directive 2012/27/EU[412].

4.3.5.2.3 Renewable Energy Act (EEG): amendment 2012 and 2014

The cost of subsidizing renewable energy in Germany has increased constantly and reached the level of 0.8% of GDP in 2014. All these costs are paid mostly through the higher price of electricity for households. Firms are exempted from the renewables surcharge[413]. The electricity price increased from 0.15€ in 2000 to 0.25€ per kWh in order to support the renewables. However, energy intensive industries are exempted from the renewables surcharge[414]. In 2012, on the other hand, the incidents of power shortages in winter 2012 and the negative market price in 2013 showed that the development of renewables must be managed better and there is a need for new regulation. As a result, the German government reduced the feed-in tariff and obliged big renewable producers to sell the produced electricity at the market price and broadened the range of electricity users paying the surcharge[415]. In the renewable energy act of 2014 (EEG 2014), even CHP plants are obliged to pay the renewable surcharge and only micro-CHPs are exempted[416].

4.3.5.2.4 "Second Energy Saving Ordinance" (EnEV 2013)

To implement the European Directive on Energy Performance of Buildings (2010/31/EU) and integrate it into the Energy Concept in 2011, the German government published the Energy Saving Ordinance (EnEV 2013) on 21 November 2013, which came into force on 1st May 2014 and replaced the Energy Saving Ordinance of 29th April

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[411] Dickel, R. (2014). The New German Energy Policy: What Role for Gas in a De-carbonization Policy?, Oxford Institute for Energy Studies.

[412] BMWi (2014). 3rd National Energy Efficiency Action Plan (NEEAP) 2014 for the Federal Republic of Germany , pursuant to Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency.

[413] OECD (2014). OECD Economic Surveys GERMANY.

[414] Advisory, P. (2013). Decarbonisation and the Economy An empirical analysis of the economic impact of energy and climate change policies in Denmark, Sweden, Germany, UK and The Netherlands. PwC.

[415] OECD (2014). OECD Economic Surveys GERMANY.

[416] Kraft-Wärme-Kopplung, B. (2014). Eigenverbrauchsregelung nach §61 EEG 2014, BKWK.

2009[417]. The EnEV reduced the standards of minimum energy intensity of new buildings by an average of 12.5% in 2014 and 2016[418].

4.3.5.2.5 New amendment of the EEW-G of July 4, 2013

In 2006, the EU commission decided to promote renewable energy by increasing the share of renewables in the heating and cooling of buildings by 20% until 2020. Germany approved the Renewable Energy Heat Act (EE-Wärme-G) in 2009[419]. Since the coming into effect of the Renewable Energy Heat Act (EE-Wärme-G) all owners of newly built buildings, are obliged to partially cover the heat demand of their buildings through renewable energies[420]. As an "alternative implementation" to fulfill the EE-Wärme-G, building owners should acquire at least 50% of the heat for their building directly from high-efficiency CHP plants as well as district heating[421].

4.3.5.2.6 CHP Act Amendement (Kraft-Wärme-Kopplungsgesetz (KWKG 2012))

After the second CHP act in 2009, the analysis showed that a share of 20% CHP by 2020 could not be reached[422]. In 2012, the government decided to increase incentives such as the CHP bonus in the amount of a few cents per kWh produced electricity and add the Emission Trading Scheme bonus of about 0.3 cents for CHPs larger than 4 MW output power. Moreover, in the context of the energy concept, the target of a 20% share of CHP by 2020 was changed to 25%[423]. The regulation is analyzed completely in the next chapter. It must be considered that despite of thousands of installed micro-CHP units every year (see Figure 4-30), the capacity of micro-CHPs constitutes a small share of other bigger CHP plants (see Figure 4-31).

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[417] BBSR, B. f. B. S. u. R. (2013). "Energy Saving Ordinance (EnEV)." from http://www.bbsr-energieeinsparung.de/EnEVPortal/EN/EnEV/enev_node.html.

[418] ENTRANZE (2013). Overview of the EU-27 building policies and programs. Factsheets on the nine Entranze target countries Cross-analysis on Member-States' plans to develop their building regulations towards the nZEB standard, ENTRANZE.

[419] lpb-bw (2015). "Das Erneuerbare-Energien-Wärmegesetz (EEWärmeG)." from http://www.lpb-bw.de/eewaermeg.html.

[420] AGFW (2015). "EEWärmeG und Fernwärme."

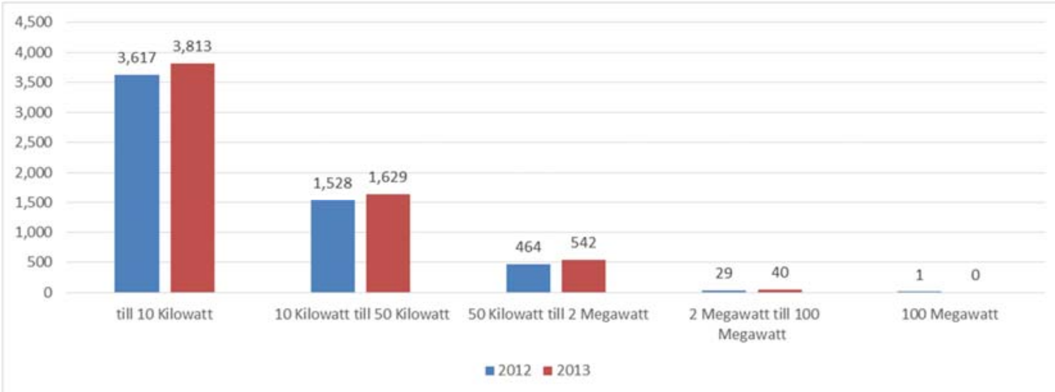
[421] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

[422] Golbach, A. (2012). GERMAN POLICY AND MARKET UPDATE. COGEN Europe Webinar.

[423] ASUE-Arbeitskreis „Brennstoffzellen/BHKW“ (2012). Das KWK-Gesetz 2012,

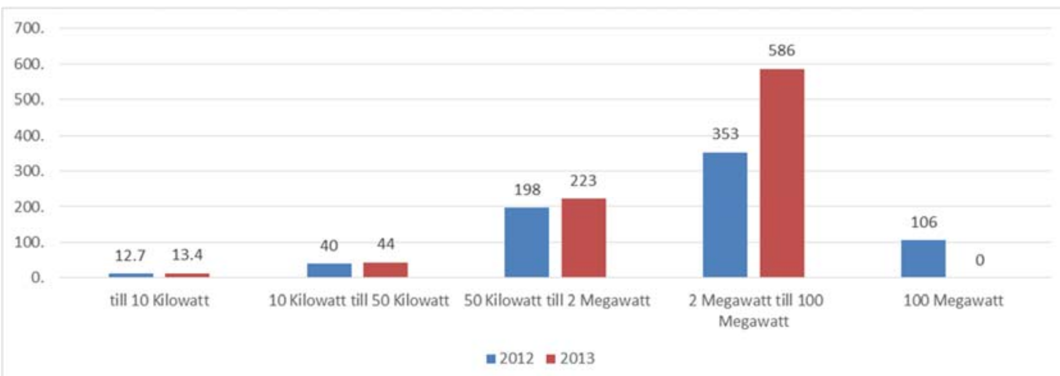
Grundlagen, Förderung, praktische Hinweise.

Figure 4-30. Number of installed CHP plants in Germany in the years 2012 and 2013



Source: (BAFA 2015)

Figure 4-31. Installed capacity of CHP plants (MW) in Germany in the years 2012 and 2013



Source: (BAFA 2015)

4.3.5.3 *Niche level 2010-2014*

The years after 2010 can be seen as new age for Fuel Cell micro-CHP. The Japanese company EneFarm in cooperation with Panasonic, Eneos (JX Nippon Oil & Sanyo) and Toshiba has sold more than 65,000 systems worldwide since 2009, mostly in Japan, and plays a very important role in shaping the global niche market for FC micro-CHP. Other Japanese companies like Kyocera and Eneos started to sell the product in 2012. The governments of Japan and South Korea have planned a widespread commercialization in 2015–2020. In the Callux program three manufacturers, Hexis, Vaillant (both SOFC) and Baxi Innotech (PEMFC) planned to install 800 units until 2012 in Germany but because of technical problems, only 200 units were installed[424]. The IEA forecasts a full commercialization of micro-CHP in Europe in 2020 with a demand of 72,000 units per year[425]. Germany planned for 500,000 fuel cell vehicles by 2020[426]. Such a plan requires many technological developments, which directly affects the FC micro cogeneration market. During the Callux project in Germany three manufacturer installed 100 FC micro-CHP units until 2010 and the installation of 800 units was planned until 2012[427]. The fuel cell micro-CHP technology is very close to full commercialization. Until 2012 around 11,000 units were installed worldwide and around 7,000 of these are micro-CHP systems of less than 10 kWe, 80 % PEMFC and 20 % SOFC[428] (Riffat 2014). In 2014, three FC micro-CHP units were introduced by Callux for the residential sector. All units consume natural gas as an input fuel and have 1kWe output power. Boxi and other manufacturers tried to reduce the production cost and increase the performance. These three systems have specifications, which are very suitable for the household sector and the replacement of boilers (see Figures 4-32, 33 and 34).

Figure 4-32. Baxi Innotech fuel cell micro-CHP model: GAMMA PREMIO

CHP section	
Type	low-temperature PEM fuel cell (70 °C)
Output (e/th)	max. 1.0 kWe/1.87 kWth
Modulation range	approx. 100 – 40% PeN
Fuel	natural gas, biomethane
Electrical efficiency (NCV)	34,1 %
Thermal efficiency (CHP)	62,0 %
Total CHP efficiency	96,1 %
Integrated auxiliary heater	
Type	condensing appliance
Output	3,5-20 kW
Efficiency	109 % (ηN at 40/30 °C)
Complete system	
Dimensions (mm)	600 long x 600 wide x 1,515 high
Weight	235 kg
Housing	coated, fully enclosed
Natural gas pressure	20/25 mbar (EN 437)
Electrical connection	230 V/50 Hz
Operating mode	power-controlled, heat-controlled, energy manager-controlled; central control (virtual power plant)

Source: (callux 2014)

[424] Gangi, S. C. a. J. (2014). 2013 Fuel Cell Technologies Market Report. Washington, D.C. , Breakthrough Technologies Institute, Inc.

[425] Ibid.

[426] IPHE (2010). 2010 Hydrogen and Fuel Cell Global Commercialization & Development Update.

[427] D. J. L. Brett, N. P. B., et al. (2011). Fuel cell systems for small and micro combined heat and power (CHP) applications. Small and Micro Combined Heat and Power (CHP) Systems: Advanced Design, Performance, Materials and Applications

R. Beith, Elsevier Science.

[428] Riffat, T. E. a. S. B. (2014). State of the Art Review: Fuel Cell Technologies in the Domestic Built Environment. Progress in Sustainable Energy Technologies Vol II: Creating Sustainable Development

I. Dincer, A. Midilli and H. Kucuk, Springer International Publishing.

Figure 4-33. Hexis fuel cell micro-CHP model: Galileo 1000 N

CHP section	
Type	solid oxide fuel cell (SOFC)
Output (e/th)	1.0 kWe/1,8 kWth
Modulation range	100-50%
Fuel	natural gas, biomethane
Electrical efficiency (NCV)	> 30 – 35%
Total CHP efficiency	> 95% (at 40/30 °C)
Integrated auxiliary heater	
Type	condensing appliance
Output	4 – 20 kW
Efficiency	109% (ηN at 40/30 °C)
Complete system	
Total efficiency	> 95% (according to EN 50465 at 60/40 °C flow/return)
Dimensions (mm)	620 long x 580 wide x 1,640 high
Weight	approx. 170 kg
Housing	coated, fully enclosed
Natural gas pressure	20-25 mbar (EN 437)
Electrical connection	230 V/50 Hz
Operating mode	heat-controlled, energy manager-controlled; remote control option

Source: (callux 2014)

Figure 4-34. Vaillant fuel cell model micro-CHP

Type	solid oxide fuel cell (SOFC)
Output (e/th)	max. 1.0 kWe/2.0 kWth
Application	single-family home
Fuel	natural gas, biomethane
Electrical efficiency (NCV)	31 %
Total CHP efficiency	87 %
Appliance data	
Dimensions (mm)	600 long x 625 wide x 986 high
Weight	approx. 150 kg
Housing	coated, fully enclosed
Natural gas pressure	20-25 mbar (EN 437)
Electrical connection	230 V/ 50 Hz
Operating mode	heat-controlled, energy manager-controlled; remote control option
External peak heater	
Type	condensing appliance
Output	configuration as required by user
Efficiency	109% (ηN at 40/30 °C)

Source: (callux 2014)

One of the important characteristics of these systems is their size, which enables them to be installed inside the house and not just in the basement. However, these systems are still bigger than current home boilers. In Japan, EneFarm hoped to sell 50,000 units by 2015 and 2.5 million by 2030[429]. The biggest market share globally belongs to Japan; in 2013, most available technology in Europe came from Germany. (See Table 4-7).

[429] Ibid.

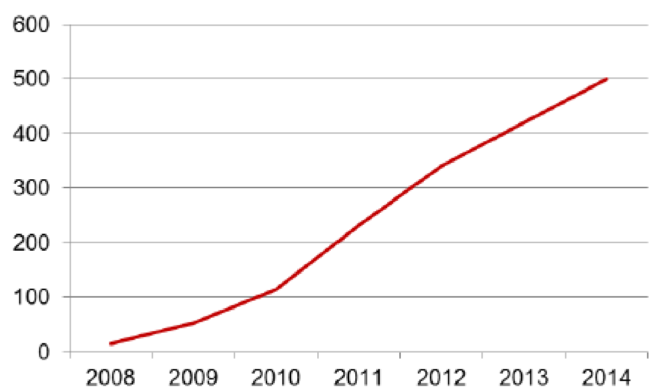
Table 4-7. Micro-CHP products available in Europe in 2013 "ICE = internal combustion engine, SE =Stirling Engine"

Manufacturer	Product name	Techno-logy	Capacity (kWe)	First commercialised
BDR Thermea	Senertec Dachs	ICE	5.5	Germany, 1997
	Ecogen / eVita	SE	1	UK, 2010
	Senertec Stirling SE	SE	1	Germany, 2011
Kirsch Energy Systems	L4.12	ICE	4	Germany, 2011
	Nano	ICE	1.8	Germany, 2013
Lion Energy	Powerblock	SE	1.5	Germany, 2011
Proenvis	Primus 1.4	ICE	4	Germany, 2011
	Primus 5.2	ICE	1.9	Germany, 2013
RMB	Neotower	ICE	5	Germany, 2011
Vaillant	Ecopower 3.0	ICE	3	Germany, 2009
	Ecopower 4.7	ICE	4.7	Germany, 2005
Vaillant / Honda	Ecopower 1.0	ICE	1	Germany, 2010
Viessmann	Vitotwin	SE	1	Germany, 2011
	Vitobloc EM-5/12	ICE	5	Germany, 2012
Yanmar	CP5	ICE	5	Japan, 2002

Source: (Dwyer 2014)

In order to analyze entrepreneurial activities, it is interesting to notice how venture capital from private investors flows to FC development in Germany. Despite the fact that, after the year 2000, 90% of all patents in FC in Europe came from Germany, there is not a single German company among the top 10 FC investors (See Table 4-8). When it comes to venture capital and private investment, Germany ranks 7th among the top 10 countries with 5% of VC in US and 17% of total VC in UK. Figure 4-35 indicates the accumulated number of installed FC micro-CHP in Germany by the Callux program.

Figure 4-35. Accumulated number of installed FC micro-CHP in Germany by Callux



Source: (callux 2014)

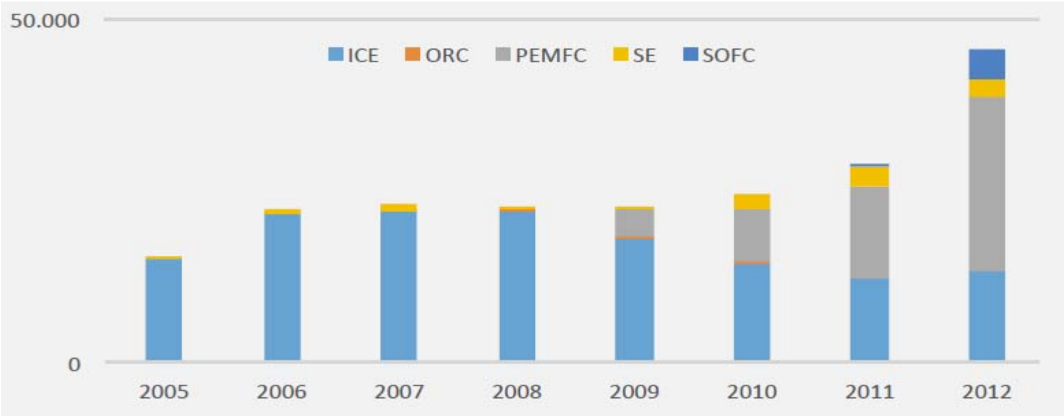
Table 4-8. "Top Ten Venture Capital and Private Equity Investors in Fuel Cells, By Company and By Country (Cumulative 1/1/2000-12/31/2013)"

Top Ten Fuel Cell Investors		**Top Ten Countries with Highest Levels of Private Investment in Fuel Cells**	
Company	Amount (millionUSD)	Country	Total All VC and PE Investment (million USD)
Credit Suisse (Switzerland)	136.2	U.S.	789.9
Kleiner Perkins Caufield & Byers (U.S.)	105.7	U.K.	243.1
New Enterprise Associates (U.S.)	71	Switzerland	156.5
Mobius Venture Capital, Inc. (U.S.)	68.2	Canada	73.8
GSV Capital Corp. (U.S.)	54.2	Singapore	50
DAG Ventures LLC (U.S.)	54.2	New Zealand	50
Rolls-Royce Holdings PLC (U.K.)	50	**Germany**	**42.5**
Enertek Services Pte Ltd (Singapore)	50	Sweden	23.6
Superannuation Fund (New Zealand)	50	Russian Federation	21
Meditor Capital Management (U.K.)	36.7	Denmark	20

Source: (Gangi 2014) p. 8

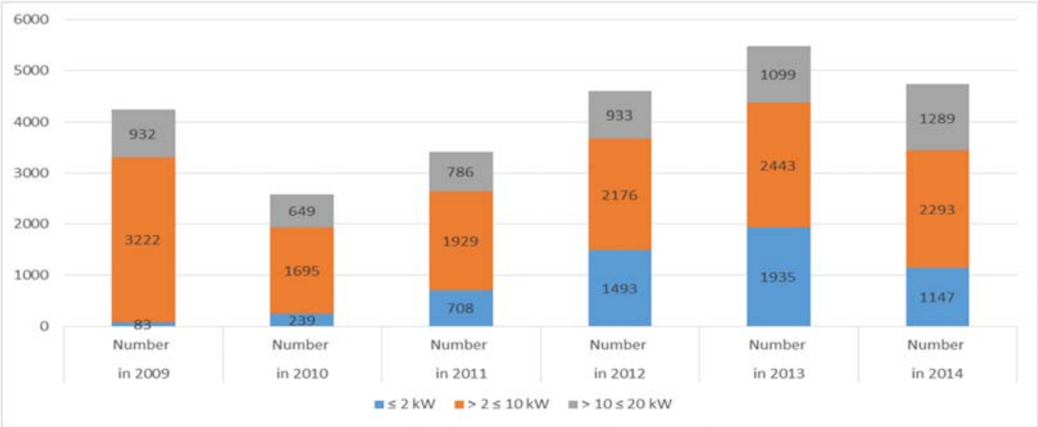
By looking at the market niche of micro-CHP at a global scale, it can be concluded that the share of FC micro-CHP is increasing very rapidly after 2009 due to the two technologies of PEMFC and SOFC. In addition, simultaneously the share of other technologies like reciprocating and Sterling engines is decreasing (See Figure 4-36). In summary, both the number of micro CHP units and installed capacity increased from 2010 until 2014. As figures 4-37 indicates, the number of installed unit in 2014 was less than 2013 however as we see in Figure 4-38, the total installed capacity increased due to the more installation of micro CHP with output power higher than 10 kWe.

Figure 4-36. Global micro-CHP sales by technology



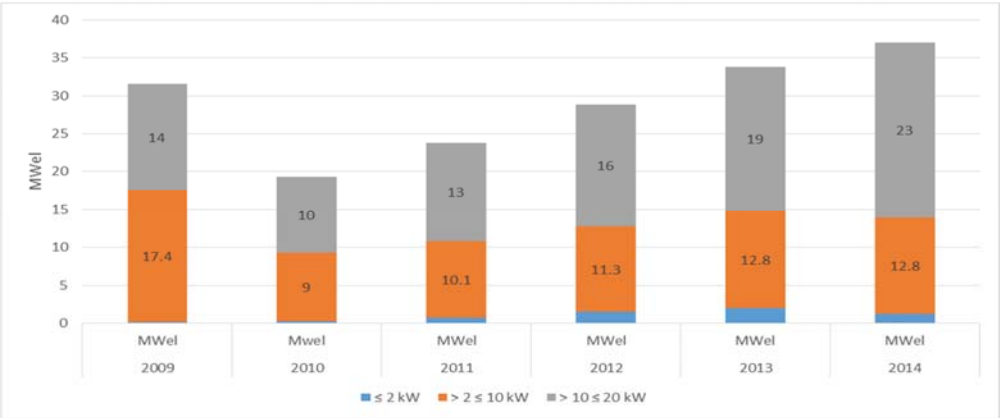
Source: (Dwyer 2014)

Figure 4-37. Number of installed micro-CHP units per year in Germany from 2009 to 2014



Source: author: data gathered and adapted from ***(BAFA 2015)***

Figure 4-38. Installed capacity of micro-CHP units per year in Germany from 2009 to 2014

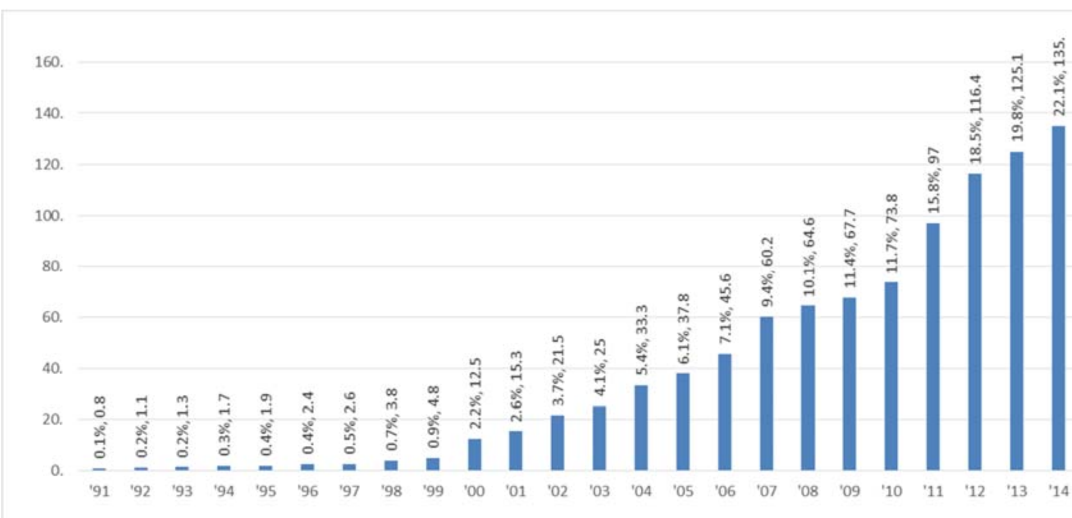


Source: author: data gathered and adapted from ***(BAFA 2015)***

4.3.6 Competition and monopoly

Micro-CHP cannot leave the niche level until it can stand independently in the energy market of Germany, which has traditionally been under the control of the established big utility companies. For many years, the monopoly structure of Germany's energy market made it difficult for distributed generators to access the grid. The German government in order to unbundle the ownership of the energy supply chain and to ensure the free access of everyone to the grid passed the first electricity market liberalization law in 1998. However, because of negotiated mechanism of access to the grid, the liberalization process was not successful. The process of liberalization accelerated after the National Energy Act of 2005 was passed and access to the grid became regulated. Nevertheless, the use of market power by the big utilities can still hinder development. On the other hand, some of the big utilities such as E.ON started to buy micro-CHP producers and are now among their stakeholders, which can be beneficial for the further development of micro-CHP. In the analysis of the liberalization process, studying the share of private electricity producers can show us to what degree there is monopoly power in the market. Figure 4-39 shows the share of the private sector in the production of electricity in Germany.

