



Nuclear Shutdown to NIMBY-ism

*An Assessment of Public Attitudes Before and After the Nuclear
Phase-out in Germany*

Theodor Bennett

Suryadeep Seal

Supervisor: Egil Lillestøl

MSc. in Economics and Business Administration

Major in Energy, Natural Resources, and the Environment

Major in International Business

NORWEGIAN SCHOOL OF ECONOMICS

This thesis was written as a part of the Master of Science in Economics and Business Administration at NHH. Please note that neither the institution nor the examiners are responsible – through the approval of this thesis – for the theories and methods used, or results and conclusions drawn in this work.

Abstract

The Merkel Government's decision in 2011 to phase-out nuclear power in Germany by 2022 marked a seminal moment in German energy policy. The decision after the Fukushima Daiichi accident was a combination of a strong anti-nuclear movement and impending elections conducive to its realization. As much as mounting public pressure was pivotal in the nuclear shutdown, public acceptance has been equally important in subsequent implementation of the *Energiewende*. Public opposition to infrastructure projects needed to realize secure supply of energy, such as the expansion of the transmission grid and development of wind farms, has faced local opposition and been attributed to NIMBY (Not In My Backyard) behavior, opposed to a perceived decrease in aesthetic appeal, real estate value, and associated health costs. However, an analysis of research conducted on public opinions reflects that more than the largely localized NIMBY resistance, changes in affordability could have a greater impact on acceptance levels. Relative to nuclear, the System Levelized Costs of Energy and the inherent profile, balancing, and dispatchability costs are problematic for further renewable integration. Additionally, continually increasing domestic consumer prices and unequal distribution of the EEG surcharge could further augment public resistance.

The paper further compares public opinions before and after the nuclear phase-out. The anti-nuclear movement can be largely characterized as a NIABY (Not In Any Backyard) movement with collectively resonating norms against it. In contrast, public attitudes after the phase-out are a combination of NIMBY-ism and resistance to specific projects without rejecting the overarching principle as a whole reflected in a majority of the German public polling in favour of the *Energiewende* being relevant for the German population. Of importance also is the role of perceived justice and fairness and the lack thereof could also lower public acceptance, especially in terms of distribution of the costs of the *Energiewende*.

To this end, the paper concludes that while not currently of a scale comparable to the anti-nuclear movement, public opinions must nonetheless be engaged by the Government through more transparent and collaborative decision making processes. While the German government is taking steps towards including the public more, most of its plans are still nascent and their efficacy remains to be assessed after they are implemented.

Contents

1.	Introduction.....	11
1.1.	Research Question	11
1.2.	The Nuclear Shutdown.....	12
1.3.	Goals of the Energy Transition	13
1.4.	Structure of Paper	16
2.	Theory	18
2.1.	Understanding NIMBY-ism.....	18
2.2.	Scope of Public Opposition.....	21
3.	Background.....	24
3.1.	German Energy Mix	24
3.2.	German Electricity Mix	25
3.3.	Nuclear energy production in Germany.....	26
3.3.1.	Historical overview and the shut down.....	26
3.3.2.	The Shut Down	29
3.3.3.	Current Status of the German reactors	31
3.3.4.	Organization and Structure of the German Nuclear Power Industry	35
3.3.5.	Nuclear Reactor Design in Germany	38
3.3.6.	Safety standards in Germany	43
3.3.7.	Chernobyl and Fukushima	47
3.3.8.	The Fukushima Daiichi Accident.....	50
3.3.9.	The possibility of Thorium as an alternative.....	53
3.4.	Storage – the Achilles heel of Nuclear Power?.....	56
4.	Analysis.....	58
4.1.	Security of Supply.....	58
4.1.1.	Terminology: Dispatchable and Intermittent Generating Technologies.....	58
4.1.2.	Changes in Base Load Generation	58
4.1.3.	Grid Reliability	59

4.1.4.	Grid Extension	62
4.1.5.	Developing Wind Energy.....	64
4.1.6.	Storage Capacities.....	65
4.3.	Affordability	67
4.3.1.	LCOE	67
4.3.2.	System LCOE and the issues of variability, uncertainty and location specificity	71
4.3.3.	EROI	78
4.3.4.	Electricity prices in European and international Comparison.....	79
4.3.5.	EEG.....	82
4.4.	Environmental Sustainability	86
4.4.1.	The Energy Concept 2010.....	86
4.4.2.	The Energy Package 2011.....	87
4.4.3.	Greenhouse gas emissions	87
4.5.	Acceptance.....	89
4.5.1.	The German Anti-Nuclear Movement	89
4.5.2.	From a Fossil Fuel-Nuclear to a Renewables Regime	97
5.	Discussion.....	107
6.	Conclusion	112
	Works Cited	114

List of Figures

Figure 1: Direct and indirect impact of arguments/motives on resistance to wind turbine projects	20
Figure 2: Germany Energy Mix	24
Figure 3: Gross Electricity Generation Germany 2013.....	25
Figure 4: Hierarchy of the National Regulations and the Issuing Authorities	35
Figure 5: Status and Location of Germany's Nuclear Power Plants end of 2011	37
Figure 6: Insulation of Alpha-, Beta- and Gamma Radiation by different matters.....	39
Figure 7: The Main Principle of Thermal Nuclear Reactors.....	40
Figure 8: Example of the Brokdorf Nuclear Reactor	41
Figure 9: BWRs- Example of the Gundremmingen Block C Reactor	42
Figure 10: Reactor Safety Barriers in Germany	43
Figure 11: INES Framework and a Count of Germany's Events	46
Figure 12: Multi-barrier Principle of German Reactor	48
Figure 13: Chernobyl Reactor without Containment	49
Figure 14: Overview of German SAIDI Values since 2006	60
Figure 15: SAIDI Values (unplanned interruptions excluding exceptional events).....	61
Figure 16: Germany's new grids	63
Figure 17: Estimated Levelized Cost (EUR/MWh) for Electricity Generation Technologies.....	70
Figure 18: Minimum-, Average- and Maximum LCoE in the US	72
Figure 19: LCoE, System LCoE and the Drivers of Integration Costs	74
Figure 20: I.E.A Estimations for Wind Balancing Costs 2009.	75
Figure 21: Transmission Cost in EUR in the US per Technology	76
Figure 22: Example of the System LCoE for Wind in Europe	77
Figure 23: EROI with (buffered) and without (unbuffered) energy storage	78
Figure 24: Price Development from S2 2011 to S2 2014 in %	81
Figure 25: Comparison of Domestic User Prices in the EU	81
Figure 26: Price Development for Domestic Users - 2 500-5 000 kWh	82
Figure 27: EEG surcharge in cent per kilowatt hour.....	84

List of Tables

Table 1: Nuclear Power Plants in Germany 2013	33
Table 2: Capacity Factors Benchmark According to the U.S Energy Information Administration	69
Table 3: Price Breakdown for Domestic Users from 2007-2014	80
Table 4: The German Energy Concept, 2010.....	86
Table 5: Acceptance of the Energiewende	98
Table 6: Share of areas of inconvenience on total outage costs adapted from Praktiknjo (2013).....	102

Table of Abbreviations

Abbreviation	Definition
AEG	AEG AG
Al	Aluminium
AtSMV	Die Atomrechtliche Sicherheitsbeauftragten- und Meldeverordnung (Ordinance Concerning Procedures according to Atomic Energy Act)
Ba	Barium
BfS	Bundesamt für Strahlenschutz
Bi	Bismuth
BMUB	German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
BMWi	Federal Ministry for Economic Affairs and Energy
BWR	Boiling Water Reactor
C	Celsius
CC	Combined Cycle
CCS	Carbon Capture and Storage
CDU	Christlich Demokratische Union
CEA	Commissariat à l'énergie atomique et aux énergies alternatives
CEEPR	MIT Centre for Energy and Environmental Policy Research
Cf	Fuel cost
cm	Centimeter
Co	Maintenance cost
Cp	Capital cost
Cs	Cesium
DAtF	German Atomic Forum
DDR	The German Democratic Republic
DNO	Distribution Network Operator
EEG	German Renewable Energy Act
EIA	U.S Energy Information Administration
ERAM	Enlager für Radioaktive Abfälle Morsleben
ESK	German Nuclear Waste Management Commission
EU	European Union
EUR	Euro
EWIS	European Wind Integration Study
f	Capacity factor
FBR	Fast Breeder Reactor
FDP	Free Democratic Party
GE	General Electric
GHG	Greenhouse gas
GKN	Kernkraftwerk Neckarwestheim
GRS	<i>Gesellschaft für Anlagen- und Reaktorsicherheit</i>