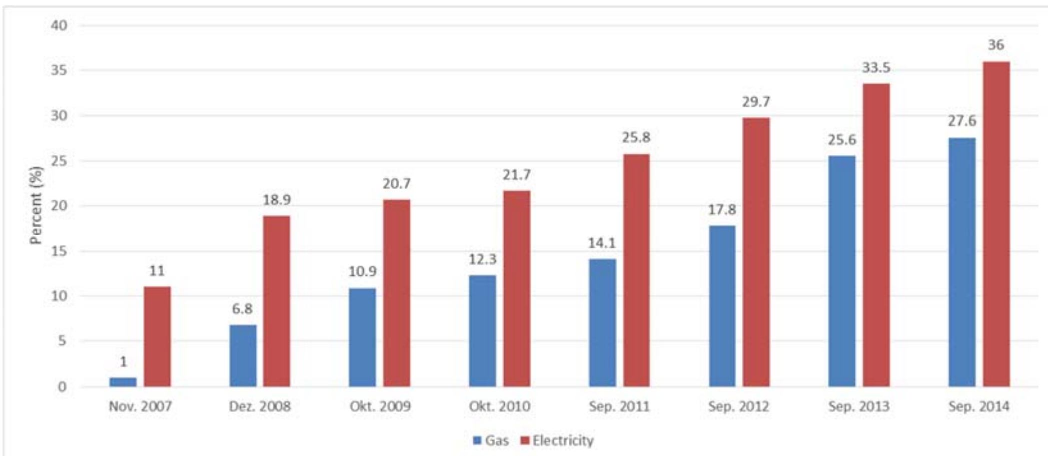
Figure 4-39. Electricity generation in Germany by the private sector from 1991 to 2013 (in terawatt hours)



Source: (BMWi 2014)

From Figure 4-40, It can be seen that the share of the private sector increased from less than 1% in 1999, right after the first liberalization, to more than 22% in 2014. In 2014, 36% of customers in the residential sector in Germany changed their electricity supplier and 27.6% changed their gas supplier. Compared to the year 2010, the exchange rate rose by more than 65% for electricity and about 100% for gas. It can be concluded that the mechanism of competition in the German energy market has been functioning correctly[430].

Figure 4-40. Percent of households that changed their gas and electricity provider from 2007 to 2014



Source: by author, adapted from (StatistaGmbH 2015)

4.3.7 Demand for new products

Micro-CHP can be used as a replacement for traditional boilers. However, studies show that most micro-CHP users in Germany do not like to change their current heat system until it is old and cannot be used anymore[431]. One of the important factors for increasing the share of micro-CHP is heat demand. Incentive policies such as tax exemptions can increase demand. Research indicates that despite of the increase in living space per person in Germany, heat demand is decreasing (See Figure 4-41). Lower heat demand reduces the need for heating systems such as micro-CHP. Nevertheless, it does

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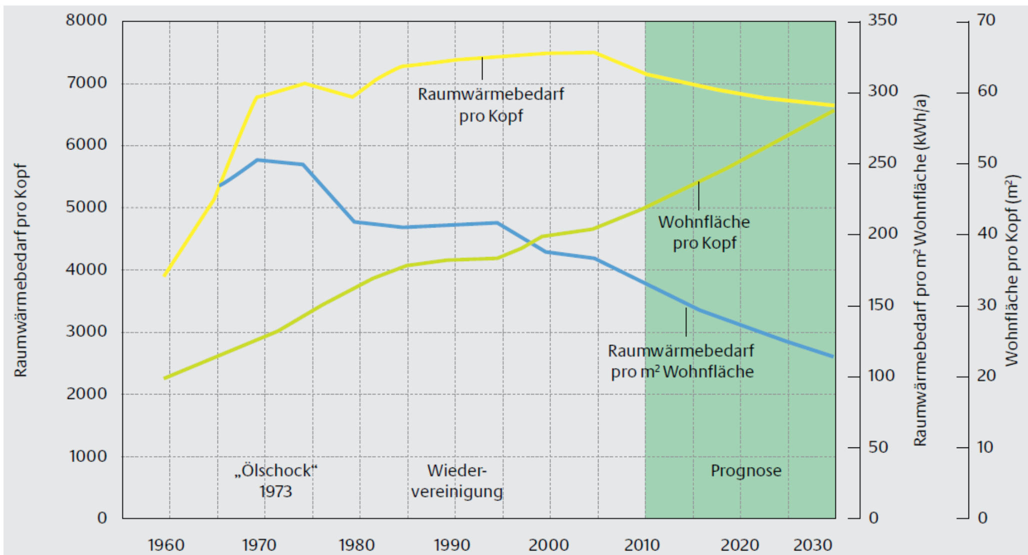
[430] BDEW (2014). "BDEW zum Wechselverhalten im Energiemarkt: Kunden nutzen Angebotsvielfalt der Versorger." from https://www.bdew.de/internet.nsf/id/20141105-pi-kunden-nutzen-angebotsvielfalt-der-versorger-de?open&ccm=900030.

[431] Barbara Praetorius , D. B., Martin Cames , Corinna Fischer,Martin Pehnt , Katja Schumacher, Jan-Peter Voß (2009). Innovation for Sustainable Electricity Systems: Exploring the Dynamics of Energy Transitions, Physica-Verlag Heidelberg Springer.

not necessarily lead to lower demand for all heating technologies. Boilers and micro-CHP technologies with low electricity to heat ratio (10%-30%) will face lower demand. On the other hand, the demand for technologies such as fuel cell micro-CHP with high electricity to heat ratio (50% - 110%) will increase. Such technologies will be very attractive because they have more benefits than only heat generation. Moreover, the ability to store energy can increase the demand for micro-CHP by 6 to 10%[432].

Figure 4-41. Heat demand in Germany for residential buildings



Source: (BMWi 2011) p. 29

A study indicates that among 700,000 installed heating systems in 2009-2010, less than 0.5% were micro-CHP. However, this share is predicted to reach 8% by 2020[433]. In order to achieve such an increase, the existence of infrastructure necessary for the supply of gas to the residential sector is an important factor. The share of households with connection to the gas grid has increased from 30% in 2010 to 37% in 2014 and is expected to reach 50% until 2020[434].

[432] Prognos, B., AGFW (2013). Maßnahmen zur nachhaltigen Integration von Systemen zur gekoppelten Strom und Wärmebereitstellung in das neue Energieversorgungssystem. Berlin.

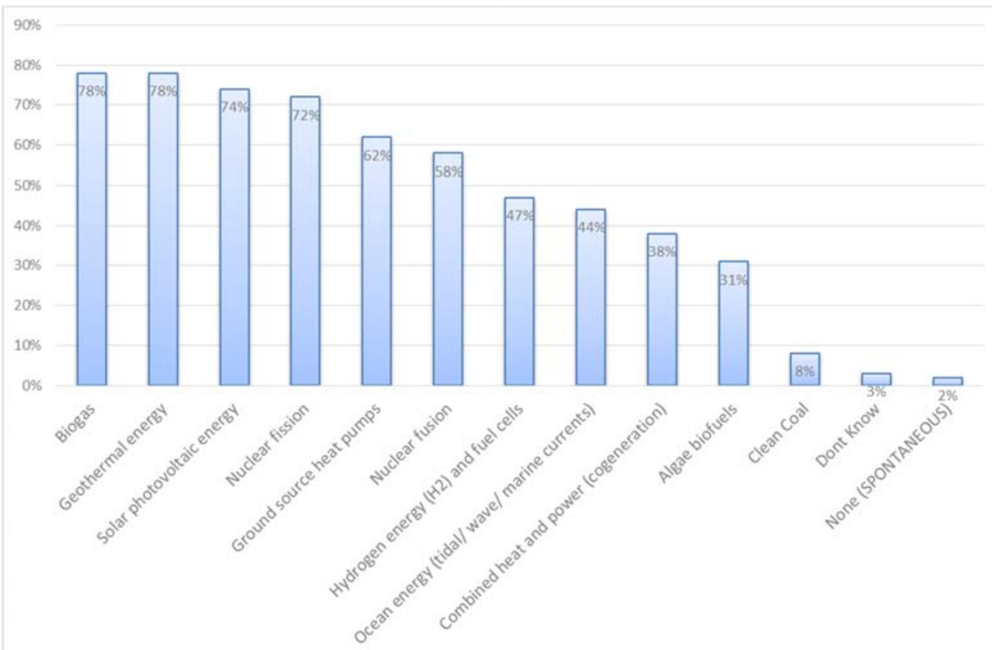
[433] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

[434] http://de.statista.com/ (2015). Bevölkerung in Deutschland nach Besitz eines Gasanschlusses im Haushalt von 2010 bis 2014 (Personen in Millionen). V.-u. M. VuMA, http://de.statista.com/.

4.3.8 Lack of Awareness

Several studies suggest that one of the biggest problems regarding the development of micro-CHP is the lack of awareness in society. Surveys by the EU-Commission regarding public awareness of different ways of energy supply showed that in Germany only 38% of people had heard about CHP at least once (see Figure 4-42).

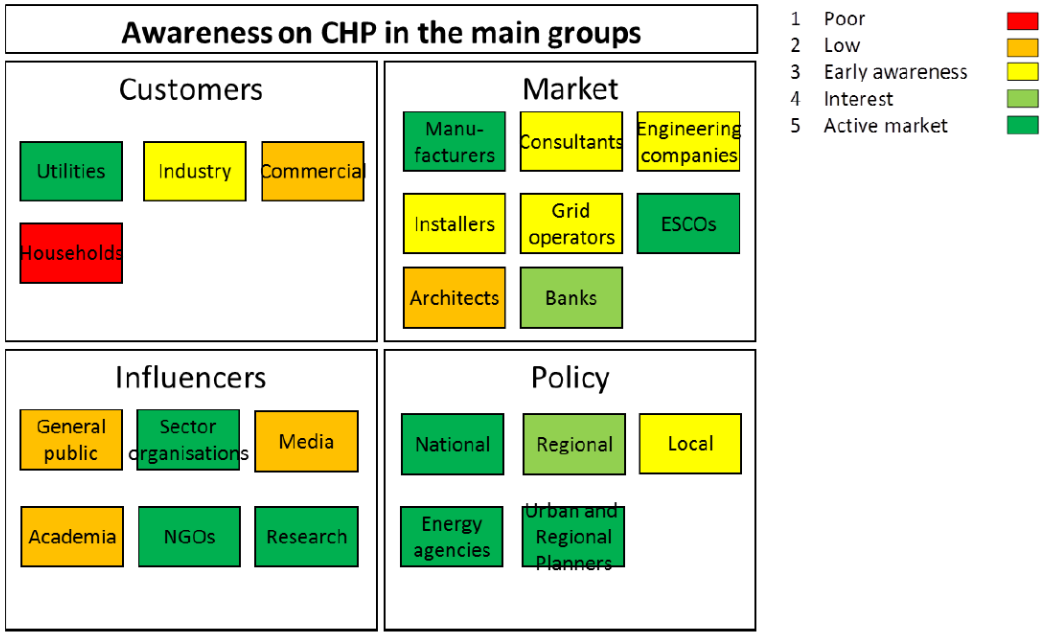
Figure 4-42. Answers to the question: "In the context of energy production, which, if any, of the following have you heard of?"



Source: Generated by author with data from (EUROBAROMETER 2011)

Another study found that among German households awareness of micro-CHP and its advantages is relatively poor. Figure 4-43 shows the degree of awareness of various groups regarding CHP. Unfortunately, the level of awareness in academic groups and the media is low. Even boiler installers and energy servicing companies are only in the early stages of awareness.

Figure 4-43. "Awareness of CHP in the main socio-economic groups"



Source: (code2-project 2013) p.12

5 Regulatory framework regarding the development of micro-CHP in Germany: Regulations and supportive policies

In this chapter, we analyze the regulatory framework for micro-CHP in the year 2014 and its effects on costs and benefits for users of the micro-CHP technology. The German national power and gas regulatory framework is more incentive-based with a revenue cap which focuses on reducing all costs by benchmarking similar operators against each other[435].The regulatory framework related to micro-CHP application in Germany, is very complicated and depending on the application and the technology type, the detailed analysis of related regulations is required. The operating time of a plant, the kind of fuel it uses, the output power of the plant and the ownership situation of the plant all influence the application of regulations and can led to very different results. In Germany, there are nine regulations, which directly influence the implementation of micro-CHP in 2014:

11. CHP Act (Kraft-Wärme-Kopplungsgesetz (KWKG 2012))
12. Renewable Energy Act (Erneuerbare-Energien-Gesetz (EEG 2012))
13. Energy Tax Law (Energiesteuergesetz)
14. Electricity Tax Law (Stromsteuergesetz)
15. Value Added Tax Law (Umsatzsteuer)
16. Income Tax Law (Ertragssteuer)
17. Renewable Energy Heat Law (Erneuerbare-Energien-Wärmegesetz (EEWärmeG))
18. Mini-CHP Incentives (Mini-KWK-Förderrichtlinie)
19. KfW Incentive Programm (KfW-Förderprogramm)
20. Other incentives programs at the local level

Each regulation leads to different results in different situations of micro-CHP usage[436].

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[435] Perrin, L.-M. (2013). Mapping power and utilities regulation in Europe, Assurance Power & Utilities Sector Resident,EY.

[436] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

5.1 CHP Act (Kraft-Wärme-Kopplungsgesetz (KWKG 2012))

As explained in previous chapters, the first CHP law in Germany was introduced in 2000 and after some modifications, initiated in 2002 as a regulation to mitigate the consequences of market liberalization. Its main goal was to protect existing CHPs that mostly belonged to municipal utilities in the short term and provide a regulatory framework for the development of new plants. In the first year, the CHP owners received 1.5 cents/kWh generated electricity, which was reduced by 0.25 cents/year until 2004[437].

After several amendments, the last version of the CHP law was initiated in 2012. The goal of the new law (KWK 2012) is to support the market entrance of CHPs with fuel cell technology and supporting the heat and cold storage and network systems. The plant operators receive a CHP-premium based on the start time of the plant operation. According to the CHP Act, the operator bears the cost of the connection between the cogeneration plant and grid connection point[438]. DNOs are obliged to buy electricity with a regulated price and must pay the micro-CHP owners the feed-in tariff based on the price of electricity in the market (published by European Energy exchange market (EEX) in Leipzig). For example, Figure 5-1 depicts the historical changes of the electricity price. (Interestingly, despite the continuous reduction in market price, the household price is increasing). Moreover, plant owners receive a bonus for avoided network usage, which is about 0.5 cents per kWh. The plant operator can also sell the fed electricity by way of a third party with a compromised price[439]. However, this model has not worked until now because the regulations are incomplete and have deficiencies[440]. For micro-CHP plants installed after July 19th 2012, regardless of the internal consumption of electricity or feed into grid, owners are being paid the bonus with an amount of 5.41 Cent/kWh[441]. For plants

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[437] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

[438] ASUE-Arbeitskreis „Brennstoffzellen/BHKW“ (2012). Das KWK-Gesetz 2012,

Grundlagen, Förderung, praktische Hinweise.

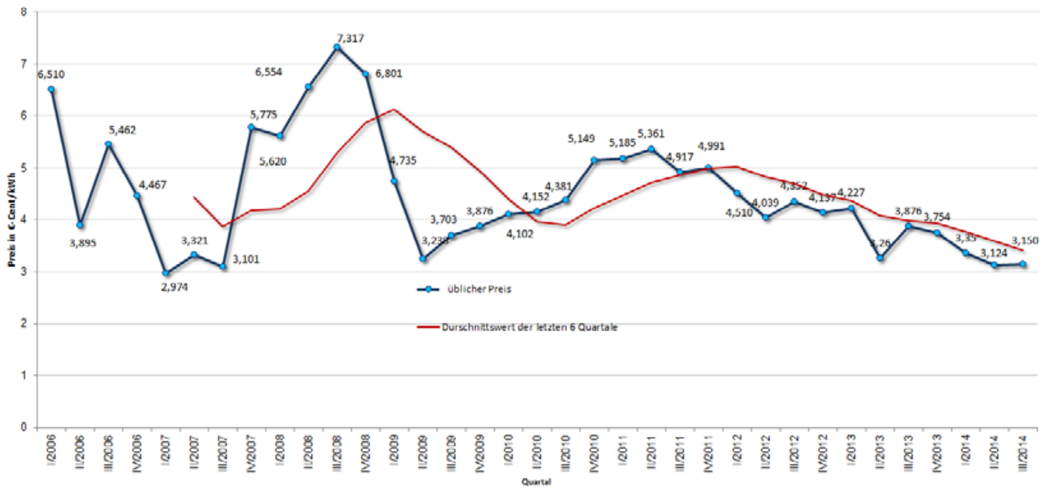
[439] BAFA (2013). KWK-Zuschlag.

[440] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

[441] BAFA (2014). Zuschuss für Mini-KWK-Anlagen, Das Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA).

before this date, the CHP law of 2009 is valid with 5.11 Cent/kWh. Also for plants with an electrical capacity of less than 2 kWe, the payment for 30,000 hours (full operation time) at the beginning is possible.

Figure 5-1: Price of electricity in the market in Cent/kWh



Source: (EEX 2014)

Moreover, the bonus is valid only for 30,000 hours of full operating time or a period of 10 years. In the case of modernization (which is rarely applicable for micro-CHP plants), if the cost amounts to 25% of the price of the new plant, then the supporting bonus is valid for 5 years or 15,000 full operating hours. In addition, if the modernization cost become 50% or higher than the price of a new plant, a maximum 10 years or 30,000 operating hours will be included in the CHP law[442]. The CHP law also proposes support for heating and cooling network development. If 60% of the heat or cold comes from micro-CHP plants, the developers receive 100 euros per meter of network piping system with a maximum amount of 40% of the investment cost if the diameter of the pipe is less than 100 mm. Moreover, no bonus is paid for projects above 10 million euros[443]. Figure 5-2 shows the changes in CHP bonuses (regardless if the electricity is fed to grid or used internally) with an output capacity which is highest for micro-CHP. Moreover, big CHPs with output power of more than 4MW can benefit from an emission-trading scheme based on the EU ETS directive.

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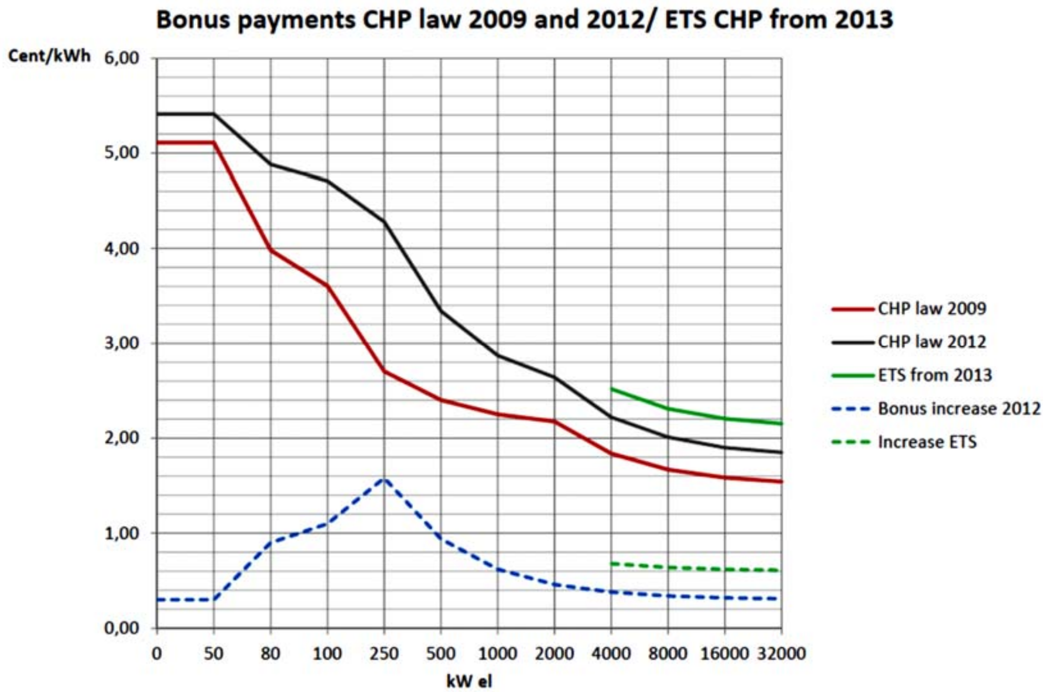
[442] BAFA (2013). KWK-Zuschlag.

[443] BAFA (2014). Zuschuss für Mini-KWK-Anlagen, Das Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA).

Figure 5-2. CHP bonus in Germany

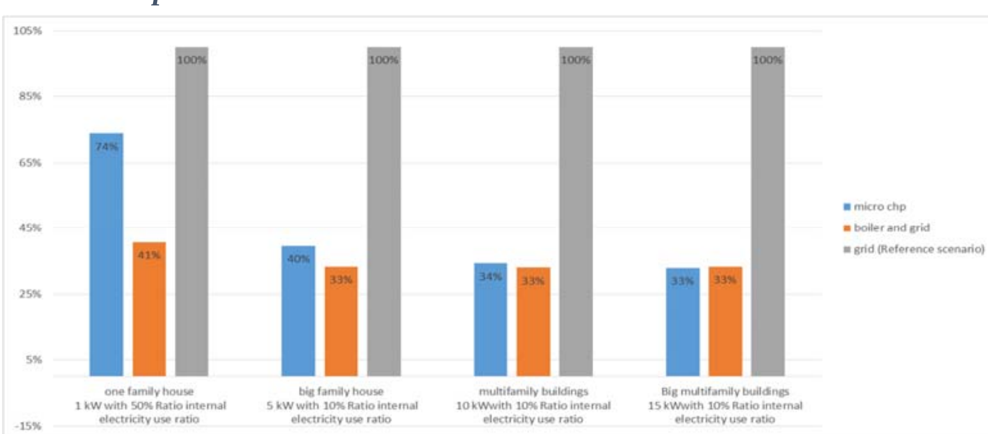


Source: (Golbach 2012) p.8

According to Appendix 2, we apply the CHP law to different micro-CHP cases in order to analyze the effects of this regulation. We analyze five cases of 1 kWe micro-CHP plants for one family house application, 5 kWe for big family houses and 10 kWe and 15 kWe for multifamily buildings and using a gas boiler instead of micro-CHP. Assumptions about the optimum hours of operation and the optimum electrical capacity of micro-CHP based on heat demand require many calculations as well as mathematical optimization and modelling. These calculation and modelling framework is described in Appendix 2 , we are using assumptions based on official reports published by governmental agencies. Moreover, we only analyze the current existing technology in the market. According to Table A-2 in Appendix 2, we calculate the present cost in different situations and compare them with the reference situation. The reference scenario refers to a situation in which electricity and heat both are acquired from the electricity grid to 100%. In addition, the percent of internal electricity usage is very important in the calculation of current costs.