GWh	Giga watt hours
H	Hydrogen
H	Time period
H₂O	Water
HTR	High Temperature Reactor
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IGCC	Integrated Coal Gasification Combined Cycle
INES	International Nuclear and Radiological Event Scale
ITER	International Thermonuclear Experimental Reactor
JAEA	Japan Atomic Energy
KBR	Kernkraftwerk Brokdorf
KKB	Kernkraftwerk Brunsbüttel
KKE	Kernkraftwerk Emsland
KKG	Kernkraftwerk Grafenrheinfeld
KKI	Kernkraftwerk Isar
KKK	Kernkraftwerk Krümmel
KKP	Kernkraftwerk Philippsburg
KKU	Kernkraftwerk Unterweser
Kr	Krypton
KRB	Kernkraftwerk Gundremmigen
KTA	Nuclear Safety Standards Commission
KTG	Kerntechnische Gesellschaft
KWG	Kernkraftwerk Grohnde
l	Levelization factor
LCoE	Levelized Cost of Electricity
MeV	Megaelectron Volt
MWe	Mega Watt
NEA	OECD Nuclear Energy Agency
NG	Natural Gas
NIABY	Not In Any Backyard
NIMBY	Not In My Backyard
NISA	Nuclear and Industrial Safety Agency
NSC	Nuclear Safety Commission
O&M	Operation and maintenance
OECD	Organization for Economic Cooperation And Development
Pb	Lead
PTR	Pressure Tube Reactor
Pu	Plutonium
PV	Photovoltaic
PWR	Pressurized Water Reactor
R	Recovery factor
Rb	Rubidium
RBMK	Reactor Bolschoi Moschtschnosti Kanalny

RES-E	Renewable Energy-Sourced Electricity
RSK	Reactor safety Commission
sLCoE	System Levelized Cost of Electricity
SPD	Socialist Party of Germany
SSK	German Commission for Radiological Protection
SSR	Superheated Steam Cooled Reactor
StandAG	Site Selection Law
TEPCO	Tokyo Electric Power Company
Th	Thorium
ThO₂	Thorium dioxide
Tl	Thallium
TSO	Transmission System Operator
TUR	Transuranic waste
TWh	Tera watt hours
U	Uranium
USD	US Dollar
W	Watt
WLN	Weiterleitungsnachricht

1. Introduction

This Master Thesis seeks to provide a comprehensive evaluation of the nature of public attitudes in Germany, before and after Chancellor Angela Merkel's Coalition Government's decision in 2011 to phase-out nuclear power in the country following the accident at the Fukushima Daiichi reactor in Japan. This paper contends that while the German Energy Transition or the *Energiewende* is usually analyzed through three foci — security of supply, affordability, and sustainability, its success rests in large part on its public acceptance as well as the policies required to realize the proposed goals. While Germany is on track to satisfy the share of renewables in final energy consumption, it lags behind in meeting the targets for reduction in GHG emissions and energy efficiency.

Building on this argument, the paper examines the social processes that impact both – the decision to withdraw from nuclear power as well as Germany's ambitious targets for an increased share of renewables in the German energy and electricity mixes. The framework thus incorporates the three interconnected tenets of the *Energiewende*: security of supply, affordability, and sustainability but in line with the proposed argumentation, analyses it within the overall aegis of public acceptance. This chapter thus introduces the research question of the paper and introduces the context in which it emerges—the nuclear shutdown and the German *Energiewende*.