Modern sterling engines can reach an efficiency of 80-90 %, which is higher than conventional separate methods of producing heat and power[444]. However, a CHP plant compared to a boiler has poorer thermal efficiency for providing the same amount of heat. As a result, the operational costs of fuel is higher in CHP systems compared to boilers. On the other hand, the investment and operational costs can be reimbursed through saved electricity and selling it to the grid. The analysis of micro-CHP plants must be done based on the base electricity and heat loads. The yearly operational hours of a micro-CHP plant constitute the most important factor for economic application. According to the fact that the feed in tariff is not equal to the electricity price for households, the internal usage of electricity led to less electricity purchased from the grid and means fewer costs. Based on the data in Appendix 2, we assumed that one family house could consume about 50% of the generated electricity internally. In addition, for other cases we assumed that about 90% of electricity feeds to the grid and only 10% is being used internally. Figure 5-3 indicates that, for one family house the costs of micro-CHP in 10 years is 74% of the costs of purchasing all electricity from the grid. Moreover, it indicates that a combination of a gas boiler for internal heat and electricity from the grid always has fewer costs than micro-CHP. We can see that by increasing the capacity of micro-CHP plants, the total cost of the system reduces constantly.

Figure 5-3. Comparison between present costs of different technologies based on the CHP act 2012 in 10 years and assuming partial internal usage of produced electricity by micro CHP plant

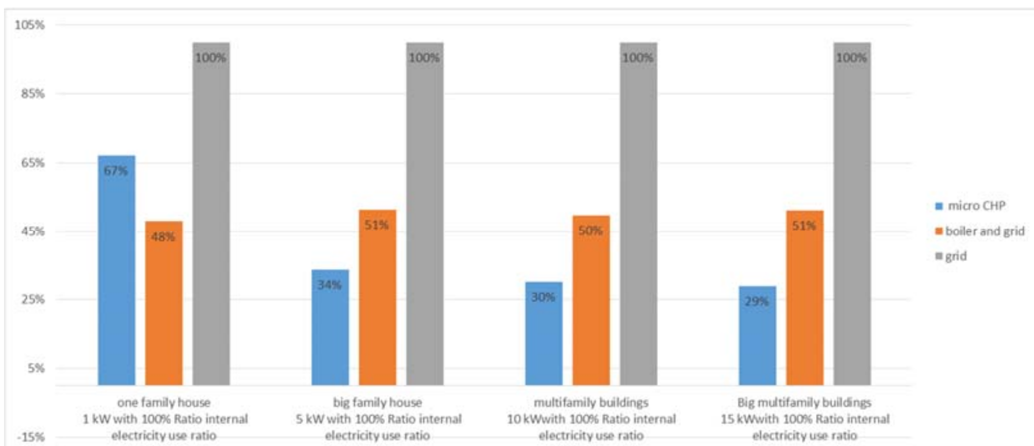


Source: author

[444] Kabus, M. (2014). Einsatz von Kraft-Wärme-Kopplung in Wohngebäuden. Wuppertal, EnergieAgenturNRW.

In another important case, we showed the importance of storage. Here we assume that the micro-CHP systems have the ability to store the generated electricity instead of feeding it to the grid. The stored electricity can later be used internally. As a result, we assumed that in all cases 100% of the generated electricity is used internally. Figure 5-4 shows the result of 100% internal usage of electricity. We see that only in the case of one family houses with 1 kW micro-CHP systems, the combination of boiler and grid is economically more efficient. However, in all other cases, using the micro-CHP system can reduce the costs by 70% in 10 years in comparison with 100% grid usage and by 50% in the case of boiler and grid.

Figure 5-4. Comparison between present costs of different technologies based on the CHP act of 2012 in 10 years and assuming 100% internal usage of produced electricity by a micro-CHP plant



Source: author

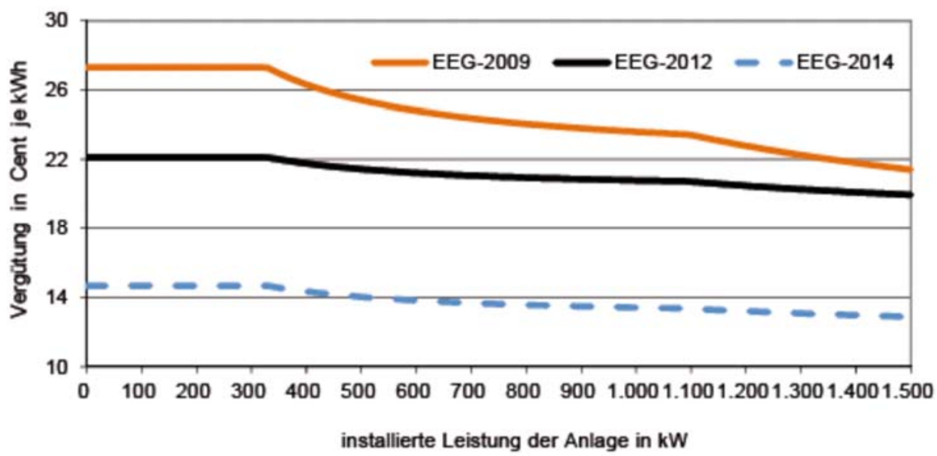
5.2 Renewable Energy Act (Erneuerbare Energien-Gesetz (EE-G 2012 and EE-G 2014))

We explained in previous chapters how several renewable energy acts were initiated and developed since 1990 to promote renewable energy. Biogas and wood are considered as renewable sources of energy, which are included in the renewable energy act. These fuels can be burned in CHP systems as well as micro-CHPs. With regard to the EEG 2012, from the beginning of 2012, micro-CHP plants are eligible for the bonuses of the renewable energy law if the micro-CHP plant uses biomass such as biogas, bio methane, wood or pellets. On August 2014, some changes were applied to the EEG 2012 to reduce the cost of energy transition. The new act can be seen as a new phase in the energy economy of Germany and specifically affected all CHP plants by obliging them to pay the RE-surcharge. The plant operator can decide about receiving one of the following payment models[445]:

- Market Premium model: with subsidized direct marketing
- Direct marketing without receiving subsidies

Figure 5-5 indicates the changes in feed-in tariffs after the new renewable energy acts of 2012 and 2014.

Figure 5-5. Changes in feed -in tariff in new renewable energy act from



Source: (Daniela Thrän (DBFZ/UFZ) 2014) p.6

In addition to a substantial reduction in the fixed feed-in tariff, the new law obliges plant owners to provide possibilities to control the plant remotely and must implement it at least two month after starting the plant[446]. Due to the fact that the changes in the new RE act mostly aim at controlling the adverse effects of renewables on the market (for example oversupply of renewables) and electricity prices in the spot market became negative, the new act reduced the bonus from 14.3 to 13.66 cent/kWh[447]. Despite the fact

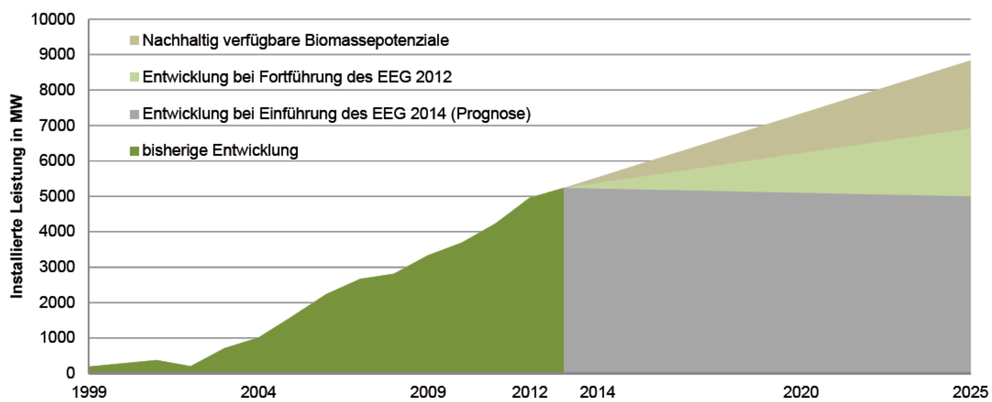
[445] BMWI (2014). Key elements of a revised Renewable Energy Sources Act. Berlin, German Federal Ministry for Economic Affairs and Energy.

[446] Herbold, T. (2014). Renewable Energy Sources Act 2014 - Overview of the most important changes. Cologne, GÖRG

[447] Matthias Lang, U. M. (2014). Overview Renewable Energy Sources Act, German Energy Blog.

that the reduction in the feed-in tariff and direct marketing of electricity were aimed at raising innovation, there are many concerns about the negative effects of the new RE act on micro-CHP development[448]. For example, some studies suggest that the new RE act can completely stop the trend of biomass development in Germany. For example, a study by DBFZ (Deutsches Biomasseforschungszentrum) predicts not only that the progress of biomass will be stopped by the new RE act of 2014, but also that it will experience a negative progress with lower installed capacity in 2025 than 2014[449]. (See Figure 5-6).

Figure 5-6. Effects of the new EEG on Bio micro-CHP plants



Source: (Daniela Thrän (DBFZ/UFZ) 2014) p.3

The new RE act of 2014 has two main negative influences on micro-CHP systems based on biomass:

First, bio micro-CHP plants are obliged to sell their electricity via direct marketing. This means that plant owners sell the generated electricity in the stock market or it must be commercialized via a marketing company. As a result, in addition to the market price they receive the so-called market premium.

Feed-in bonus = average monthly market price + market premium

The market premium is an instrument of the government for developing RE in an economically sustainable way by providing incentives for RE owners, at the same time

[448] Binde, W. (2014). Referentenentwurf Novelle des Erneuerbare-Energien-Gesetzes (EEG 2014)-verfassungsrechtlich kritisch, untauglich als Strompreisbremse und kontraproduktiv für die Energiewende. Berlin, B.KWK

[449] Daniela Thrän (DBFZ/UFZ), A. K., Mattes Scheftelowitz,Volker Lenz, Jan Liebetrau, Jaqueline Daniel-Gromke, Martin Zeymer, Michael Nelles (2014). Auswirkungen der gegenwärtig diskutierten Novellierungsvorschläge für das EEG-2014. Leipzig.

prevents economic, and market failure. The funds for the market premium come from the sum of the RE surcharges (EEG-Umlage) which all electricity consumers pay per kWh of electricity consumption. The plants with output power of less than 500 kW, which started before 1 January 2016, and plants with an output of less than 100 kW which will start operation after 31 December 2015, excluded from direct marketing. However, the fixed feed-in tariff will be about 0.3 cent/kWh lower[450]. The market premium will not be paid to systems with an installed capacity higher than 100 kW and with an electricity production of more than 50% of their installed capacity. Switching between these two models is possible in every month. However, switching between the CHP act and the RE act is possible only once[451].

Secondly, contrary to the CHP act, for the first time the new EEG-2014 obliged plant owners which produce electricity for their internal use to pay the Renewable Energy Surcharge (EE-Umlage) which can reach up to 6.24 cent/kWh based on various conditions[452]. Figure 5-7 explains the regulation of the RE-Surcharge for plants after August 1st 2014. In this chapter, we analyze the influence of this obligatory regulation on micro-CHP. The third influence of the RE act of 2014 is that the plants, which generate electricity from renewable energy sources, have priority over plants consuming mineral gas in connection to the electricity networks[453]. Moreover, the RE act of 2014 reduced the feed-in tariff for different biofuels by eliminating the gas-processing bonus and raw material bonus. Table 5-1 indicates the differences in feed-in tariffs for CHP-plants (less than 150 kW) between EEG-2012 and EEG-2014.

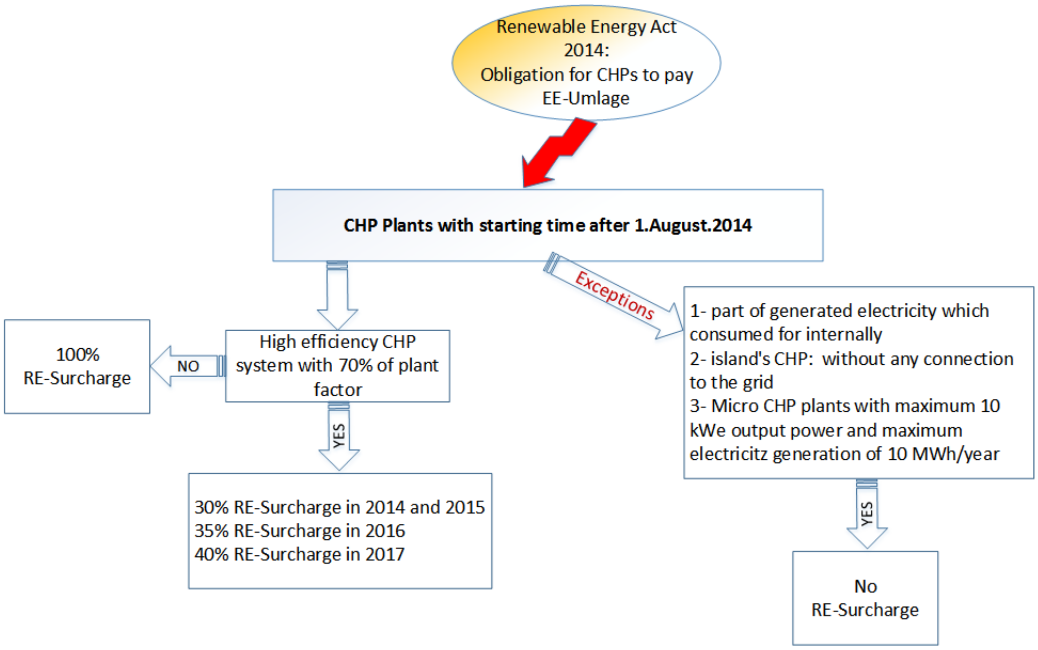
[450] Herbold, T. (2014). Renewable Energy Sources Act 2014 - Overview of the most important changes. Cologne, GÖRG

[451] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

[452] BMWi (2014). Erneuerbare-Energien-Gesetz 2014 (EEG 2014), Bundesministerium für Wirtschaft und Energie.

[453] Ibid.

Figure 5-7. RE Act 2014 for plants after August 1st 2014



Source: generated by author adopted from (Kraft-Wärme-Kopplung 2014)

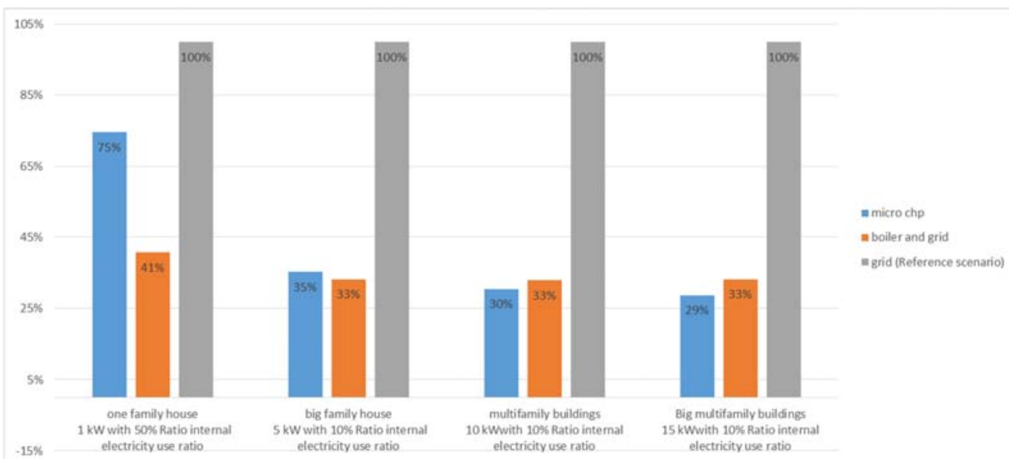
Table 5-1. Comparison between feed-in tariffs for different fuel types in RE act of 2012 and RE act of 2014.

	Fuel type			**Raw material Bonus**		
	Biomass	**bio waste**	**Manure max. 75 kW**	**Class 1** (Gas Fuel)	**Class 2** (Solid Fuel)	**Gas processing Bonus** (till 700 m3/h)
EEG-2012: Fixed feed in tariff	14,30 Cent/kWh	16 Cent/kWh	25 Cent/kWh	6 Cent/kWh	8 Cent/kWh	3 Cent/kWh
EEG-2014: Direct marketing with extra market premium	13,66 Cent/kWh	15,26 Cent/kWh	23,73 Cent/kWh	0	0	0

Source: Data adapted and generated by author from (VDI 2013)and (Binde 2014)

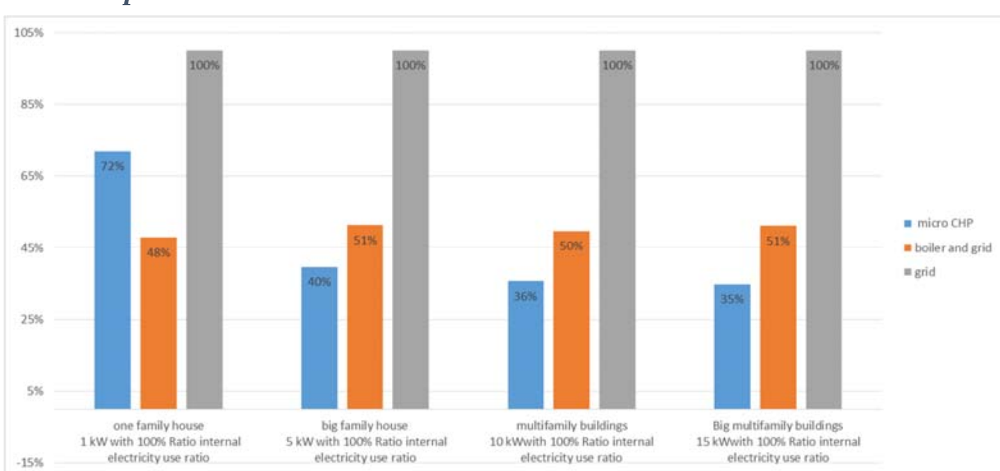
We analyze the cost of different micro-CHP plants if they follow the RE act of 2014 and the same scenarios as we did in analyzing the CHP act of 2012. The only difference is the bonus model. The assumptions are explained in Appendix 2. Figure 5-8 indicates the results based on the RE act of 2014, if the generated electricity is partially used internally. We can see that in all micro-CHP capacities the cost of boilers in combination with grid usage is lower than the use of micro-CHP systems. Figure 5-9 indicates the results if the generated electricity can be stored. In addition, all stored electricity can be used for internal usage without any feeding into the grid. In this case, the boiler combination with the grid has lower costs only for one family house applications. The CHP act of 2012 provided stronger incentives for micro-CHPs, however, if the operators use all generated electricity internally there is no significant difference.

Figure 5-8. Comparison between present costs of different technologies based on RE act of 2014 in 10 years and assuming partial internal usage of produced electricity by micro-CHP plant



Source: author

Figure 5-9. Comparison between present costs of different technologies based on RE act of 2014 in 10 years and assuming 100% internal usage of produced electricity by micro-CHP plant



Source: author

5.3 Energy Tax Law (Energiesteuergesetz)

In Germany, taxation on energy includes mineral oil taxes and electricity taxes. As explained previously, the Ecological Tax Reform (ETR) tried to increase the tax for fossil fuels (except coal) and by excluding high-efficiency technologies like CHP, encourage the energy system to produce less GHG emissions. The negative aspect of the ETR is that it taxes natural gas but exempts coal. This imbalance led to disadvantages for all CHP systems that use natural gas as well as micro-CHPs[454]. By the way, the energy tax law provides some tax refunds for high efficiency stationary CHP until 2 MW with an efficiency of at least 70% in case their operating hours are more than 60% of their annual capacity. There is another tax relief mechanism for business companies who use micro-CHP plants for business purposes[455]. The micro-CHP plant are eligible for the tax refund if it has 3 main traits:

1- The plant must be highly energy efficient (according to Index III of EU-CHP law and EU-energy efficiency law)[456]
2- plant factor with At least 70% (rate of utilization)[457]
3- For old renewed plants (usually more than 10 years), the cost of renewing must be higher than 50% of the price of a completely new plant[458].

The amount of refundable tax are summarizes in table 5-2. We can apply the energy tax law on our previous cases to see the extent of the regulation on the costs of micro-CHP in 10 years. Table 5-3 indicates the results of the analysis and shows that by

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[454] Martin Cames, K. S., Jan-Peter Voß, Katherina Grashof (2006). Institutional Framework and Innovation Policy for Micro Cogeneration in Germany. Micro Cogeneration: Towards Decentralized Energy Systems. M. C. Martin Pehnt, Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß, springer.

[455] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

[456] B.KWK (2013). Energiesteuererstattung für KWK-Anlagen gemäß §53a Energiesteuergesetz ist beihilferechtlich von der EU-Kommission genehmigt. B.KWK Newsletter. Berlin, B.KWK.

[457] Ibid.

[458] Ibid.

increasing the capacity of micro-CHP plants, the energy tax law can reduce the costs by more than 8%. Still it cannot reduce the costs of micro-CHP less that gas boiler.

5.4 Electricity Tax Law (Stromsteuergesetz)

According to the Electricity Tax Law, small electricity producers with production capacities of less than 2 MW, are exempt from paying electricity consumption taxes. The tax exemption is only valid if the electricity is used for internal consumption or directly delivered to end users. The current electricity tax is 2.05 cent/kWh[459]. In the case of feeding electricity to the grid, the owner is obliged to report the amount of fed electricity for taxing issues.

Table 5-2. Refundable tax based on German energy tax act and the EU energy tax act

Energy carrier	Reduced tax rate (according to German energy tax act)	Reduced tax rate (according to the EU energy tax act)
Diesel fuel	61.35 Euro/1000 liter	21 Euro/1000 liter
Natural Gas	5.5 Euro / MWh	1.08 Euro / MWh
Liquefied petroleum Gas (LPG)	60.60 Euro/1000 kg	0 Euro/1000 kg

Source: generated by author, data from (B.KWK 2013)

This case became especially important when the sum of local electricity from micro-CHP exceeds the limit of 2 MW as mentioned in tax exemption law[460]. However, the Federal Ministry of Finance (BMF) mentioned various limitations and exceptions regarding the 2 MW limitation. It describes possible ways in which the sum of the individual capacities can be violated. Operators should carefully control these legal facts, particularly prior to the construction of virtual power plants or pools of CHP plants[461].

[459] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

[460] BMJV (2014). Stromsteuergesetz (StromStG), Bundesministeriums der Justiz.

[461] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

Table 5-3. Influence of Energy Tax Law on the total costs of micro-CHP in 10 years

	one family house 1 kW	big family house 5 kW	multifamily buildings 10 kW	Big multifamily buildings 15 kW
micro CHP costs in 10 years (1000 Euro)	24.8	48.6	94.3	123.3
micro CHP costs in 10 years (1000 Euro) by considering the energy tax law	24.1	45.4	87.3	113.5
Cost reduction by energy tax law in 10 years	3%	7%	7%	8%

Source: author

5.5 Value Added Tax (VAT) Law (Umsatzsteuergesetz)

The value added tax act classifies the operator of a cogeneration plant as a private company, which must pay VAT tax. However, for investment and operating costs such as fuel and maintenance, some tax reductions can be claimed depending on the turnover model in the CHP plant. If the owner of a single-family house operates the CHP plant, a full deduction is usually possible but if a business company runs the plants, it must pay at least 10% of VAT[462]. Feeding electricity into the public grid is subject to income tax. Due to the technical conditions, only owners or third parties on site (tenants) can use the generated heat. When the purchasing price is not determined, the tax is calculated based on the total annual cost (§ 10 paragraph 4 of the UStG.) corresponding to the production costs and operating costs of CHP (as well as financing costs and maintenance costs).[463]

5.6 Income Tax Law (Ertragssteuer)

Micro-CHP operators obtain income from commercial operations. The profit assessment takes place through the cash method of accounting. By renting an apartment,

[462] Ibid.

[463] BAFA (2014). Zuschuss für Mini-KWK-Anlagen, Das Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA).

the revenues from heat and electricity are not considered income from rental properties (leasing) but rather as operating income of a business establishment.

As long as commercial operation from a private property owner causes no problem in regulation, renting join business partnership can be problematic. In this condition, a tax consultant is required. The profits of commercial micro-CHP can have an effect on the rental profits.[464]. In terms of depreciation, micro-CHP plants are considered an independent movable asset. Their average life is about 10 years and they have a linear depreciation rate of 10% per year. Under some specific conditions, a depreciation rate of 20% can be considered[465].