1.1. Research Question

The Merkel government's decision to shut down nuclear plants in Germany was primarily a response to growing public agitation after the Fukushima Daiichi nuclear reactor accident in 2011. However, the acquiescence to public opinion in this case creates difficulties in successfully reducing GHG emissions given the initially proposed role of nuclear energy as a bridge in the Energy concept until renewables had been integrated successfully. The withdrawal from nuclear will consequently result in greater dependence on fossil fuels such as coal and to a lesser degree, natural gas to fulfill the aforementioned bridging role making it more difficult to achieve the required reduction in GHG emissions.

In parallel, and with greater importance after the decision for a nuclear phase-out, Germany is likely to satisfy the share of renewables in energy consumption. Public approval for greater integration of renewables has been high. At the same time, the increased integration of renewables necessitates parallel development of the national electrical grids for requisite

transport of the electricity. However, critics question the magnitude of these plans especially its impact on security of supply and affordability. This is further exacerbated by opposition from local communities opposing the social costs such as diminishing property values and lower amenity value of landscapes, which could be a result of the eventual siting of new electrical facilities such as masts and power lines. This conflict is referred to as ‘NIMBY-ism’ (Not In My Backyard behavior) and could increase in coming years. Grid expansion is central to ensure that Germany meets its target of 55% of power generated from renewable sources by 2035 but while support for renewable energies is evident, the implementation and application of proposed plans could be challenged by this opposition.

In light of this situation, the paper seeks to delve into the following topic:

Nuclear Shutdown to NIMBY-ism: An Assessment of Public Attitudes Before and After the Nuclear Phase-out in Germany

Encompassed within the aegis of this topic are the following questions, which the thesis seeks to answer.

- To what extent do changes in security of supply, affordability, and sustainability impact public acceptance?
- To what extent are public attitudes before and after the nuclear shutdown different?
- What challenges confront public acceptance of the German Government’s implementation of the *Energiewende* and how can it best address it?

1.2. The Nuclear Shutdown

Wende is German for a reversal or U-turn and in the context of German energy policy, refers to Chancellor Angela Merkel’s announcement of the *Energiewende* in the aftermath of the Fukushima Daiichi accident in Japan in March 2011—the expedited switch to renewables and the parallel shutdown of Germany’s remaining 17 nuclear plants (Gross, 2011). Six months prior to the announcement of the *Energiewende*, Merkel’s conservative-liberal Democrat Coalition Government had reversed a plan by her predecessor, Gerhard Schröder’s social Democrat-Green party coalition in 2000 to have the last nuclear reactor go offline by 2020. Instead, Merkel extended the lifetime of the 10 more modern reactors to dates between 2028 and 2035. The remaining 7 were intended to stay online until 2018 or 2020. Essentially, in reversing Schröder’s decision, Merkel’s decision had extended the lifetime of the reactors by

an average of an extra 12 years compared to the earlier plan (Gross, 2011). While a proponent of nuclear technology, Merkel changed her mind after the Fukushima accident in Japan on the 11th of March. The fact that a nuclear disaster could impact one of the world's most technologically advanced nations was a cause for alarm and the Merkel government deliberated the idea of a moratorium, essentially cancelling the runtime extension and switching off the remaining 7 older reactors for at least three months (Gross, 2011). The nuclear shutdown is discussed in greater detail in Chapter 3.3.2 (p.29).

1.3. Goals of the Energy Transition

Germany has established a salient challenge in terms of its energy policy—moving away from fossil fuels and nuclear power, while still trying to retain its position as a major industrial power. Termed the *Energiewende*, the German Energy Transition has the following goals within the overarching premise of a secure, environmentally friendly, and economically successful future (BMW_i):

- i) Taking the last nuclear plant in Germany off stream in 2022
- ii) Incorporating a greater share of renewable energy, which is to account for 80% of electricity supply by 2050
- iii) Less dependence on oil and gas imports
- iv) Reduction of environmentally harmful Greenhouse Gas (GHG) emissions by 80 to 95% by 2050
- v) More efficient use of energy
- vi) Utilizing the restructuring of energy supply to drive innovation for Germany as an industrial base, in turn generating growth and creating sustainable and secure jobs

Drawing upon these goals, The Federal Ministry for Economic Affairs and Energy (BMW_i) identifies two key pillars for the energy transition: Renewable Energy and Energy Efficiency. The first of these calls for greater integration of renewable sources such as solar and wind to produce 50% of electricity by 2030. The latter focuses on using less energy by utilizing modern, energy efficient technologies and changing public behavior to minimize energy use. In June 2014, the BMW_i drew out a '10-point energy agenda' which delineates subsequent steps and key projects in the 18th legislative term.

An overview of the ten key points as adapted from ‘The energy transition: key projects of the 18th legislative term’ published by the BMWi are as follows (BMWi, 2014):

- i) *Renewables, Renewable Energy Sources Act*: The 2014 reform of the Renewable Energy Sources Act (EEG) has facilitated the feasible funding of renewables for the future, at the same time working towards a demanding expansion corridor and ensuring that electricity intensive manufacturing in Germany remains competitive.

Additionally, subsequent action towards competition-based promotion of renewable energy sources is planned. In January 2015, the BMWi presented the ordinance governing pilot auctions for ground-mounted photovoltaic installations basis which, a pilot project is to be implemented in 2015. The findings from this project will in turn be fed into the EEG; the revision of the EEG scheduled to be adopted in 2016 intends to place the rules for the level of funding for renewables (all technologies) to normally be set by auction.

- ii) *European Climate and Energy Framework 2010/ETS*: The BMWi underscores the importance of decisions reached by the European Council of October 2014 on the European climate and energy framework 2030, as well as the reform of European emissions trading in successfully implementing energy reforms. These decisions continue the tripartite targets adopted under the German EU Council Presidency: 40% reduction in internal EU GHG emissions (versus 1990); a separate and binding EU target of 27% for the share of renewables in energy consumption; and finally, an energy efficiency target of 27% at the minimum.
- iii) *Electricity market design*: The BMWi seeks to ensure that the electricity market of the future makes efficient use of power plants with parallel increase in the share of renewables. Simultaneously, the market design must ensure that energy is secure.
- iv) *Regional cooperation (in EU)/internal market*: The success of the *Energiewende* is contingent on the integration of Europe’s electricity markets. Consumers of electricity would benefit from more choice, lower electricity prices, and greater

energy security and Germany accordingly seeks to deepen cooperation in Europe to progress further on integration of markets.

- v) *Transmission grids*: To ensure both security of supply and affordability of electricity, several thousand kilometers of upgraded or new power lines are needed, especially to ensure requisite transmission of renewables to users—both industries and households.
- vi) *Distribution grids*: Distribution grids will have to be adapted to account for the *Energiewende*, particularly to connect the greater share of electricity generated by renewables.
- vii) *Efficiency strategy*: Energy efficiency is the second pillar of the *Energiewende*, as established when the National Action Plan on Energy Efficiency (NAPE) was adopted in early December 2014. The Plan outlines the Federal Government's energy efficiency strategy for the 18th legislative term and seeks to involve all stakeholders to improve and bolster energy efficiency.
- viii) *Buildings strategy*: In December 2014, the BMWi published a paper on 'Renovation Needs in the Building Stock' to chart how buildings could be made virtually climate neutral by 2050; this forms the precursor for the Energy Efficiency Strategy for Buildings, intended to be adopted in November 2015.
- ix) *Gas supply strategy*: Security of gas supply needs to be ensured for the future, especially given that gas covers slightly less than 25% of Germany's primary energy consumption.
- x) *Monitoring of the energy transition/Platforms*: To more closely monitor the progress of its energy reforms and intervene when required, the Federal Government launched the 'Energy of the future' monitoring process. Additionally, current expert forums and platforms have been reformed to successfully incorporate different groups in society.

1.4. Structure of Paper

This thesis is divided into six chapters, the content for which is as follows.

Chapter 1 introduces the research question and the context in which it emerges. The research topic is deconstructed into three specific questions encompassed within the broader topic. More specifically, it outlines the two cornerstones of the paper—Germany's decision for a nuclear phase-out and the guiding tenets of the *Energiewende* towards a low carbon energy system.