5.7 Renewable Energy Heat Act (Erneuerbare-Energien-Wärmegesetz (EEWärmeG))

According to the Renewable Energy Heat Act (EE-Wärme-G), all owners of newly built buildings are obliged to cover partial part of the heat demand of their building by using renewable energies. This regulation is valid for new buildings built after 01.01.2009. The violation of the regulation in new buildings with an area greater than 50 square meters results in a penalty[466]. The mandatory use of RE can be implemented by using biomass fuels such as biogas under the following conditions:

- At least 30% of heat demand must be covered by biogas
- The biomass must be used in a CHP plant and heat must come via CHP

As an "alternative implementation" to fulfill the EE-Wärme-G, building owners can cover the heat demand of the building to at least 50% directly from high-efficiency CHP plants as well as district heating[467].

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[464] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

[465] pmw (2010). Steuerliche Behandlung von KWK-Anlagen –Besonderheiten in Ertrag-und Umsatzsteuer.

[466] AGFW (2015). "EEWärmeG und Fernwärme."

[467] lpb-bw (2015). "Das Erneuerbare-Energien-Wärmegesetz (EEWärmeG)." from http://www.lpb-bw.de/eewaermeg.html.

5.8 Mini CHP Incentives (Mini-KWK-Förderrichtlinie)

In the CHP Act of 2012, the Federal Government has set the objective of increasing the share of electricity from CHP plants to 25% by the year 2020. The Federal Ministry for the Environment, Reactor Protection and Pollution Control (BMU) on 18 January 2012 put in place new guidelines for funding mini-CHP systems. This support program applies to CHP systems up to 20 kW (electrical capacity)[468]. Under this scheme, a one-time payment of investment subsidies is scaled according to the electrical power of the plant. For example, an owner of a CHP system with one kWe receives 1500 euros and for large plants with 19 kWe the subsidy is about 3450 euros. Table 5-4 shows the amount of incentives for different capacities.

Table 5-4. Incentives for micro-CHP plants up to 20 kWel

Power Min (kWel)	Power Max. (kWel)	Incentive
More than 0	less than 1	1.500 € / kWel
More than 1	less than 4	300 € / kWel
More than 4	less than 10	100 € / kWel
More than 10	less than 20	50 € / kWel

Source: (bhkw-prinz.de 2014)

These investment subsidies were reduced by 6% from January 1st 2014 and will be reduced by 5% each year[469]. The investment promotion is subject to a number of requirements such as:

- The plant must not be located in an area with connection possibilities to district heating[470].
- Only buildings constructed before 1 January 2009 are eligible for incentives[471].

[468] VDI, A. B., Wulf Binde, Michael Buller, Markus Fischer, Jens Matics, Wulf-Hagen Scholz, Patrick Selzam, Bernd Thomas, Rudi Zilch (2013). Mikro-Kraft-Wärme-Kopplungsanlagen Status und Perspektiven.

[469] BAFA (2014). Zuschuss für Mini-KWK-Anlagen, Das Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA).

[470] bhkw-prinz.de (2014). BAFA-Förderung für Mini-KWK-Anlagen inkl. Tabelle, bhkw-prinz.de.

[471] Förder.Navi (2014). BHKW / KWK (Öl, Erdgas, Flüssiggas) alle Fördergeber, EnergieAgentur.NRW.

- The contract proposal for using the plant must include a maintenance contract[472].
- An energy meter must be installed to determine the production of power and heat[473].
- A sufficiently large buffer storage with an energy content of at least 1.6 kWh per installed kW (thermal) (but not less than 6.9 kWh or 300 liters) must be installed [474].
- Total annual efficiency of 85% and only systems are listed in the BAFA are eligible[475].

This incentive can be combined with other promotion programs as far as the total amount of incentives does not exceed the maximum amount of 3325 euros or twice the amount of the incentive[476].

Table 5-5. The influence of Mini CHP incentives on total costs of micro-CHP in 10 years

	one family house 1 kW	big family house 5 kW	multifamily buildings 10 kW	big multifamily buildings 15 kW
Micro-CHP costs in 10 years (Euro)	24844	48593	94294	123270
Mini-KWK-Förderrichtlinie (Euro)	1500	500	1000	750
Incentive ratio to total cost	6%	1%	1%	1%

Source: author

5.9 KfW Incentive Programm (KfW-Förderprogramm)

The Credit Institute for Reconstruction (KfW (Kreditanstalt für Wiederaufbau)) of which 80% belong to the German government and 20% to the federal states governments has a balance of 450 billion euros and is among three biggest German Banks. One of the main duties of the bank (which does not have any physical branches) is to support the environment. KfW includes climate protection programs, which covers around one third

[472] Ibid.

[473] Ibid.

[474] Ibid.

[475] Ibid.

[476] Förder.Navi (2014). BHKW / KWK (Biomasse, Biogas) Förderung, EnergieAgentur.NRW.

of the total supports in this area[477]. The KfW development bank offers a wide range of funding programs in the areas of housing, construction and energy saving that it uses to finance investments in residential real estate. The Federal Republic is liable for all liabilities and loans from KfW[478]. For projects such as supplying building heat through renewable sources or from micro-CHP plants, versions programs are available. Promotion depends partly on the size and type of facility. After buying a micro-CHP or after construction, the application is not acceptable by KfW[479]. 5-credit programs by KfW assigned to promotion of micro CHP. Table 5-6 summarized these programs and explained their characteristics such as preconditions,incentives and target groups. One of the important aspects of the KfW program is the necessity of an energy expert's opinion. This precondition provides opportunities for entrepreneurial activities. Moreover, the amount of loans is significant but making the right decision about spending it on micro-CHP systems and other energy efficient technologies requires technical and financial studies by energy experts.

5.10 Other incentives programs at the local level

Berlin: The states of Berlin, Saxony-Anhalt, and Thuringia currently offer no CHP promotion[480]. However, there was an incentive program, which is now expired. Based on the incentive, everyone interested in micro-CHP in Berlin could apply for funding through state investment grants. The Environmental Relief Programme Berlin (Umweltentlastungsprogramm Berlin (UEP II)) promoted the development of combined heat and power in the power range of 20 to 50 kW of electric power with a grant of approximately 30 percent of the investment costs.

[477] KFW (2014). "KfW-Energieeffizienzprogramm Energiekosten sparen, nachhaltig profitieren." from https://www.kfw.de/inlandsfoerderung/Unternehmen/Energie-Umwelt/Finanzierungsangebote/Energieeffizienzprogramm-(242-243-244)/?kfwmc=VT.Adwords.GewerblicherUmweltschutz2013.EnergieeffizienzBRAND.Blockheizkraftwerk.

[478] bhkw-prinz.de (2012). "KfW-Förderprogramme für Mini-BHKW in Wohngebäuden." from http://www.bhkw-prinz.de/kfw-forderprogramme-fur-mini-bhkw-in-wohngebauden/2852.

[479] heizungsfinder.de (2014). "KfW BHKW Förderung - Programme & Konditionen." from http://www.heizungsfinder.de/bhkw/foerderung/kfw.

[480] Märtel, C. (2014). BHKW Förderung durch die Bundesländer, heizungsfinder.

Table 5-6. Five-credit program by KfW for the promotion of micro-CHP

	Credit program 153	Credit program 151	Credit program 152	Grant Program 430	Grant program 431
Name	"Energieeffizient Bauen"	"Energieeffizient Sanieren KfW-Effizienzhaus"	"Energieeffizient Sanieren Einzelmaßnahmen"	Energieeffizient Sanieren Investititonszuschuss	Energieeffizient Sanieren Baubegleitung
Purpose	for more energy efficient residential buildings.	increasing existing energy efficiency standards in residential buildings.	individual measures for partial renovations in residential buildings	investment subsidy for energy efficient renovation	using the energy expert advice for energy efficient construction
Target group	all builders or buyers of residential buildings	owner of a residential property and tenants	owner or tenants, want to renovate living room	buyers, owner of a one- or two family house	owner of a residential property and tenants
Target infrastructure	construction or purchase of a new house	energy system modernization	energy system of a part of building	energy system modernization	energy expert planning and supervision
Preconditions of infrastructure	KfW Efficiency House 70, 55, 40	buildings registered before 01.01.1995	buildings registered before 01.01.1995	buildings registered before 01.01.1995	no later than three months after rehabilitation
Loan amount	max. 50.000, euros per residential unit,	max. 75,000 euros per residential unit	max. 50.000, - euros per residential unit,	max. 15,000 euros or max. 20% of eligible costs	max. 4000 euros or max. 50% of the consultancy cost
Payback duration	4-10 years, 11-20 years or 21-30 years	4-10 years, 11-20 years or 21-30 years	4-10 years, 11-20 years or 21-30 years	NO	NO
Repayment exemption bonus	max. 5,000 euros per residential unit	max. 9,375 euros or max. 12.5% of the loan amount	NO	complete exemption from payback	complete exemption from payback
Precondition for Repayment bonus	expert and the bank must confirm efficiency standards and total costs	energy expert consultant and the bank must confirm		energy expert consultant and the bank must confirm	must be combined with the program (151, 152) or (430)

Source: author

However, candidates had to meet high standards and cope with a high degree of bureaucracy[481]. Currently, there are around 300 CHP in Berlin, of which about two-thirds are under 50 kWe.

- **Baden Württemberg:** Baden Württemberg offers a CHP promotion via the "CO2 Reduction Program". Combined heat and power units of more than 15 kW are promoted for small and medium-sized enterprises and individuals. Furthermore, CHP plants are eligible for funding if biogas or wood pellets are used as the primary energy source. CHP will also be eligible for the "Environmental and Energy Saving Program" and the "Bioenergy Village" project with a maximum of 20% of the total amount. The promotion is generally limited to a maximum of 100,000 euros[482].
- **Bayern:** Bavaria promotes heating systems which use biomass. To receive funding, the CHP plant must reduce CO2 emissions by at least 500 tons in 7 years. The CHP fuel must exclusively consist of wood or biomass products from regional production[483]. According to this criterion and based on our calculations, this incentive is valid for systems with a capacity of more than 10 kWe[484].
- **Brandenburg:** The state of Brandenburg promotes every CHP system with a plant factor of 70% in the "RENplus" program. The subsidy is 25% of the eligible investment up to a maximum of 50,000 euros per plant[485],[486].
- **Bremen:** Through REN (Rationelle Energienutzung) program, Bremen offers a CHP promotion of up to 50 kW electric power for industrial and commercial enterprises. The amount of the loan is 2500 euros plus 320 euros per kW of electric power[487],[488].

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481 Pilsak, F. K. u. W. J. (2012). "BHKW-Förderung mit dem Berliner UEP II." from http://www.bhkw-infothek.de/nachrichten/9014/2012-07-24-bhkw-forderung-mit-dem-berliner-uep-ii/.

482 Märtel, C. (2014). BHKW Förderung durch die Bundesländer, heizungsfinder.

483 Ibid.

484 blockheizkraftwerk-bhkw (2014). "Förderprogramme nach Bundesländern." from http://www.blockheizkraftwerk-bhkw.net/foerderung#berlin.

485 Märtel, C. (2014). BHKW Förderung durch die Bundesländer, heizungsfinder.

486 blockheizkraftwerk-bhkw (2014). "Förderprogramme nach Bundesländern." from http://www.blockheizkraftwerk-bhkw.net/foerderung#berlin.

487 Ibid.

488 Märtel, C. (2014). BHKW Förderung durch die Bundesländer, heizungsfinder.

- **Hamburg:** Hamburg is helping CHP owners with the promotion program "Bioenergy" (bioenergy and companies for resource protection). This program supports CHPs using vegetable oil such as palm oil. The incentive is 75 euros per kilowatt thermal power up to a maximum of 100,000 euros. This promotion is available for power plant owners and landowners[489],[490].
- **Hessen:** Hessen promotes biogas plants coupled with CHP through the program "Organic Raw Materials from Agriculture and Forestry" with subsidies of up to 75,000 euros. Eligible applicants include all real and legal individuals. The incentives includes biogas complexes which use CHP systems[491],[492].
- **Mecklenburg-Vorpommern:** Mecklenburg-Vorpommern promotes CHP up to 1.5 MW via the "Climate Protection Action Plan Cogeneration" program that covers 20% of the eligible investment. The amount of the subsidy is at least 20,000 euros up to a maximum of 200,000 euros[493]. Associations, municipalities, small and medium enterprises and the housing industry are eligible to apply[494].
- **Niedersachsen:** Niedersachsen supports research projects in the field of renewable energies and energy modernization and CO2 reduction[495]. The funding amount depends on the specific project design and on the size of the reduction in CO2[496].
- **Nordrhein-Westfalen:** Nordrhein-Westfalen promotes biogas CHP, biomass and vegetable oil CHP plants through the program "progres.nrw". Eligible applicants are entrepreneurs and legal entities[497]. Depending on output power, the subsidy ranges

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[489] Ibid.

[490] blockheizkraftwerk-bhkw (2014). "Förderprogramme nach Bundesländern." from http://www.blockheizkraftwerk-bhkw.net/foerderung#berlin.

[491] Ibid.

[492] Märtel, C. (2014). BHKW Förderung durch die Bundesländer, heizungsfinder.

[493] Ibid.

[494] blockheizkraftwerk-bhkw (2014). "Förderprogramme nach Bundesländern." from http://www.blockheizkraftwerk-bhkw.net/foerderung#berlin.

[495]

[496] blockheizkraftwerk-bhkw (2014). "Förderprogramme nach Bundesländern." from http://www.blockheizkraftwerk-bhkw.net/foerderung#berlin.

[497] Märtel, C. (2014). BHKW Förderung durch die Bundesländer, heizungsfinder.

between 1,500 euros and 17,000 euros totally. The program supports plants with an electrical power of less than 50 kW, which have a connection to the public grid[498].

- **Rheinland Pfalz:** Rheinland Pfalz promotes CHP based on the funding guidelines "subsidies for investments in energy efficiency and energy supply, including renewable energies". Eligible applicants are all individuals, industries, organizations and public services[499]. The minimum investment costs must be higher than 30,000 euros. Subsidies are valid for a period of 7 years[500].
- **Saarland:** Saarland promotes CHP through the "Future Energy Technology Program". All individuals and legal entities and small and medium-sized enterprises are eligible for application[501]. The program supports small CHPs with up to 20 kW in areas in which district heating is not available and supports investments with a minimum of 3,000 euros per plant. Legal and real persons are eligible to apply. The grants are subject to the condition of property and integration of the cogeneration systems into the existing heating network[502].
- **Sachsen:** Sachsen promotes CHP plants which use vegetables oil in the agricultural sector. Eligible applicants include companies from agriculture[503]. The Development Bank of Saxony (SAB) also supports grants for investments in cogeneration. Based on the performance of the CHP, the owners receive subsidies in the amount of 1,000 euros per kW for plants with an output of electrical power between 0 and 4 kW and 300 euros per kW for plants higher than 6 kW[504].

Schleswig-Holstein: Schleswig-Holstein offers a biogas promotion as well as promotion for CHP plants. Municipal associations, individuals and legal entities are

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[498] blockheizkraftwerk-bhkw (2014). "Förderprogramme nach Bundesländern." from http://www.blockheizkraftwerk-bhkw.net/foerderung#berlin.

[499] Märtel, C. (2014). BHKW Förderung durch die Bundesländer, heizungsfinder.

[500] Ibid.

[501] Ibid.

[502] blockheizkraftwerk-bhkw (2014). "Förderprogramme nach Bundesländern." from http://www.blockheizkraftwerk-bhkw.net/foerderung#berlin.

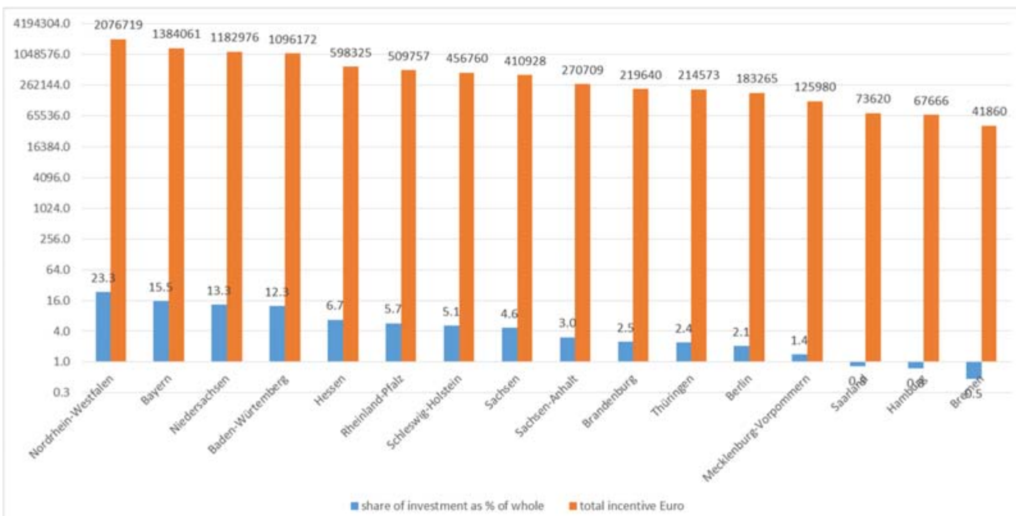
[503] Märtel, C. (2014). BHKW Förderung durch die Bundesländer, heizungsfinder.

[504] blockheizkraftwerk-bhkw (2014). "Förderprogramme nach Bundesländern." from http://www.blockheizkraftwerk-bhkw.net/foerderung#berlin.

eligible for applying. The homeowner is not the target group of the promotion. The program "Biomass and Energy" is temporarily suspended since May 2010[505],[506].

In Table 5-7, the different programs are summarized and compared. Five incentives programs by states are only aimed at the promotion of biofuels and renewable resources and the other seven programs cover all fuel types. Only five incentives programs directly targeted the promotion of micro-CHP of which three cover all fuel types. Five incentive programs cover all groups of owners as well households. Four incentive programs are targeted only towards entrepreneurs and small and medium enterprises (SME). All incentive programs provide subsidies for investment. Figure 5-10 compares the amount of total incentives in euros and its ratio to the sum of incentives by states in 2013.

Figure 5-10. Comparison of total incentives and its ratio to sum of incentives by states in 2013



Source: (generated by author, data extracted from (bafa 2013)

Figure 5-11 indicates the total number of installed micro-CHP in different states of Germany. By comparing Figure 5-10 and Figure 5-11, interestingly, we observe that the ratio of the installed number of micro-CHP in each state is equal to the ratio of total incentives by that state. It shows the direct effect of investment subsidies on the development of micro-CHP in Germany.

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505 Ibid.

506 Märtel, C. (2014). BHKW Förderung durch die Bundesländer, heizungsfinder.

Table 5-7. Comparison between states level programs for promotion of micro CHP in 2014

	direct targeting of micro CHP	limitation in micro-CHP plants	type of incentive	limitation in amount of incentive	fuel type	eligible applicant groups
Baden Württemberg	NO (via CO2 reduction program)	more than 15 kW	investment subsidy	20% of investment to maximum of 100,000 euros	biogas or wood pellets	all
Bayern	NO (via promoting heating systems which use biomass)	must reduce at least 500 tons of CO2 emission in 7 years (more than 10 kWe)	investment subsidy	no	wood or biomass from regional production	all
Brandenburg	YES (via RENplus)	70% rate of utilization	investment subsidy	25% of investment up to of 50000 euros	all	all
Bremen	YES (via REN (Rationelle Energienutzung) program	less than 50 kW for industrial and commercial	investment subsidy	2500 euros plus 320 euros per kW	all	Industrial and commercial
Hamburg	NO (via "Bioenergy" Promotion Program)	Only using vegetable oil	investment subsidy	75 euros per kW thermal up to 100,000 euros	vegetable oil such as palm oil	power plant owners and agricultural landowners
Hessen	NO (via program "Organic Raw Materials from Agriculture and Forestry"	biogas complexes which use CHP systems	investment subsidy	up to 75,000 euros	biogas	all real and legal individuals
Mecklenburg-Vorpommern	YES (via "Climate Protection Action Plan CHP")	up to 1.5 MW	investment subsidy	20% of investment to maximum of 200,000 euros	all	municipalities, small and medium-sized enterprises, associations and the housing industry

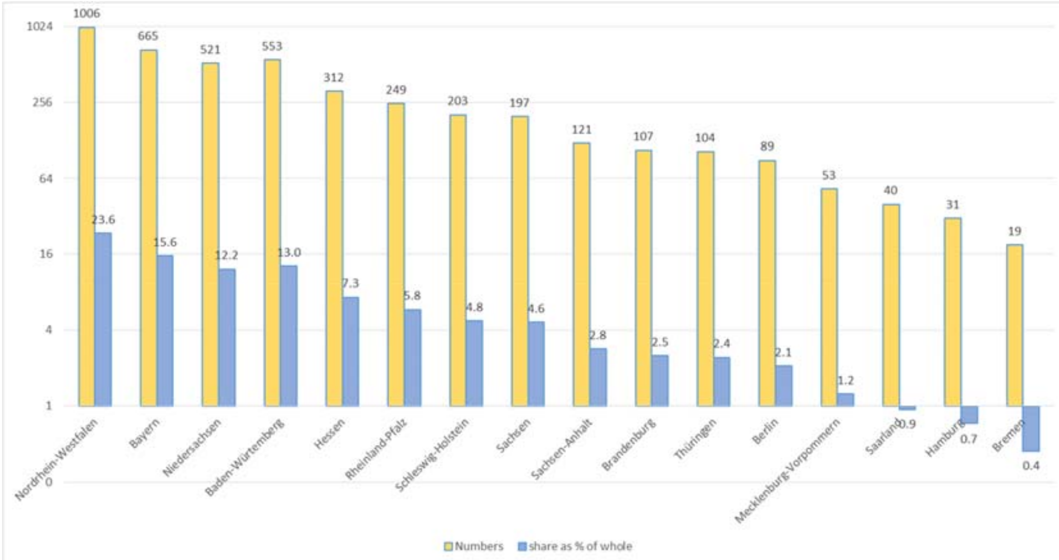
Source: author

Table 5-7. Continued

	direct targeting of micro-CHP	limitation in micro-CHP plants	type of incentive	limitation in amount of incentive	fuel type	eligible applicant groups
Niedersachsen	NO (via supporting research projects related to renewable energies, and CO2 reduction)	-	-	depends on the project design and the amount of the CO2 reduction	all	all
Nordrhein - Westfalen	YES (through the program "progres.nrw")	bio fuel CHP and less than 50 kW	investment subsidy	between 1,500 euros and 17,000 euros	biogas, biomass and vegetable oil	entrepreneurs and legal entities
Rheinland Pfalz	NO (via "subsidies for investments in energy efficiency and energy supply, including renewable energies"	investment costs must be higher than 30,000 euros	investment subsidy	are valid for a period of 7 years	all	all individuals, entrepreneurs, industries, organizations and public services
Saarland	NO (via "Future Energy Technology Program")	up to 20 kW in areas which district heating is not available	investment subsidy	minimum 3,000 euros	all	All Individuals and legal entities and small and medium-sized enterprises
Sachsen	YES (via program "Investitionszuschüsse für Blockheizkraftwerke	CHP use vegetables oil	investment subsidy	1,000 euros per kW for plant 0 and 4 kWe and 300 euros per kW for higher than 6 kW	all	companies from agriculture

Source: author

Figure 5-11. Number of micro-CHP units and share of each state in 2013



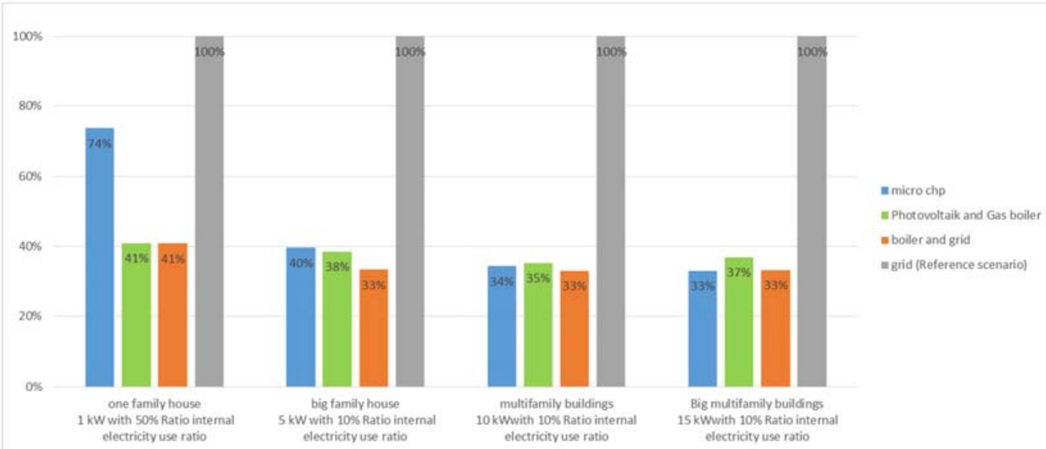
Source: (generated by author, data extracted from (bafa 2013)

5.11 Competition with solar systems

We conducted the same analysis for using a solar system for supplying the electricity and heat demand. In Germany, the power output of thermal solar panels ranges between 250 to 600 kWh per square meter per year[507]. The efficiency of solar thermal panels is very low and installing a solar heating system with a capacity equal to micro-CHP requires a very big surface of the solar collector and is only suitable for single-family houses. For example, a heating capacity of more than 10kW requires an area of more than 225 m^2. In addition, the solar heating systems have less reliability and accessibility and cannot compete with gas boilers. As a result, we assumed only conditions, which the photovoltaic solar panels are combined with gas boiler. All technical assumptions regarding solar systems, such as costs and efficiency are explained in Appendix 2. In our analysis, we calculated the costs of micro-CHP systems based on the CHP Act of 2012. Figure 5-12 shows that if the micro-CHP owners feed part of the generated electricity into the grid, the solar panels in combination with gas have lower costs during a 10-year time-period for single and big family houses. However, for capacities of more than 10 kWe, there exists no significant difference.

[507] Frahm, T. (2014). "Solarthermie & Ertrag - Berechnung für ein Einfamilienhaus." from http://www.solaranlagen-portal.com/solarthermie/thermische-solaranlage/ertrag.

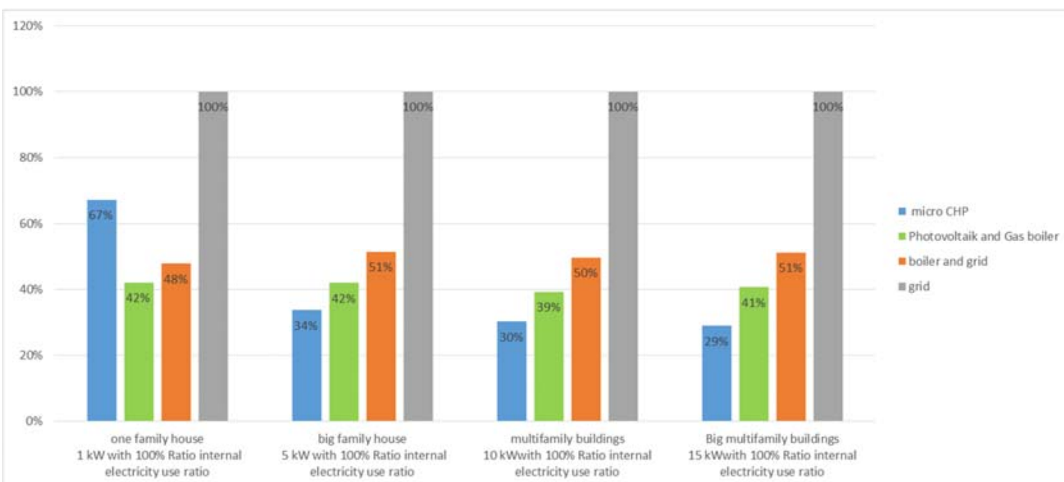
Figure 5-12. Comparison between present cost of solar photovoltaic and other technologies in 10 years and assuming partial internal usage of generated electricity by micro-CHP plant



Source: author

Figure 5-13 shows the situation of 100% internal consumption of generated electricity (probable with help of enough storage). In this situation, solar is the best option only for single-family houses. However, for bigger capacities, micro-CHP has lower costs in 10 years of operation.

Figure 5-13. Comparison between present cost of solar photovoltaic and other different technologies in 10 years and assuming partial internal usage of generated electricity by a micro-CHP plant



Source: author

6 Concluding considerations

In this chapter, we summarize the previous arguments by focusing on the case of micro-CHP to see how these general factors and the cultural dimension shape the development path of micro-CHP in Germany. We conclude that some value proposition models can be developed better according to the specific cultural and institutional dimensions in Germany. Moreover, we look at Germany's regulatory framework to see if it is in symmetry with the cultural dimensions and the manner in which it offers value to the stakeholders. In this chapter, we proved following hypothesizes:

- The cultural and institutional system in Germany is positively affecting entrepreneurial activities but it has some weaknesses. The uncertainty avoidance culture of Germans and complexity of regulations are among them.
- Macro level phenomena at global and EU level, helped establishment of a supportive institutional setting in favor of micro CHP development positively. For example, Phase out of nuclear and less supports of Renewable energies in recent years provide more space for micro CHP development
- At regime level, the institutional setting also was against the development of micro CHP in the past; however, both market liberalization and purchasing the micro CHP developers by big utilities provided more hopes for future development. For example, the goal of energy market liberalization was raising competitiveness and innovation, and several CHP acts passed by the government in order to support the technology. However, entrepreneurial activities require more networking and awareness of customers. Based on specific cultural and institutional features of Germany, some forms of proposing micro-CHP technology such as Fuel-cell micro CHP can be more successful and develop better. However, until there are few or even no benefits for distributed network operators and large utilities in micro-CHP development, micro-CHP cannot be promoted only by incentive policies and the regulatory framework. Innovative activities require the cooperation of all stakeholders.

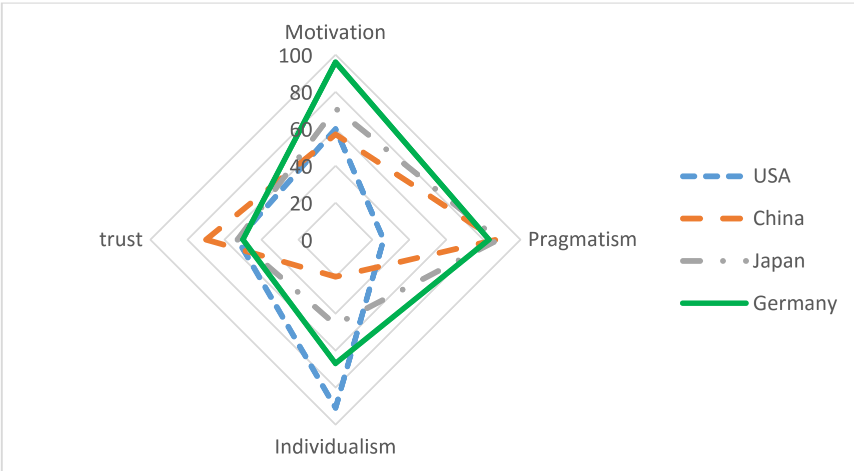
6.1 How do the general factors and cultural features of society influence entrepreneurial activities?

In 2014, Germany ranked fourth in the field of qualified infrastructures for development and particularly its transport system and physical network is among the best in the world. With respect to market efficiency, Germany is among the top ten countries. The World Talent Report ranks Germany third when it comes to capacity for innovation and 16th regarding the ability of countries to absorb the latest technological changes at firm level. However, some weaknesses exist in the labor market, which Germany ranks 113th in the world while Germany's institutions ranked 15th in the world, which leaves ample room for improvement. Based on the economic theory of entrepreneurship and culture, more pragmatism regarding collective behavior and high levels of trust facilitate an effective environment for working on ambitious projects with high levels of entrepreneurial activities and innovation[508]. These conditions are exactly what we see in Germany. The international reports also rank Germany as one of the leading innovation-driven countries and prove the theories' predictions right. However, innovative activities in the fields of science and technology are much stronger in Germanys' culture than entrepreneurial activities. There are several cultural and structural factors in Germany, which lower entrepreneurial activities. From a cultural point of view, the level of trust in Germany in comparison with other countries is not very high, as is required for high entrepreneurial activities. Figure 6-1 shows the four cultural dimensions of four biggest economic powers in the world as well as Germany according to their cultural dimension index (not country rank). The culture of Germany has the strongest dimensional combination for the promotion of entrepreneurial activities among the world's largest economies. The level of individualism is lower than in the US but higher than in Japan and China. The trust level is not very high which is rooted in the German culture's tendency to avoid uncertainty. In this regard, Germany in one hand try to be best at science and technology, which enables it to compete in the market with highest innovative activities among other countries. On the other hand, uncertainty avoidance culture led to lower degree of trust and increase conservative behavior among investors. The effect is visible in the level of available venture capital in Germany (see Table 4-8). Another

[508] Casson, M. (2010). Entrepreneurship: Theory, Networks, History, Edward Elgar.

example is the lack of balance between the number of patents (70% of all patents in Europe) and the amount of private sector investments in fuel cells, which is less than 10% of total Europe and less than 5% in US.

Figure 6-1. Country score of four dimensions of culture in the USA, China, Japan and Germany.



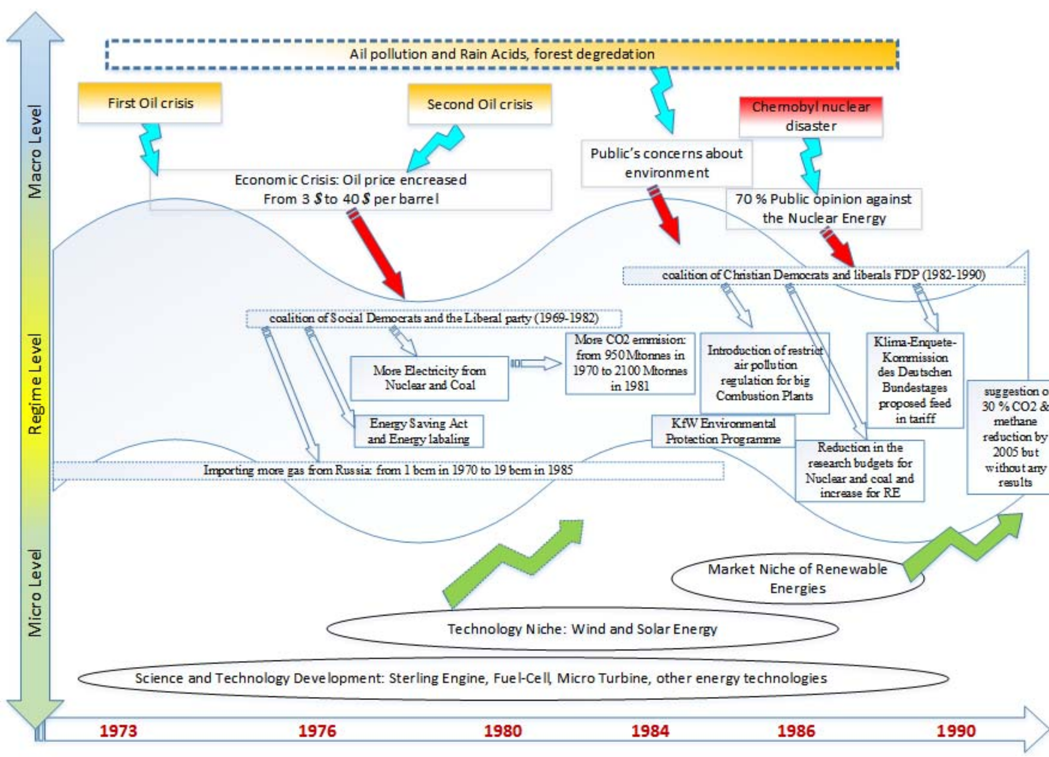
Source: author

However, Uncertainty avoidance in combination with other cultural dimensions shapes culture of cooperation and collaboration to fulfill common interests, which is positive, however, the emergence of large industrial consortiums led to the establishment of industrial monopolies and reduces the space available for small and medium enterprises such as entrepreneurial activities regarding micro CHP. Based on the German culture, it is expected that quality in terms of the reliability and safety of micro-CHP systems is the most important factor for selecting it. Uncertainty avoidance not only can be seen on the customer side but also many boiler installers and other energy service advisors display conservative reactions towards micro-CHP and refuse to suggest new innovative technologies to customers. In fact, the incumbent installers have their own customers and markets and do not like to take risks by suggesting new technologies such as micro-CHP that may negatively influence their reputation. It follows that new entrepreneurs are required for the installation and distribution of micro-CHP systems. Among the various micro-CHP technologies, reciprocating engines and sterling engines are not popular among customers. They have many moving mechanical parts and need regular servicing such as oil changes.

6.2 How do dynamics in the institutional setting of the energy system shape the development of micro-CHP?

Figure 6-2 shows the dynamics of Germany energy system from 1973 to 1990 in a multi-level perspective. The period before 1990 was a preparation for bigger changes for Germany's energy system. The first oil crisis in 1973 and the second one in 1980, plus the Chernobyl disaster, constituted the most significant pressures from global phenomena on the macro level and the regime level. Another significant source of pressure originated in the public's opinion regarding air pollution and nuclear energy. In fact, the public's worry about nuclear energy and the environment existed prior to the Chernobyl disaster and acid rains or air pollution problems.

Figure 6-2. Changes in the regime of Germany's energy system in multi-level perspective.

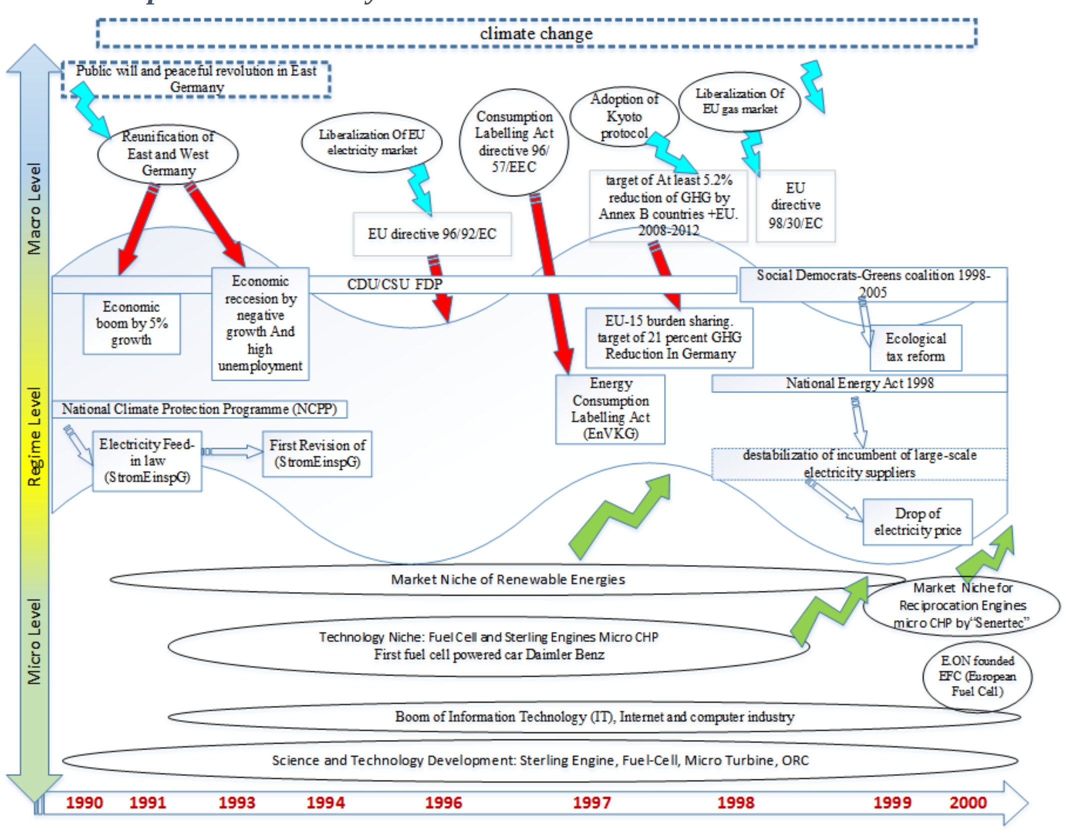


Source: Author

Nevertheless, these incidents unified society and triggered a chain of actions to pressure the political system for change. From an institutional point of view, the period prior to 1990 can be seen as a preparation time for bigger changes and the maturing of society and its politicians concerning the environmental risks of technology and the concept of sustainability.

The dynamics of institutional changes for period 1990 to 2000, have been shown in figure 6-3. The liberalization of the EU energy market in 1996 through directive (96/92/EC) obliged free access of new producers to the gas and electricity grid. Two years later, Germany approved the National Energy Act and the market became liberalized. However, the network access mechanism was negotiated and grid access still was a problematic issue for private and small producers such as micro CHP. Within The Kyoto Protocol of the UN, Germany promised 21% GHG reduction by 2008 based on the level of 1990 accompanied with many reforms were launched in the 1990s, such as the Ecological tax reform in 1999 and the energy labeling act in 1997, all were a begin for institutional formation in favor of micro CHP. Another effort for setting up the required institutional framework was the electricity feed-in law and its revision for protection of renewables, which later has been used as a model for micro-CHP.

Figure 6-3. A multi-level perspective of changes from 1990 to 2000 regarding micro CHP development in Germany

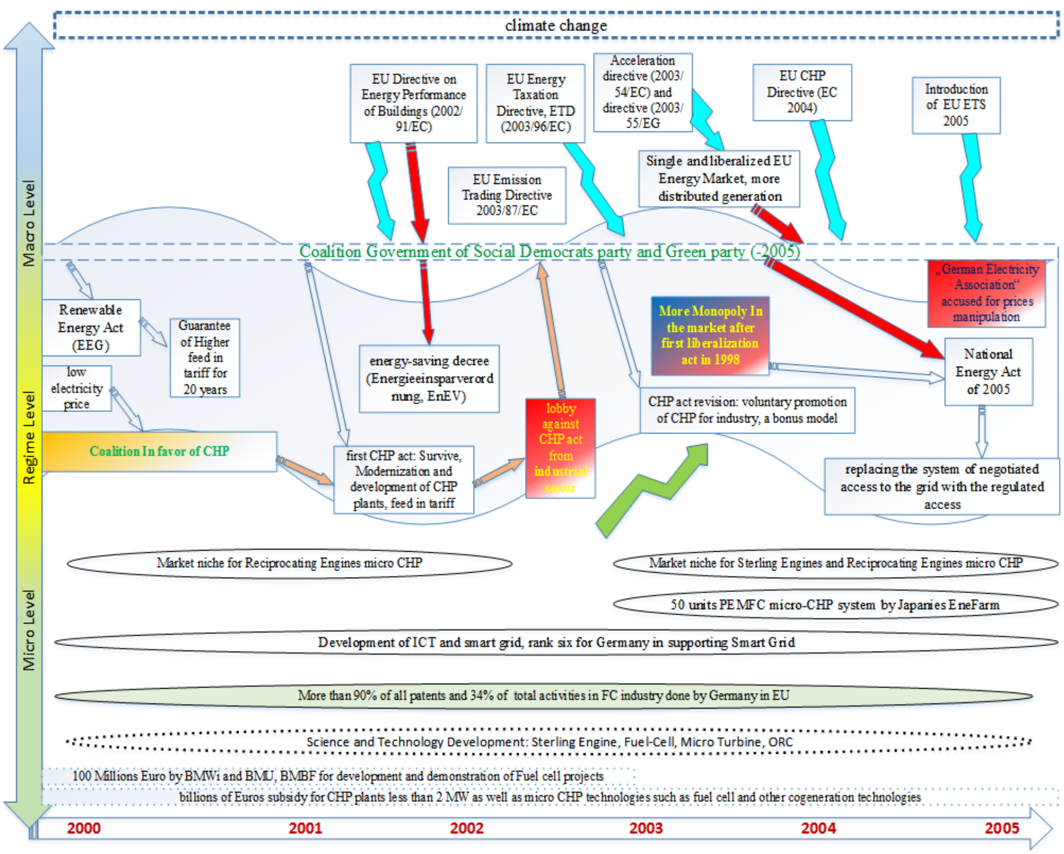


Source: Author

In the 1990s, the reciprocating engine technologies on the niche level matured and were introduced to the market niche in 1999. The very quick development of ICT provided technical support for the idea of smart grid and integrated distributed generation and the idea started to enter the technological niche. The fuel cell, ORC and micro turbine technologies came to the technological niche level as a potential for future micro CHP technologies. In summary, period 1990 -2000 was a starting period for goal setting, and stabilizing the economy after reunification and important decisions regarding GHG reduction and green technology development, provided spaces for micro CHP technologies at niche level.

In the period 2000-2010, the micro-CHP technology was still at the niche level. The whole picture of institutional changes in a multi-level perspective is shown in Figure 6-4 and Figure 6-5.

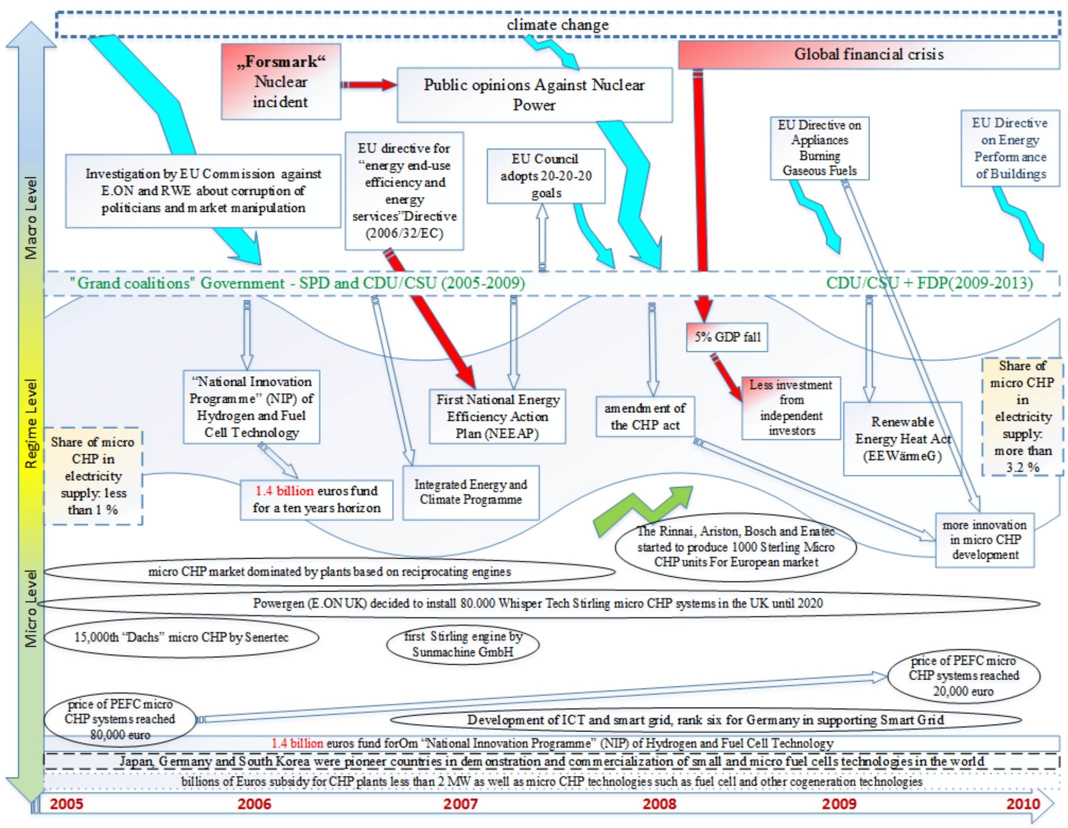
Figure 6-4. A multi-level perspective of changes from 2000 to 2005 regarding micro-CHP development in Germany



Source: Author

During the period from 2000 to 2010, the EU commission played an active role in shaping the energy policies of EU member states and initiated nine different directives, which also influenced the development of micro-CHP in Germany. Among them the acceleration directive 2003/54/EC and directive 2003/55/EG for shaping a single energy market in EU, had the most fundamental influence on the institutional setting of Germany. After these two directives, the EU put more pressure on Germany to modify regulations aimed at energy liberalization. Accusations of "German Electricity Association" for price manipulation in 2005 and an investigation of the EU Commission into corruption in E.ON and RWE, increased the pressure on Germany. On the other hand, studies showed that in spite of the full market liberalization in 1998, monopoly power in Germany's energy market had increased in 2005. The German government in 2005 initiated the National Energy Act. The new law replaced the previous regulation of negotiated access to the grid with a regulated mechanism and obligations for more unbundling.

Figure 6-5. Multi-level perspectives of changes from 2005 to 2010 regarding micro-CHP development in Germany



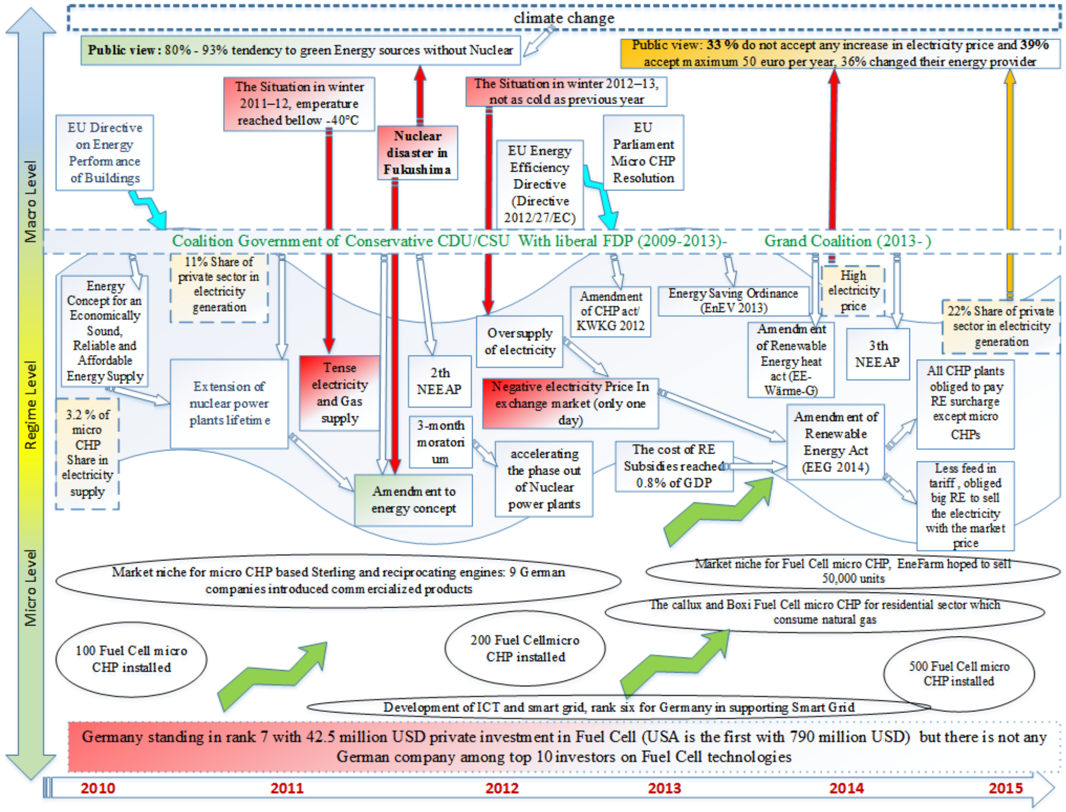
Source: Author

Such reforms really accelerated the liberalization. The share of the private sector in electricity production increased from 6% in 2006 to 11% in 2010 and the statistics indicate 21% of households changed their electricity providers in 2010. It shows an increase of 100% from 2006. On the gas market, 12% of residential customers changed their gas supplier. The number of changes was less than 1% in 2007. The most important institutional setting that was supporting micro-CHP was the CHP act. After the first CHP act, which was a result of a strong coalition of all stakeholders, the lobby of industry led to the revision, but micro-CHP was not influenced. Several factors such as the first national energy efficiency action plan (NEEAP), integrated energy and climate programme provided more support of CHP technologies. In 2008, the amendment of the CHP act introduced and provided much better incentives for micro-CHP owners through feed-in tariff and CHP bonus, which was comparable with the incentives for renewables. Other regulations at the EU level obliged the developers of gaseous appliance including micro-CHP to innovate more. In 2006, Senertec produced more than 15,000 units of micro-CHP based reciprocating engines. As the market was dominated by reciprocating engines, after 2005, several micro-CHP systems based on Sterling engines entered into the niche market. By solving many technological problems of fuel cells, such as the lifetime and hydrogen production from methane, the fuel cell micro-CHP started to enter the technology niche level and many manufacturers started to develop technology and planned for market introduction. The price of fuel cell micro-CHP decreased from 80,000 euro to 20,000 euros prior to 2010. In 2006, in a cooperation between the federal government and industry, the national innovation program (NIP) of hydrogen and fuel cell technology, assigned 1.4 billion euros for the development of all kinds of fuel cell applications. 9% of the budget dedicated to stationary units including micro CHP units. Germany was the leading country in the EU in terms of innovation and technology development by share of more than 70% of all patent in Europe. Moreover, Germany started to support several projects related to smart grids and was ranked sixth among top smart grid supporters in the world. Moreover, as discussed before, smart grid infrastructure is playing positive role in development of micro-CHP.

In the late 1990s and even in the years 2000-2005, we see a very slow development of micro-CHP in the energy system. One of the main barriers was the fact that more than 70% of low voltage Distribution Network Operators (DNOs), belong to the four big producers and the DNOs are responsible for the connection of micro-CHP units to the grid. This monopoly power led big utilities to use their influence on DNOs to make the connection of micro-CHP units to the grid more difficult. Still, in 2014 four big electricity supply companies owned 100% of all grid companies in Germany. However, their share in electricity generation was reduced to 77%. Another institutional change was the acquisition of some big gas companies by big electricity generators. For example, E.ON as one of the biggest electricity producers in Germany (and most profitable electricity company in the world) acquired the gas distributor company Ruhrgas in 2003. This has a double effect on the development of micro-CHP: On one hand, it motivates big generators to further develop the technology of micro-CHP because they can sell more gas and on the other hand, it increases monopoly power in the energy market and hinders the innovation process.

The period after 2010 can be seen as the take-off stages for micro-CHP entrepreneurial activities. Many manufacturers introduced their products with competitive prices in comparison with boiler technologies. The institutional setting is relatively more stable in comparison to the period of 2000-2010 and the liberalization accelerated. With the amendment of the Renewable Energy Act in 2014, the incentives for renewables and CHPs were reduced but micro-CHPs were excluded from these new changes. As a result, the institutional situation for the two competitor technologies of Renewable Energies and bigger CHP is more difficult than prior to 2010. On the other hand, the amendment of the CHP Act in 2012 increased the bonus for produced electricity from micro-CHP plants. At the mega scale, the phase-out of nuclear energy by 2022 can provide a lot of space for micro-CHP. Still, in 2014 the share of micro CHP in the energy market of Germany was not significant. With the installation of about 5000 new units in 2014, a total capacity of 30 MW capacity was added to the system, which is nothing in comparison with the 180,000 MW installed capacity in Germany. The picture is depicted in a multi-level perspective in Figure 6-6. It shows the interactions and dynamics in the different parts of the German energy system, which influences the development of micro-CHP in Germany after 2010. Climate change and the Fukushima disaster in 2011 increasingly influenced public opinion to the detriment of nuclear energy. As a result, the German government changed its policy of keeping nuclear power plants in operation and moved toward a faster phase-out of nuclear energy.

Figure 6-6. A multi-level perspective of changes from 2005 to 2010 regarding micro-CHP development in Germany



Source: Author

The shutting down of about 9000 MW of capacity of nuclear power plants provided a lot of space for other technologies, including micro-CHP. Appealing incentives for renewables in the EE-G led to the accelerated development of wind and solar power. At the same time, Germany increased its import of natural gas by 19% in 2014 in comparison to 2010 import levels. More natural gas also provided more opportunity for the use of micro cogeneration. Another factor at the macro level was the cold weather in the winter of 2011-12, which led to a tense situation in the German energy supply system. The inability of renewables to answer the demand showed that renewable resources are not as reliable as it was thought before. In addition, it showed the importance of further development of Germany electricity grid. Consequently, Germany prepared itself for the next winter. However, the moderate winter led to an oversupply, caused negative price of electricity in the exchange market, and again showed the other side of renewables for the German economy. The very high price of electricity for the residential sector reduced the popularity of renewables in the public's view. In 2013, the cost of subsidies for renewables was increasing constantly and reached 0.8% of Germany's GDP. As a result, Germany increased the investments in the expansion of the national grid and tried to prevent future negative effects of rapid development of renewables by introducing the amendment of the Renewable Energy Act in 2014.

After 2010 is the maturity period of regulations regarding green technologies like CHP and renewables. Between 2010 and 2014, unlike during previous periods, the government approved less new regulation and mostly previous regulations were revised. For example, several amendments for cogeneration, renewables and energy efficiency were introduced. Most amendments do not have a significant influence on the development of micro-CHP, except the amendment of the CHP Act in 2012, which provided more incentives for micro-CHP. The liberalization of the energy market is an essential requirement for the development of entrepreneurial activities in the field of micro-CHP. After 2010, the market liberalization for natural gas and electricity increased and the share of the private sector in electricity production increased from 11% in 2010 to 22% in 2014. In the natural gas market, 27.6% of residential customers changed their gas supplier and were able to choose one among 890 gas companies in the German market. The number of changes were less than 11% in 2011 and less that 1% in 2007. Despite of all positive signs of liberalization in Germany, in 2014, 77% of all electricity in Germany was produced by 4 big utilities which control 100% of the grid. At the niche level, fuel cell micro-CHP entered the market level in 2014. Most of the budget and support for the development of fuel cells stems from governmental programs and resources. Despite the fact that most innovations in the field of fuel cells come from Germany, the country is ranked seventh in the world and third in Europe in funding from private investors and funds. The number of private investors in the UK is 6 times higher that Germany. This shows that entrepreneurial activities from the private sector in Germany have a very big potential for absorbing more investment. Moreover, new smart technologies like the smart home, smart home robots and the integration of ICT with energy systems, supports more than ever the idea of using micro-CHP systems in smart grids and smart cities. Due to the carbon price and the typical capacity of micro-CHP units, some policies such as emission trading schemes have not affected micro-CHP significantly. In 2014, about 5000 micro-CHP units were installed, less than 500 of which were fuel cell micro-CHP. It can be concluded that FC micro-CHP is still at the niche level in Germany.

In the beginning of the 2000s, a strong advocacy coalition around CHP led to the CHP Act for the protection of mostly large CHP plants. To this day, there is no coalition advocating the further development of micro-CHP. However, several energy efficiency acts and acquisitions of producers by big utilities helped the development of technology. In Germany, micro-CHP is mostly considered a marginal technology in social networks of energy professional such as fuel cell, distributed generation, smart grid, CHP and technologies to increase energy efficiency in buildings. In fact, the natural gas industry is one of the biggest supporters of the development of fuel cell micro-CHPs. For example, the "Fuel Cell Initiative" (Initiative Brennstoffzelle) supported the development of a virtual power plant compound of several fuel cell CHP systems[509].

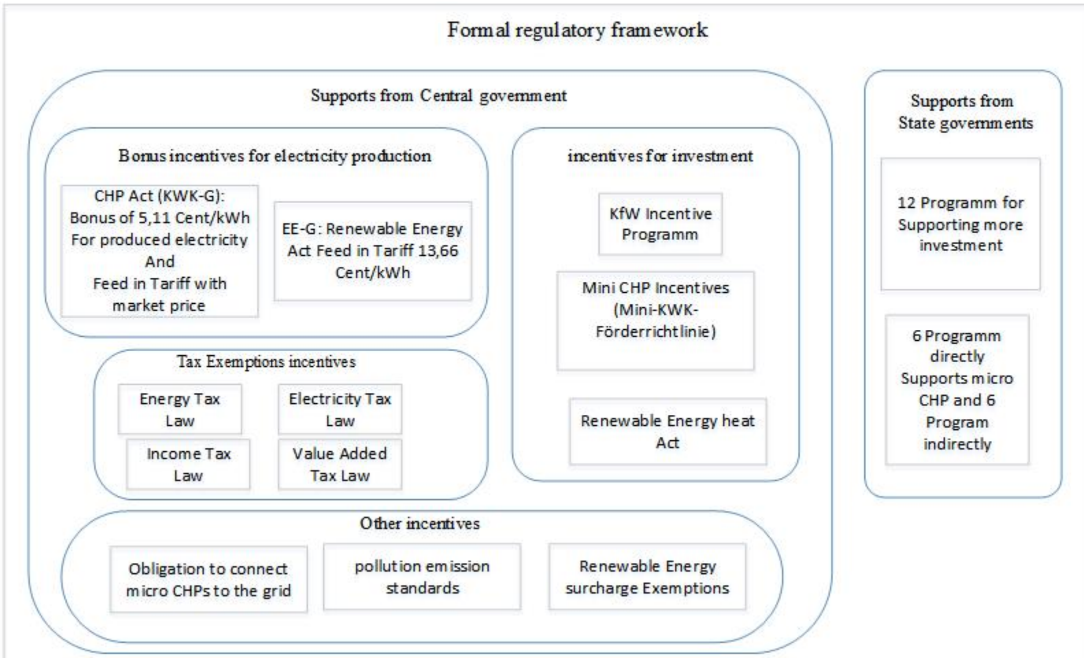
6.3 How regulations influence entrepreneurial activities in the field of micro-CHP in Germany?

As previously discussed, there are several regulations that influence the development of micro CHP in Germany. The most important one is the CHP Act (KWK-G) which provides supports by the means of feed-in tariffs, and obliges the distributed network operators to buy electricity from producers. In addition, there exist many supporting acts from the central and state governments for encouraging investments and reducing the costs of investment in micro CHP plants (See Fig 6-7). The instability of regulations, which change constantly, increases the transaction costs as well as the risks of planning and causes some sort of uncertainty about the future of this technology. For example, the RE Act of 2014 indicates the situation of RE-surcharge payments until 2017. However, the situation after 2017 is not clear. The bonus in the CHP Act of 2012 seems attractive but still cannot compete in terms of costs with a combination of boiler and grid usage for single-family house applications. Only if operators use all generated electricity internally, costs can be lower, but not for one family houses. In the current regulatory framework, the CHP Act of 2012 in general and the RE Act of 2014 in particular, play a central role in providing incentives for end-users of renewable fuels. Figure 6-8 compares the costs of micro-CHP in 10 years in the context of the RE Act of 2014 and the CHP Act of 2012. In this situation, except in the case of single-family houses, the RE Act of 2014

[509] Martin Pehnt, M. C., Corinna Fischer, Barbara Praetorius, Lambert Schneider, Katja Schumacher, Jan-Peter Voß (2006). Micro Cogeneration: Towards Decentralized Energy Systems, springer.

provides more incentives for micro-CHP. On the other hand, Figure 6-9 compares the RE Act of 2014 and the CHP Act of 2012 based on the present cost of different technologies over a period of 10 years and assuming 100% internal usage of generated electricity.

Figure 6-7. Formal regulatory setting for supporting micro-CHP in Germany

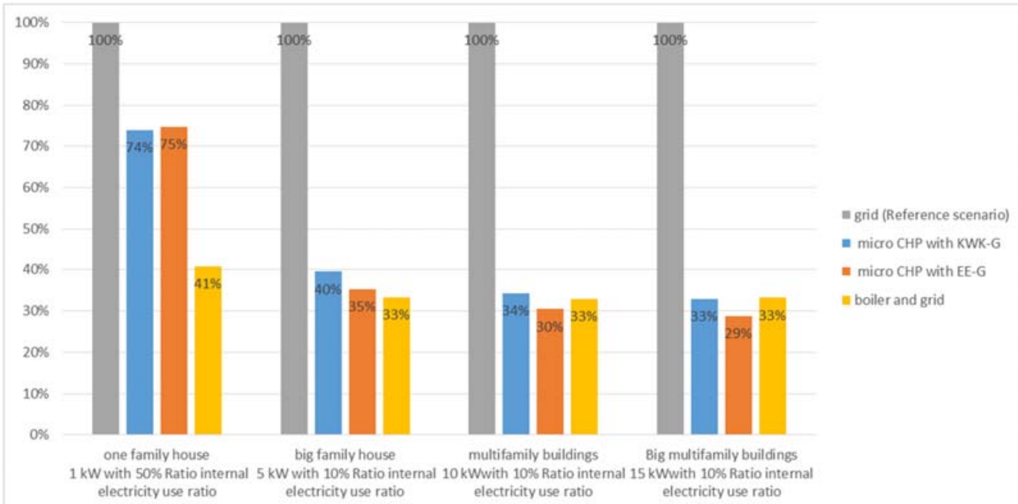


Source: author

In this situation, the CHP Act of 2012 resulted in lower costs. The reason is that in the context of the CHP Act, micro-CHP owners receive a CHP bonus regardless of whether they feed electricity into the grid or not. It can be concluded that the CHP Act encourages the generators to consume the generated electricity mostly internally rather than feeding it into the grid.

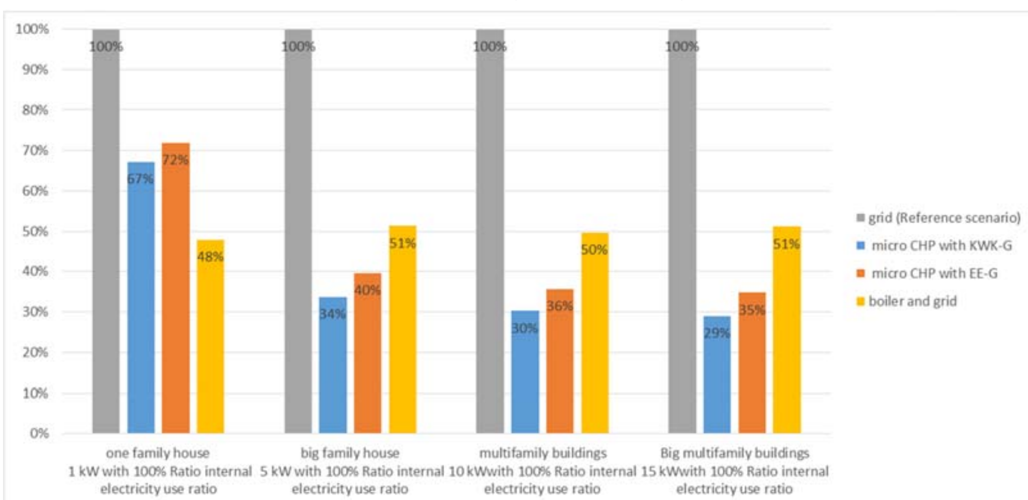
Incentives such as the energy tax law provide attractive incentives by reducing costs from 3% to 8%. Regulations regarding value added tax and income tax can reduce costs but their regulatory frameworks are complicated and depend on many other technical and non-technical issues. For example, variables such as the ownership of the property, apartment rent, the level of feeding electricity into the grid and the age of the building all change the profit model and introduce excess transaction costs in the way of technology implementations. The role of the state governments is as important as that of the federal government. At the state level, each German state propose attractive incentives for the promotion of highly efficient technologies such as micro-CHP.

Figure 6-8. Comparison between the RE Act of 2014 and the CHP Act of 2012 based on the present cost of different technologies over a 10 year time period and assuming partial internal usage of electricity generated by the micro-CHP plant



Source: author

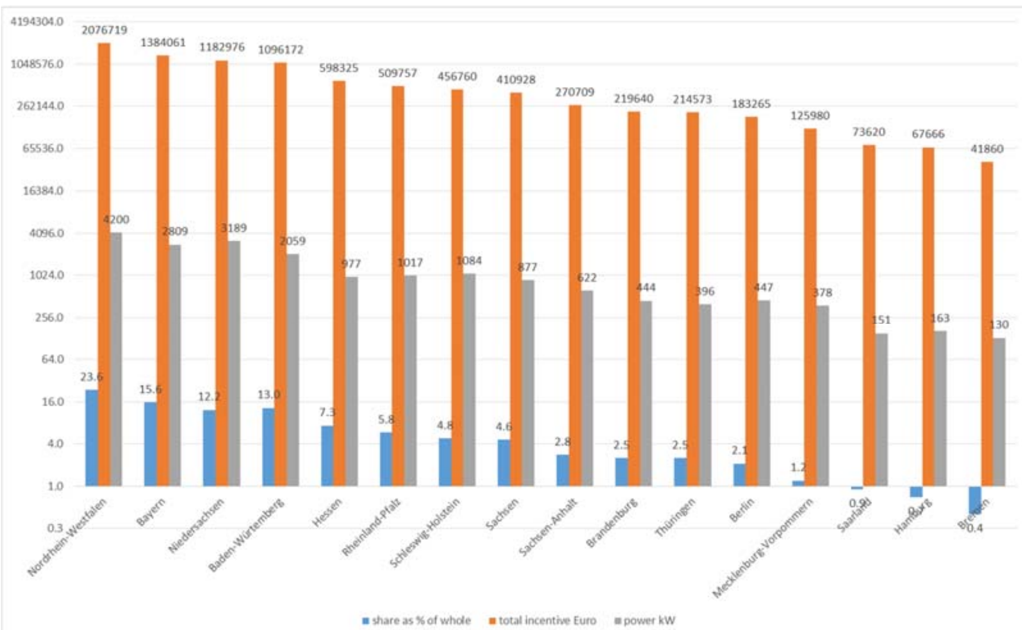
Figure 6-9. Comparison between the RE Act of 2014 and the CHP Act of 2012 based on the present cost of different technologies over a 10 year time period and assuming 100% internal usage of electricity generated by the micro-CHP plant



Source: author

The analysis shows that the installed capacity of micro-CHP in Germany is directly related to the amount of incentives provided by each state. Figure 6-10 indicates the total installed capacity in each state in comparison to the total amount of incentives granted in each state. Loan and subsidy programs at the federal level, such as mini-CHP incentives and the KfW Incentive Program, provide support for investments in micro-CHP, but the procedure of application and the terms and conditions are complicated. Other regulations such as the German civil law for tenants and property owners are ambiguous when it comes to the costs of micro-CHP and do not clarify how the tenant is obliged to buy generated electricity from the landlord. Several legal, technical and financial calculations are required for predicting the exact costs and benefits. The complexity of regulations necessitates the presence of a lawyer in cooperation with experts in energy science. In this situation, the house owners can become frustrated by these complexities, may prefer simpler technologies, and may ignore the benefits of micro-CHP. On the other hand, these problems provide opportunities for entrepreneurial activities in the field of helping all parties to reduce the transaction costs and implement the technology.

Figure 6-10. The total installed capacity in each state in comparison to the total amount of incentives in each state

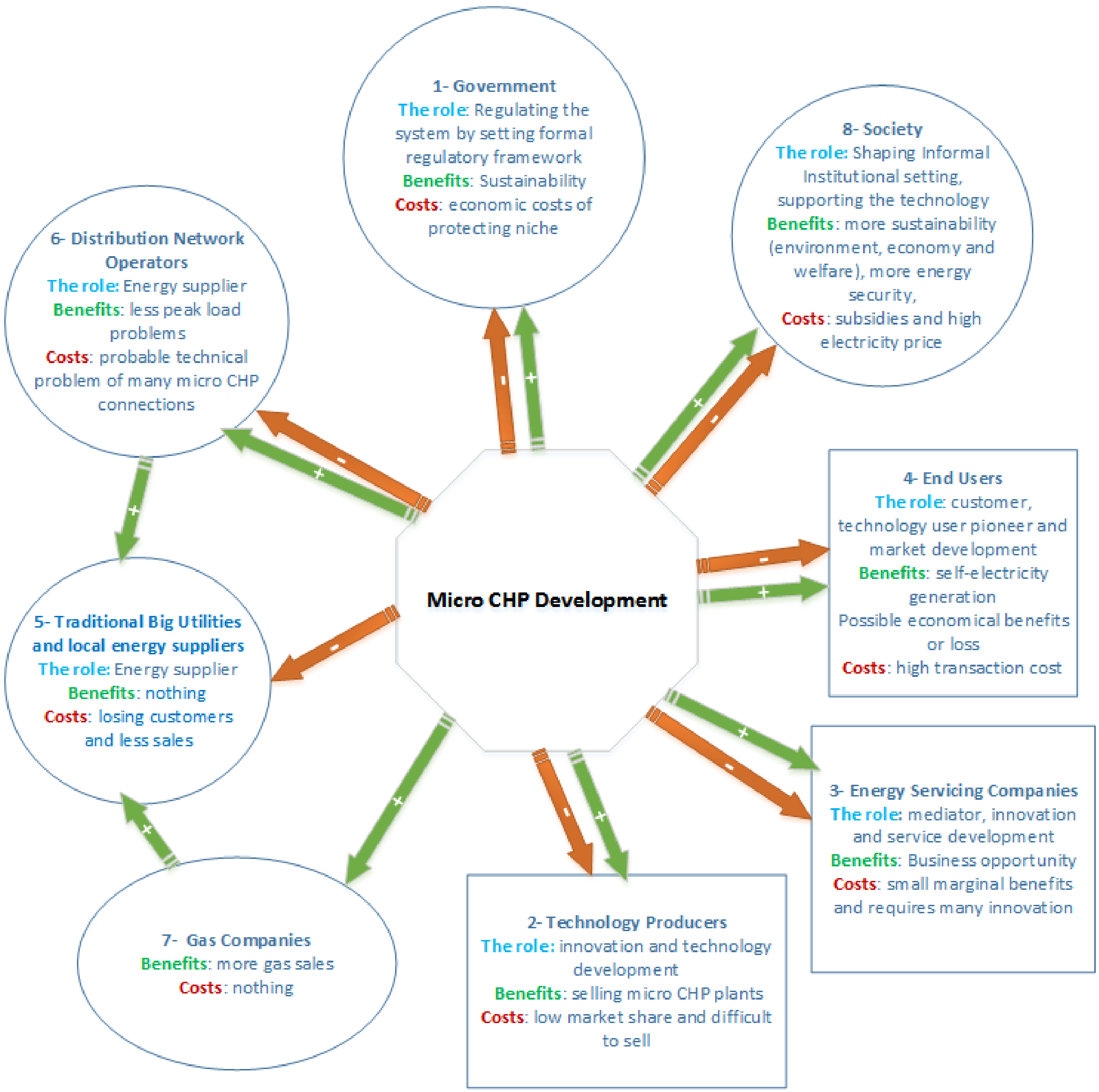


Source: generated by author, data extracted from (bafa 2013)

6.4 Costs and benefits of micro-CHP for stakeholders

Micro-CHP can offer a lot of value to stakeholders in the energy system of Germany. Despite of the original aim of its development, namely contributing to a high-efficiency energy supply system with lower CO2 and providing more energy security, the costs of micro-CHP for stakeholders hinder its development. In Figure 6-11, the actors and their benefits and costs resulting from micro-CHP development are shown.

Figure 6-11. Actors and their role, costs and benefits in micro-CHP development in Germany



Source: author

The more value it can offer the more success it has. In the following, we compare the values and costs which micro-CHP offers to each stockholder:

Values for customers:

- Reliability and security of energy supply

- Environmental protection and high technology utilization
- Economic profit

The regulatory framework can provide many incentives. However, the complexity of regulations and instability in regulatory framework increases the uncertainty about the future, which according to the German culture, can be a hindering factor. Nevertheless, some kind of value proposition mechanisms to end users can be successful.

Costs for customers:

- Investment costs
- Operation costs

These costs and values were analyzed in the chapter 5. We argued that the German government is trying to reduce costs by providing a set of incentives. However, success depends on many factors and customers can enjoy more profits when using micro-CHP under certain conditions. For example, some studies suggest that German consumers are ready to pay up to 4000 euro more for micro-CHP plants than a gas boiler[510]. Moreover, such complexity necessitate the help of lawyers and energy experts for utilization of a simple micro CHP unit as a replacement for gas boiler.

Values for grid operators:

- Fewer costs for grid expansion
- Better load management

Costs for grid operators:

- Bonus payment for avoided grid usage to micro-CHP operators
- Loss of revenue if the grid operator is owned by electricity generators

In fact, the values and costs of micro-CHP are not significant for grid operators except for those belonging to electricity producer companies. For them new micro-CHP means fewer benefits for power producers and even losing customers. Therefore, the unbundling of this ownership chain can increase the competition and diffusion of technology.

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[510] Bayar, T. (2014). Micro-CHP 'underperforming' in Europe, says report.

Costs for large electricity producers and local energy companies:

- They lose benefits due to reductions in electricity sales and a decline in their number of customers.

Probable values for large electricity producers

- If the big utilities were the producer, installer or operator of micro-CHP systems they could benefit from more development
- Because most micro-CHP technologies use natural gas as an input fuel, gas companies also enjoy higher gas sales through micro-CHP development. Gas companies can suggest contracts to their customers with micro-CHP and it can also be proposed as part of a smart energy package. If gas companies belong to electricity utilities, again, the development of micro-CHP, provides value for big electricity producers

There are opportunities for mediation between final users and technology developers and other actors to reduce their costs. For example, the planning and energy management of the building and installation, operation and maintenance of micro-CHP plants can provide opportunities for small energy servicing companies. Government is a big actor, which regulates the market and funds incentive programs. In the case of community houses or utilization of many micro CHP units as a virtual power plant, many incentives are not valid any more. It increase the risks of energy companies who want to enter the market.

6.5 Suggestions for future research

Moreover of above discussions, there are other very important influencing phenomena such as future heat demand and level of awareness among stakeholders. As discussed in previous chapter, in spite of decreasing trend of heat demand in Germany, micro-CHP with high electricity to heat ratio (50% - 110%) will face more demand than traditional Boilers and micro-CHP technologies with low electricity to heat ratio (10%-30%). Besides, the development of storage technologies can play important role in demand for micro CHP in the future. The level of awareness about micro CHP among stakeholders in Germany in comparison with other technologies is not suitable. One of the necessary effort by government and technology developers is raising the awareness among households, as the main target group of technology, and other market players.

Doing a similar research on other countries such as Japan, UK and USA might be useful. Since, through this study, factors of success or failure of these countries regarding development of micro CHP is being revealed. In addition, analyzing the regulations and tax laws by a public law specialist can provide more deep understanding of regulatory problems. Such analysis specifically is useful in the case of community utilization and virtual power plant mode of micro CHP.

Finally, it must be mentioned that the results of this research will not be valid in the future. Because the energy system of Germany is highly dynamic and is changing permanently. Cheaper technologies, more advanced technologies with storing capacities and higher electricity to gas ratio are among the most influencing factors that can change the results. In addition, the regulatory frameworks and incentives will not be as same as today; consequently, the future of micro CHP would be affected.

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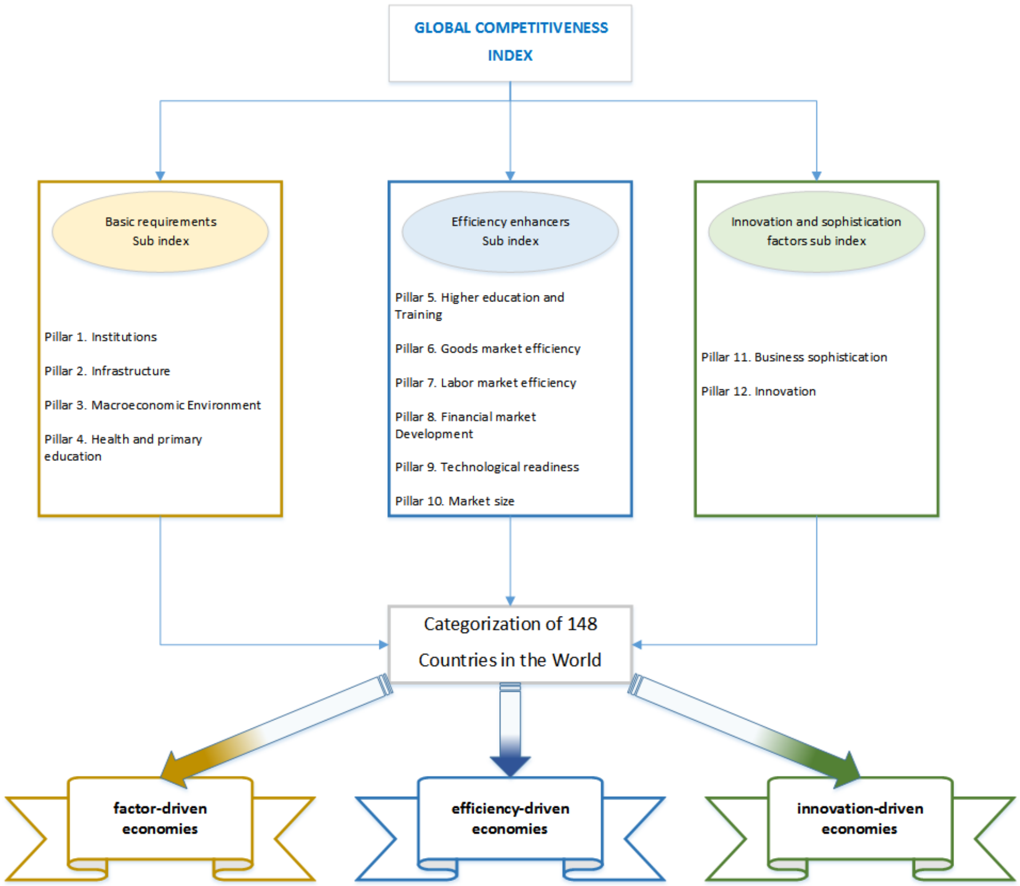
Appendixes

Appendix 1: The Global Competitiveness Index

Figure A-1. The Global Competitiveness Index framework



Source: (WorldEconomicForum 2013)

Table A-1. "The Global Competitiveness Index 2013–2014 rankings and 2012–2013 comparisons"

Country/Economy	Rank (out of 148)	Score (1–7)	Rank among 2012–2013 economies*	GCI 2012–2013
Switzerland	1	5.67	1	1
Singapore	2	5.61	2	2
Finland	3	5.54	3	3
Germany	4	5.51	4	6
United States	5	5.48	5	7
Sweden	6	5.48	6	4
Hong Kong SAR	7	5.47	7	9
Netherlands	8	5.42	8	5
Japan	9	5.40	9	10
United Kingdom	10	5.37	10	8
Norway	11	5.33	11	15
Taiwan, China	12	5.29	12	13
Qatar	13	5.24	13	11
Canada	14	5.20	14	14
Denmark	15	5.18	15	12
Austria	16	5.15	16	16
Belgium	17	5.13	17	17
New Zealand	18	5.11	18	23
United Arab Emirates	19	5.11	19	24
Saudi Arabia	20	5.10	20	18
Australia	21	5.09	21	20
Luxembourg	22	5.09	22	22
France	23	5.05	23	21
Malaysia	24	5.03	24	25
Korea, Rep.	25	5.01	25	19
Brunei Darussalam	26	4.95	26	28
Israel	27	4.94	27	26
Ireland	28	4.92	28	27
China	29	4.84	29	29
Puerto Rico	30	4.67	30	31
Iceland	31	4.66	31	30
Estonia	32	4.65	32	34
Oman	33	4.64	33	32
Chile	34	4.61	34	33
Spain	35	4.57	35	36
Kuwait	36	4.56	36	37
Thailand	37	4.54	37	38
Indonesia	38	4.53	38	50
Azerbaijan	39	4.51	39	46
Panama	40	4.50	40	40
Malta	41	4.50	41	47
Poland	42	4.46	42	41
Bahrain	43	4.45	43	35
Turkey	44	4.45	44	43
Mauritius	45	4.45	45	54
Czech Republic	46	4.43	46	39
Barbados	47	4.42	47	44
Lithuania	48	4.41	48	45
Italy	49	4.41	49	42
Kazakhstan	50	4.41	50	51
Portugal	51	4.40	51	49
Latvia	52	4.40	52	55
South Africa	53	4.37	53	52
Costa Rica	54	4.35	54	57
Mexico	55	4.34	55	53
Brazil	56	4.33	56	48
Bulgaria	57	4.31	57	62
Cyprus	58	4.30	58	58
Philippines	59	4.29	59	65
India	60	4.28	60	59
Peru	61	4.25	61	61
Slovenia	62	4.25	62	56
Hungary	63	4.25	63	60
Russian Federation	64	4.25	64	67
Sri Lanka	65	4.22	65	68
Rwanda	66	4.21	66	63
Montenegro	67	4.20	67	72
Jordan	68	4.20	68	64
Colombia	69	4.19	69	69
Vietnam	70	4.18	70	75
Ecuador	71	4.18	71	86
Georgia	72	4.15	72	77
Macedonia, FYR	73	4.14	73	80
Botswana	74	4.13	74	79
Croatia	75	4.13	75	81
Romania	76	4.13	76	78
Morocco	77	4.11	77	70
Slovak Republic	78	4.10	78	71
Armenia	79	4.10	79	82
Seychelles	80	4.10	80	76
Lao PDR	81	4.08	n/a	n/a
Iran, Islamic Rep.	82	4.07	81	66
Tunisia	83	4.06	n/a	n/a
Ukraine	84	4.05	82	73
Uruguay	85	4.05	83	74
Guatemala	86	4.04	84	83
Bosnia and Herzegovina	87	4.02	85	88
Cambodia	88	4.01	86	85
Moldova	89	3.94	87	87
Namibia	90	3.93	88	92
Greece	91	3.93	89	96
Trinidad and Tobago	92	3.91	90	84
Zambia	93	3.86	91	102
Jamaica	94	3.86	92	97
Albania	95	3.85	93	89
Kenya	96	3.85	94	106
El Salvador	97	3.84	95	101
Bolivia	98	3.84	96	104
Nicaragua	99	3.84	97	108
Algeria	100	3.79	98	110
Serbia	101	3.77	99	95
Guyana	102	3.77	100	109
Lebanon	103	3.77	101	91
Argentina	104	3.76	102	94
Dominican Republic	105	3.76	103	105
Suriname	106	3.75	104	114
Mongolia	107	3.75	105	93
Libya	108	3.73	106	113
Bhutan	109	3.73	n/a	n/a
Bangladesh	110	3.71	107	118
Honduras	111	3.70	108	90
Gabon	112	3.70	109	99
Senegal	113	3.70	110	117
Ghana	114	3.69	111	103
Cameroon	115	3.68	112	112
Gambia, The	116	3.67	113	98
Nepal	117	3.66	114	125
Egypt	118	3.63	115	107
Paraguay	119	3.61	116	116
Nigeria	120	3.57	117	115
Kyrgyz Republic	121	3.57	118	127
Cape Verde	122	3.53	119	122
Lesotho	123	3.52	120	137
Swaziland	124	3.52	121	135
Tanzania	125	3.50	122	120
Côte d'Ivoire	126	3.50	123	131
Ethiopia	127	3.50	124	121
Liberia	128	3.45	125	111
Uganda	129	3.45	126	123
Benin	130	3.45	127	119
Zimbabwe	131	3.44	128	132
Madagascar	132	3.42	129	130
Pakistan	133	3.41	130	124
Venezuela	134	3.35	131	126
Mali	135	3.33	132	128
Malawi	136	3.32	133	129
Mozambique	137	3.30	134	138
Timor-Leste	138	3.25	135	136
Myanmar	139	3.23	n/a	n/a
Burkina Faso	140	3.21	136	133
Mauritania	141	3.19	137	134
Angola	142	3.15	n/a	n/a
Haiti	143	3.11	138	142
Sierra Leone	144	3.01	139	143
Yemen	145	2.98	140	140
Burundi	146	2.92	141	144
Guinea	147	2.91	142	141
Chad	148	2.85	143	139

Source: (WorldEconomicForum 2013) page 15.

Table A-2. The Global Competitiveness Index for Germany in detail

	INDICATOR	VALUE	RANK/148
	1st pillar: Institutions		
1.01	Property rights	5.8	15
1.02	Intellectual property protection	5.6	14
1.03	Diversion of public funds	5.4	16
1.04	Public trust in politicians	4.4	19
1.05	Irregular payments and bribes	5.7	21
1.06	Judicial independence	6.0	13
1.07	Favoritism in decisions of government officials	4.6	13
1.08	Wastefulness of government spending	4.2	23
1.09	Burden of government regulation	3.6	56
1.10	Efficiency of legal framework in settling disputes	5.2	13
1.11	Efficiency of legal framework in challenging regs.	4.9	11
1.12	Transparency of government policymaking	5.0	23
1.13	Business costs of terrorism	5.7	59
1.14	Business costs of crime and violence	5.6	26
1.15	Organized crime	5.8	36
1.16	Reliability of police services	6.0	17
1.17	Ethical behavior of firms	5.7	15
1.18	Strength of auditing and reporting standards	5.5	23
1.19	Efficacy of corporate boards	5.2	22
1.20	Protection of minority shareholders' interests	4.8	29
1.21	Strength of investor protection, 0–10 (best)*	5.0	84
	2nd pillar: Infrastructure		
2.01	Quality of overall infrastructure	6.2	10
2.02	Quality of roads	6.0	11
2.03	Quality of railroad infrastructure	5.7	7
2.04	Quality of port infrastructure	5.8	9
2.05	Quality of air transport infrastructure	6.1	8
2.06	Available airline seat km/week, millions*	4,663.0	5
2.07	Quality of electricity supply	6.1	32
2.08	Mobile telephone subscriptions/100 pop.*	131.3	39
2.09	Fixed telephone lines/100 pop.*	61.8	4
	3rd pillar: Macroeconomic environment		
3.01	Government budget balance, % GDP*	0.2	28
3.02	Gross national savings, % GDP*	24.2	49
3.03	Inflation, annual % change*	2.1	1
3.04	General government debt, % GDP*	82.0	130
3.05	Country credit rating, 0–100 (best)*	92.3	6
	4th pillar: Health and primary education		
4.01	Business impact of malaria	N/Appl.	1
4.02	Malaria cases/100,000 pop.*	(NE)	1
4.03	Business impact of tuberculosis	6.6	15
4.04	Tuberculosis cases/100,000 pop.*	4.5	11
4.05	Business impact of HIV/AIDS	6.2	26
4.06	HIV prevalence, % adult pop.*	0.20	45
4.07	Infant mortality, deaths/1,000 live births*	3.3	17
4.08	Life expectancy, years*	80.7	22
4.09	Quality of primary education	5.0	25
4.10	Primary education enrollment, net %*	97.7	39
	5th pillar: Higher education and training		
5.01	Secondary education enrollment, gross %*	103.3	24
5.02	Tertiary education enrollment, gross %*	n/a	n/a
5.03	Quality of the educational system	5.1	14
5.04	Quality of math and science education	5.1	21
5.05	Quality of management schools	5.1	27
5.06	Internet access in schools	5.0	42
5.07	Availability of research and training services	6.1	2
5.08	Extent of staff training	5.1	10
	6th pillar: Goods market efficiency		
6.01	Intensity of local competition	5.9	10
6.02	Extent of market dominance	5.8	2
6.03	Effectiveness of anti-monopoly policy	5.1	12
6.04	Effect of taxation on incentives to invest	4.1	43
6.05	Total tax rate, % profits*	46.8	108
	6th pillar: Goods market efficiency *(cont'd.)*		
6.06	No. procedures to start a business*	9	104
6.07	No. days to start a business*	15	70
6.08	Agricultural policy costs	4.0	58
6.09	Prevalence of trade barriers	4.4	57
6.10	Trade tariffs, % duty*	0.8	4
6.11	Prevalence of foreign ownership	5.1	46
6.12	Business impact of rules on FDI	4.7	52
6.13	Burden of customs procedures	4.9	30
6.14	Imports as a percentage of GDP*	42.7	80
6.15	Degree of customer orientation	5.3	21
6.16	Buyer sophistication	4.4	17
	7th pillar: Labor market efficiency		
7.01	Cooperation in labor-employer relations	5.2	18
7.02	Flexibility of wage determination	3.3	141
7.03	Hiring and firing practices	3.3	118
7.04	Redundancy costs, weeks of salary*	21.6	100
7.05	Effect of taxation on incentives to work	3.7	64
7.06	Pay and productivity	4.3	42
7.07	Reliance on professional management	5.5	19
7.08	Country capacity to retain talent	5.1	9
7.09	Country capacity to attract talent	4.7	20
7.10	Women in labor force, ratio to men*	0.86	52
	8th pillar: Financial market development		
8.01	Availability of financial services	5.7	17
8.02	Affordability of financial services	5.3	20
8.03	Financing through local equity market	4.2	34
8.04	Ease of access to loans	3.2	46
8.05	Venture capital availability	3.2	33
8.06	Soundness of banks	5.1	64
8.07	Regulation of securities exchanges	4.8	37
8.08	Legal rights index, 0–10 (best)*	7	42
	9th pillar: Technological readiness		
9.01	Availability of latest technologies	6.3	13
9.02	Firm-level technology absorption	5.8	16
9.03	FDI and technology transfer	4.8	58
9.04	Individuals using Internet, %*	84.0	16
9.05	Fixed broadband Internet subscriptions/100 pop.*	34.0	9
9.06	Int'l Internet bandwidth, kb/s per user*	75.5	28
9.07	Mobile broadband subscriptions/100 pop.*	41.0	39
	10th pillar: Market size		
10.01	Domestic market size index, 1–7 (best)*	5.8	5
10.02	Foreign market size index, 1–7 (best)*	6.6	3
10.03	GDP (PPP$ billions)*	3,197.1	5
10.04	Exports as a percentage of GDP*	48.9	53
	11th pillar: Business sophistication		
11.01	Local supplier quantity	5.6	5
11.02	Local supplier quality	6.0	4
11.03	State of cluster development	5.4	4
11.04	Nature of competitive advantage	6.0	4
11.05	Value chain breadth	6.1	1
11.06	Control of international distribution	5.2	4
11.07	Production process sophistication	6.3	3
11.08	Extent of marketing	5.7	6
11.09	Willingness to delegate authority	4.9	16
	12th pillar: Innovation		
12.01	Capacity for innovation	5.6	3
12.02	Quality of scientific research institutions	5.8	6
12.03	Company spending on R&D	5.5	4
12.04	University-industry collaboration in R&D	5.4	9
12.05	Gov't procurement of advanced tech products	4.3	17
12.06	Availability of scientists and engineers	4.9	17
12.07	PCT patents, applications/million pop.*	214.6	6

Source: (WorldEconomicForum 2013) page 15.

A.1.1.Combination of cultural dimensions in various economical systems

Table A-3. Typology of cultures and different socio-economic regime

	HG High-tension pragmatic (judgemental)	HD High-tension procedural (administrative)	LG Low-tension pragmatic (spontaneous)	LD Low-tension procedural (bureaucratic)
IS Individualistic low-trust (competitive individualism)	*Enterprise culture* Aggressive competition between highly entrepreneurial selfish people	*Big business culture* Aggressive competition between selfish, ambitious but unimaginative people controlling formal organizations	*Libertarianism* Social anarchy constrained only by legal enforcement of market contracts.	*Play-the-system culture* Unprincipled competition between formal organizations regulated unsuccessfully by weak and corrupt bureaucracy
IH Individualistic high-trust (associationism)	*Entrepreneurial associationism* Orderly markets allocate resources between ambitious altruistic projects	*Administrative Associationism* Orderly competition between ambitious altruistic people running professional organizations	*Good neighbour culture* Social ambitions are limited to relief of current problems such as poverty. Individuals act on impulse to help the needy who are known to them	*Charity culture* Compassionate leaders set up formal organizations to help the needy, and recruit volunteers
CS Collectivistic low-trust (coercive collectivism)	*Revolutionary state* Totalitarian dictator personally promotes prestige projects in which people are forced to participate	*Soviet-style planning* Professional government planners implement ambitious projects using conscripted workers	*Arbitrary dictatorship* Dictator with ambition simply to survive in power improvises strategies to defeat rival bids for power	*Conformist culture* Coercive bureaucracy resists change and demands conformity from apathetic people
CT Collectivistic high-trust (paternalism)	*Charismatic leadership* Paternalistic leader with utopian vision enthuses population	*Welfare state* Ambitious altruistic programmes are devised by a paternalistic leader and administered using public service ethic	*Familism* Paternalistic leader presides over low-productivity economy where socialisation is more important than work	*Utopian solidarity* Low-productivity economy is coordinated through compulsory participation in traditional rituals presided over by leader

Source: (Casson 2010) p.220

Appendix 2: cost benefit analysis of micro CHP under various regulations

For doing a cost benefit analysis, a lot of information and assumptions are required. In this section, we briefly explain all assumptions and sources of information. We analyze five cases of 1 kWe micro-CHP plants for one family house application, 5 kWe for big family house and 10 kWe and 15 kWe for multifamily buildings and using a gas boiler instead of micro-CHP. Assumptions about the optimum hours of operation and the optimum electrical capacity of a micro-CHP based on heat demand, require several calculations and mathematical optimization and modelling. Due to the fact that this data is available, we are using assumptions based on official reports published by governmental agencies. Moreover, we only analyze the current existing technology in the market. It is possible to analyze future technologies such as fuel cell, but the regulatory framework will change in the future as well. In Table A-4, eight assumptions regarding the operating hours and heat demand in each case are summarized. The details of the calculations and assumptions are explained in the following sections. Experience has shown that the yearly plant factor of a micro-CHP plant is between 58% and 68%, which is a hurdle for economic profitability. It is assumed that during this period, generated electricity is consumed internally or being sold to the grid[511]. In the cold season from October to April, when sufficient heat demand for space heating is available, operating hours of 20 to 24 hours per day are possible, which can reach a total of up to 4,300 hours annually. The remaining 1700-2700 operating hours should be achieved in the summer months. For doing the cost benefit analysis, we analyzed the following variables and parameters:

Table A-4. assumptions regarding the operating hours and heat demand in each case

	unit	one family house	Small multifamily buildings	multifamily buildings	Big multifamily buildings
Micro CHP output electrical power	kWe	1	5	10	15
maintenance Cost	Euro /kWe	280	110	80	67
Capital Cost	euro/kWe	12000	5300	4850	4300
Other initial costs	% of Capital Cost	25%	25%	25%	25%
Maximum Heat demand	kW_{th}	11	34	78	100
Plant life	year	10	10	10	
Full operation hours per year	Hours/ year	4500	5000	5000	5000
Internal electricity usage from micro CHP	% of total produced electricity	100%			
Thermal power of micro CHP	kWth	2.7	10	22.5	30,5
Electrical efficiency	%	26%	27%	29%	31%
Total efficiency	%	92%	93%	94%	94%

Source: (ProjektIC4-42/13 2014)

[511] Kabus, M. (2014). Einsatz von Kraft-Wärme-Kopplung in Wohngebäuden. Wuppertal, EnergieAgenturNRW.

A.2.1.Initial costs

The initial costs of micro-CHP include: the micro-CHP cost, consultancy and planning costs, installation costs and all other costs, which are categorized as investment costs. These costs are as follows, as a percentage of total cost[512]:

1- Micro-CHP module cost (motor, boiler) 80%
2- Cost of silencing 2.8%
3- Cost of catalyst (to comply with the emission limits) 1%
4- Cost for building the required cabinets 6%
5- Cost of ventilation 2.7%
6- Transportation and installation cost 3.2 %
7- Planning and commissioning cost 5,2 %

The Ministry of Environment published several reports about these costs. In Table A-5, the investment cost of different micro-CHP plants are summarized.

Table A-5. The investment cost of different micro-CHP plants

	Capital Cost* Euro/kWe	other Costs** relative to plant price	grid connection*** cost (Euro)	
1 kW	15000	20%	0	till 30 kW
5 kW	5300	20%	0	till 30 kW
10 kW	4850	20%	0	till 30 kW
15 kW	4300	20%	0	till 30 kW

*Source: *(heizungsfinder.de 2014) (ProjektIC4-42/13 2014), **(heizungsfinder.de 2014) ***((LUHE) 2009)*

In the case of photovoltaic solar panels, experts estimate the total initial cost of a photovoltaic system to be about 1750 euros per kilowatt of peak. The initial cost of a solar panel is summarized in Table A-6. However, it must be kept in mind that the kWp of a solar panel does not produce an amount of energy equal to a 1kWe micro-CHP unit. In

512 heizungsfinder.de (2014). "Preise für Anschaffung und Installation eines BHKW." from http://www.heizungsfinder.de/bhkw/kosten-preise/anschaffungskosten.

Germany, a modern 1-kWp system produces from 750 to 1100 kWh of electricity per year. This value depends on the location[513]. In our analysis, we consider that 1kWp solar can produce 900 kWh per year.

Table A-6. Initial cost of a photovoltaic system

Component	Estimated cost
solar panels	0,45 euros to 0,90 euros pro Wp
inverter	500 to 2000 euros
cables (100 meters)	100 to 500 euros
assembly	100 to 150 euros pro kWp
installation	200 euros per kWp
system management	Minimum 150 euros

Source: (solaranlage-ratgeber.de 2014)

A.2.2.Variable costs

The variable costs include costs which are not fixed and depend on the operating hours of the plant as well as on external factors. We calculate the operating costs for each year based on the operating hours of the plant.

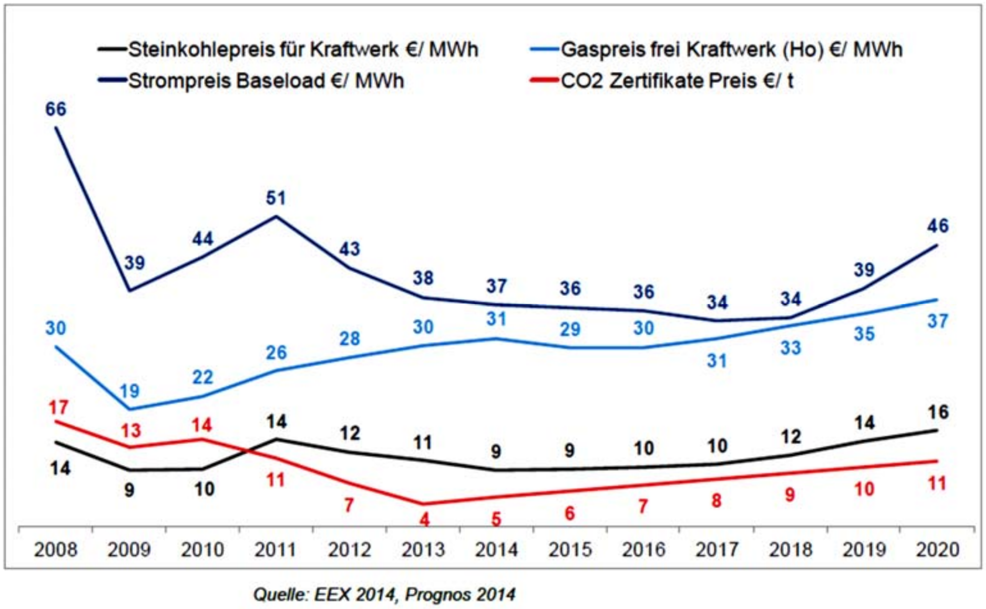
In this analysis, we assume that natural gas is the main fuel for operating micro-CHP plants. The price of natural gas and electricity is regularly predicted by official agencies and can be seen in Figure A-2. However, the residential gas price is about 20 euros higher than the exchange market price. By considering the value added tax in Table A-7, the development of the natural gas price, the household electricity price and the electricity price in the market, which have been used in this research, are summarized[514].

Based on the official published data from German governmental agencies, we considered the maintenance and servicing costs in our analysis. These are shown in Table A-8.

[513] EnergieAgentur.NRW (2014). "Online-Rechner Photovoltaik." from http://www.energieagentur.nrw.de/photovoltaik/themen/online-rechner-photovoltaik-15111.asp.

[514] ProjektIC4-42/13 (2014). Potenzial- und Kosten-Nutzen-Analyse zu den Einsatzmöglichkeiten von Kraft-Wärme-Kopplung (Umsetzung der EU-Energieeffizienzrichtlinie) sowie Evaluierung des KWKG im Jahr 2014.

Figure A-2. The prediction of energy carrier prices in the European Exchange Market in Leipzig (EEX)



Source: (ProjektIC4-42/13 2014)

Table A-7. Forecasting of residential energy price for 10 years

	Gas Price cent/kWh	Household electricity price 2014 cent/kWh	Electricity price in the market cent/kWh
2014	4.8	26.7	4.2
2015	4.8	27	4.3
2016	4.9	27.3	4.4
2017	4.9	27.6	4.4
2018	4.9	27.9	4.5
2019	4.9	27.9	4.5
2020	5.4	28.2	4.6
2021	5.4	28.1	4.7
2022	5.4	28	4.8
2023	5.5	27.9	4.9

Source: (EnergieAgentur.NRW 2014)

Table A-8. Maintenance and servicing costs

	Yearly maintenance cost* euro /kWe	Yearly maintenance cost
1 kW	280	280
5 kW	110	550
10 kW	80	800
15 kW	67	1005
Solar Panel**	-	350

Source: *(EnergieAgentur.NRW 2014) **(solaranlage-ratgeber.de 2014)

A.2.3.Technical characteristics of micro-CHP plants

The German Ministry of Environment regularly publishes reports with details about the technical characteristics of micro-CHP plants.

On the basis of these reports we considered output power and efficiency in Table A-9 for our analysis[515].

Table A-9. Output power and efficiency[516]

	Electrical power kW_e	Thermal power kW_{th}	Total efficiency
1 kW	1	2.7	0.93
5 kW	5	10	0.94
10 kW	10	22.5	0.94
15 kW	15	30.5	0.94
Gas Boiler	-	All	0.95

Source: (ProjektIC4-42/13 2014)

In Germany, the efficiency of thermal solar panels ranges between 250 to 600 kWh per square meter per year[517]. We assume the mean of 500 kWh. According to heat generated by micro-CHP, we calculated the required area and cost for solar heating system with similar capacities as micro-CHPs (See table A-10).

[515] Ibid.

[516] Ibid.

[517] Frahm, T. (2014). "Solarthermie & Ertrag - Berechnung für ein Einfamilienhaus." from http://www.solaranlagen-portal.com/solarthermie/thermische-solaranlage/ertrag.

Table A-10. The required area and cost for solar heating system with similar capacities to micro-CHP

		One family house	Small multifamily buildings	Multifamily buildings	Big multifamily buildings
Efficiency of solar thermal system in Germany	MWhth /m2	0.5	0.5	0.5	0.5
Required area for installing thermal solar system	m2	24	100	225	305
Capital cost of thermal solar system	euro	10000	25000	50000	70000

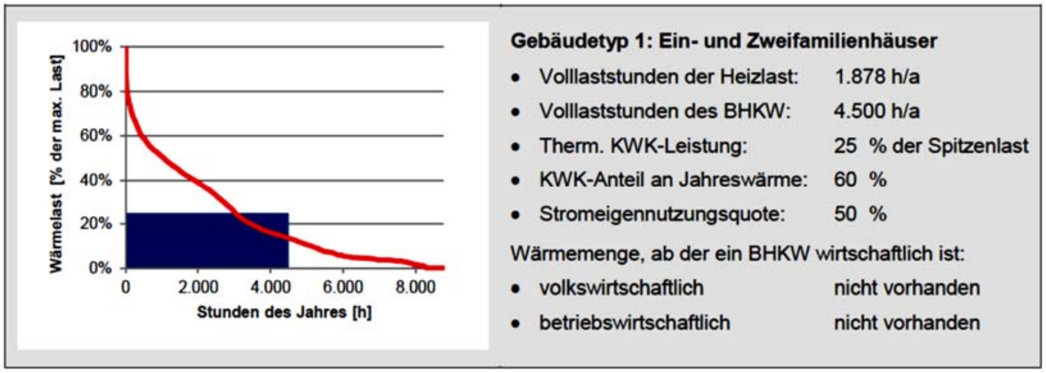
Source: author

Operating hours

Choosing the right micro-CHP output power depends on the heat demand loads of the user during a period of 8760 hours in a year. Due to the fact that micro-CHP plants are working at a constant rate of heat production, the right capacity must be chosen based on an optimization process in order to avoid producing unnecessary heat, which increases the costs and CO2 emissions. Implementing such an optimization is not easy and requires mathematical and economic modeling.

We based our assumption of operating hours and the thermal output power of micro-CHP plants on the official published reports by the Ministry of Environment. Based on these assumptions the thermal output power of micro-CHP plants is less than 40% of the maximum load and the rest of the load must be covered by a boiler. It is possible that the system produces more heat than demanded. Figure A-3 depicts an example of our assumption about the relation between capacity and working hours of the plant in one year (8760 hours). In this case, the thermal power of the micro-CHP is 25% of the peak load. For the rest of the heat demand, a boiler with 75% of the peak load must be used in parallel with micro-CHP. In order to avoid unnecessary heat production, and optimize the costs, the micro-CHP system should not operate more than 4500 hours.

Figure A-3. Relation between capacity and working hours of the plant in one year [518]



Source: (ProjektIC4-42/13 2014)

A.2.4.Economic calculations

In order to analyze the all costs and benefits during a period of 10 years, we need to sum up all cost benefits in each year based on the prices of the base year, which is 2014. For this purpose, we use an interest rate of 6%[519]. There are two main assumptions in this regard:

3- The total economic cost in year t ($C_{T,t}$) = Taxes (Energy, VAT, Income) + Fuel Cost + Maintenance Cost

4- The economic benefits in year t ($B_{T,t}$) = Bonuses + Energy saving + Feed-in tariff + Investment aids

$$the\ present\ economic\ value\ = B_T - C_T$$

$$= \sum_{t=1}^{n} \frac{(B_{T,t} - C_{T,t})}{(1+r)^n} - (Initial\ Costs\ in\ the\ 1st\ year)$$

r is the interest rate and n is the period for the contract or lifetime of the system, which in our analysis we considered to be 10 years[520]. Table A-11 shows an example of our analysis for a 1 kWe micro-CHP.

[518] ProjektIC4-42/13 (2014). Potenzial- und Kosten-Nutzen-Analyse zu den Einsatzmöglichkeiten von Kraft-Wärme-Kopplung (Umsetzung der EU-Energieeffizienzrichtlinie) sowie Evaluierung des KWKG im Jahr 2014.

[519] Ibid.

[520] USGS (2009). Advancing Statewide Spatial Data Infrastructures in Support of the National Spatial Data Infrastructure (NSDI) I. Applied Geographics.

Table A-11. Costs analysis for a 1 kWe micro-CHP unit in 10 years (author)

		Variable costs						Total Variables Costs	Initial costs			
year	fuel Tax exemptions cent/kWh	Gas Price cent /kwh	Gas Price with exempted fuel tax cent /kwh	EE-G Umlage	maintenance Cost Euro /kWhe	VAT tax	Income tax	Sum Ct	Capital Cost euro/Kwe	Contracting Cost relative to plant price	grid connection cost	
2014	0.55	4.8	4.25	0	67	0	0	10652	4300	0.25	0	till 30 KW
2015	0.55	4.8	4.25	0	67	0	0	10049				
2016	0.55	4.9	4.35	0	67	0	0	9683				
2017	0.55	4.9	4.35	0	67	0	0	9135				
2018	0.55	4.9	4.35	0	67	0	0	8618				
2019	0.55	4.9	4.35	0	67	0	0	8130				
2020	0.55	5.4	4.85	0	67	0	0	8475				
2021	0.55	5.4	4.85	0	67	0	0	7995				
2022	0.55	5.4	4.85	0	67	0	0	7543				
2023	0.55	5.5	4.95	0	67	0	0	7251				
								87531				

Source: author

Table A-12 is an example of the analysis of benefits for a 1 kWe micro-CHP unit. The net current cost of the micro-CHP is the difference between benefits and costs. We made the same calculations for all cases.

Table A-12. Benefits for a 1 kWe micro-CHP unit in 10 years (author)

year	CHP Bonus ct/kWh	feed in tariff ct/kWh	avoided Network usage ct/kWh	Sum Bt	interest rate	operation hours	Household electricity price 2014 ct/kWh	feed electricity rate	electric power kWe	Thermal power kWth
2014	5.41	4.2	0.5	6821	0.06	5000	26.7	0.9	15	30.5
2015	5.41	4.3	0.5	6495	0.06	5000	27	0.9	15	30.5
2016	5.41	4.4	0.5	6184	0.06	5000	27.3	0.9	15	30.5
2017	5.41	4.4	0.5	5834	0.06	5000	27.6	0.9	15	30.5
2018	5.41	4.5	0.5	5554	0.06	5000	27.9	0.9	15	30.5
2019	5.41	4.5	0.5	5240	0.06	5000	27.9	0.9	15	30.5
2020	5.41	4.6	0.5	4988	0.06	5000	28.2	0.9	15	30.5
2021	5.41	4.7	0.5	4748	0.06	5000	28.1	0.9	15	30.5
2022	5.41	4.8	0.5	4519	0.06	5000	28	0.9	15	30.5
2023	5.41	4.9	0.5	4301	0.06	5000	27.9	0.9	15	30.5
				54683						

Source: author

A.2.5. Appropriate capacity of micro CHP for a household user

In this section, a proposed MILP model is described which is used for scenario analysis. The objective of the modeling was to find which micro CHP capacity is suitable for a household user based on the profile of hourly heat demand in one year. We define the objective function of the model as the total costs of using a boiler and a micro CHP plant. Several researches suggests that the optimum capacity of micro CHP is equal with the height of the rectangular under the heat load curve, which its area is maximum. [521], [522], [523]. However, the argument is not competently convincing and we decided to develop an optimization model aimed to minimizing the total costs.

- List of parameter:

$C_0^{kwk}, C_0^{bo}, D_{max}, D_{min}\ and\ D_i\ \ \forall\{i\}$

$D_i\ = Heat\ Demand\ in\ time\ priod\ i$

- List of variables:

$P^{kwk} = Output\ power\ of\ Mikro - KWK$

$P_i^{bo} =\ Output\ power\ of\ Boiler\ in\ time\ priod\ i$

δ_i is the decision variable. When δ_i at time point *i*, is 1, the micro CHP is being used and when it is 0 only the gas boiler is in operation.

Objective function: $z = \sum_{i=1}^{n}\left(\delta_i \times C^{kwk} + C_i^{bo}\right)$

Then we have the Model Structure as following:

$$Min\ \ z = \sum_{i=1}^{n}\left(\delta_i \times C^{kwk} + C_i^{bo}\right)$$

Subject to:

$\delta_1 \times P^{kwk} + P_1^{bo} \geq\ D_1$

$\delta_2 \times P^{kwk} + P_2^{bo} \geq\ D_2$

[521] Cardona, E. and A. Piacentino (2003). "A methodology for sizing a trigeneration plant in mediterranean areas." Applied Thermal Engineering **23**(13): 1665-1680.

[522] Ortiga, J., et al. (2007). Review of optimization models for the design of polygeneration systems in district heating and cooling networks. Computer Aided Chemical Engineering. P. Valentin and A. Paul Şerban, Elsevier. **Volume 24:** 1121-1126.

[523] Söderman, J. and F. Pettersson (2006). "Structural and operational optimisation of distributed energy systems." Applied Thermal Engineering **26**(13): 1400-1408.

…

$\delta_n \times P^{kwk} + P_n^{bo} \geq D_n$

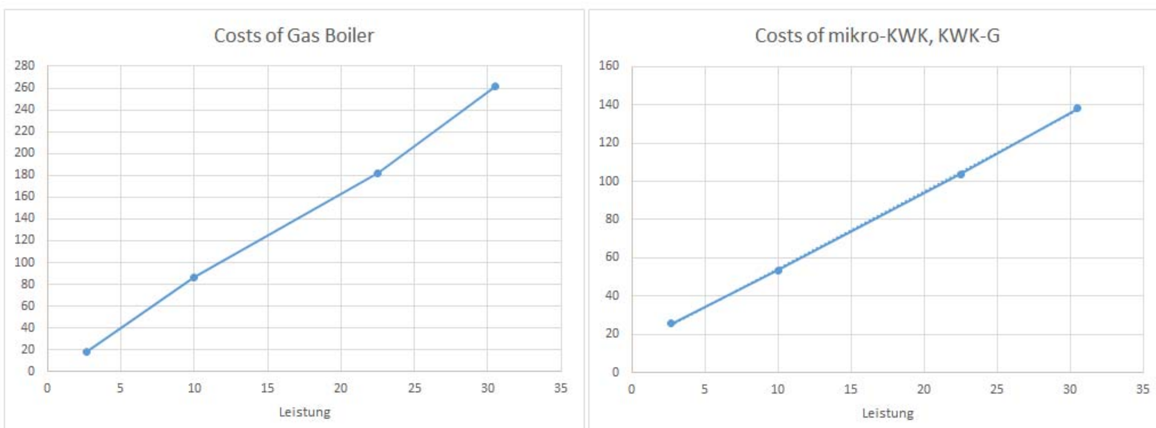
$\delta_i = 0{,}1 \qquad \forall\{i\}$

$0 \leq D_{min} \leq P^{kwk} \leq D_{max}$

$0 \leq D_{min} \leq P_i^{bo} \leq D_{max} \qquad \forall\{i\}$

Moreover, we need the relation between costs and capacities of boilers and micro CHP. According to the costs in 10 years of different of different capacities, we see that the costs behave in a linear manner with capacity (See Fig A-4).

Figure A-4. Costs of micro CHP and boiler vs the output capacity



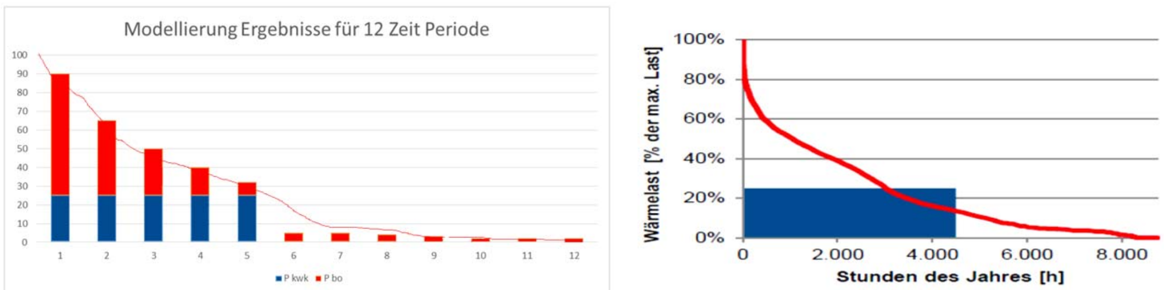
Source: author

As a result, we replace the cost terms in objective functions with following terms:

$C^{kwk} = a^{kwk} \times P^{kwk} + C_0^{kwk}$ and $C_i^{bo} = a^{bo} \times P_i^{bo} + C_0^{bo}$

For solving this problem, we used Genetic Algorithms. The results of modeling passed well with the results of reports. Figure A-5 shows the example of a one and two family houses.

Figure A-5.results of modelling. The left graphic shows the results of modeling and the right graphic indicate the suggested capacity by (ProjektIC4-42/13 2014).



Source: author