Chapter 2 provides the academic background and theoretical underpinnings to understand NIMBY-ism and the scope of public opposition. Through a brief discussion of literature on public resistance to infrastructure projects, the chapter seeks to delineate the key attributes of public resistance movements with a focus on NIMBY-ism. This is essential to discern the nature of both, the anti-nuclear movement in Germany and emergent resistance to grid extension and wind power development in Germany.

Chapter 3 deconstructs the background needed to understand the issue in question. The chapter begins with an overview of the status quo in terms of the German energy and electricity mixes. Thereafter, the section focuses on nuclear power in Germany given the paper's focus on the shutdown and an evaluation of opinions before and after it. The section first goes into chronological details of nuclear power, charting the historical overview, the shutdown, and the current status. Thereafter, the section delves into the organization of the German nuclear power industry to discern the different decision making processes embedded in it. The next parts of the section focus on safety given that safety was one of the major concerns after the Fukushima Daiichi accident; to this end, first safety standards for nuclear power in Germany are discussed and they are then compared with the reactors in Chernobyl and Fukushima. Finally, the viability of Thorium as an alternative is discussed.

Chapter 4 is the main analytical chapter of the thesis. The analysis is conducted as a comprehensive literature review of academic papers, Governmental publications, such as those published by the Federation of German Industry (BDI) and the BMWi, and reports from consultancy firms, independent think tanks, and international organizations such as the IEA, IAEA, and the OECD. In doing so, the chapter incorporates different perspectives on the German Energy Transition and seeks to provide an enriched understanding of the interplay between these different stakeholders. The chapter conducts this review through the

three pillars of Security of Supply, Affordability, and Sustainability, paying specific attention to factors that could affect public acceptance. The chapter then leads into a specific discussion of public attitudes towards nuclear power in Germany and the current state of public acceptance, especially towards the greater integration of more renewable sources.

Chapter 5 provides a comparative analysis of public acceptance before and after the nuclear phase-out in Germany based on findings of the literature review in Chapter 4. At the same time, it identifies issues of priority to the German public and the need for more participatory governance.

Chapter 6 provides a conclusion summing up key findings of the paper as well as providing questions that the German Government must consider for subsequent implementation of the *Energiwende*.

2. Theory

Schweizer et al. (2014) posit that while a policy decision may be the result of a democratic process, it is nonetheless not sufficient for many to accept it. Three major characteristics are identified in protest movements against infrastructure developments (Schweizer, et al., 2014, p. 2).

- (i) Citizens are expected to forego personal conveniences, at least temporarily, in favor of a proposed benefit to the larger community
- (ii) The proposed benefit is contentious insofar as it is difficult for the project planners, governmental or private, to communicate the benefit in a way acceptable to all. This could be caused due to problems in communication but is largely a result of plurality in opinions and preferences. In the case of the *Energiewende*, this is illustrated in discrepancies on whether wind farms should be constructed in idyllic landscapes or if networks from wind farms in the North Sea to industrial hubs in Bavaria are necessary
- (iii) Citizens directly affected by projects often view the decision-making process as being intransparent or corrupt, often mirrored in a gap between legality and legitimacy. For instance, even if implementation of transmission lines and wind farms complete all the requisite approval processes, their embedded complexity may cause citizens to feel overwhelmed and consequently removed from the decision making process

These trends are very much in line with literature on public opposition to infrastructure projects which are discussed subsequently.

2.1. Understanding NIMBY-ism

- *NIMBY-ism and Selfishness*

Van der Horst (2007) defines NIMBY behavior as a phenomenon wherein certain services are deemed beneficial by the majority of the population *in principle*, but *in practice* the facilities to provide these services are usually opposed by local residents (Horst, 2007). However, beyond this simplistic definition, literature indicates that public opposition to a local development is more nuanced.

Wolsink (2000), for example, proposes that contrary to NIMBY-ism being largely seen as common sense, it is in fact rooted in specific psychological (*social dilemma*) or economic

(*game-situation*) theories regarding provision of public goods. Essentially, individual preferences to maximize their own utility cause some public goods to be not produced, even when all individuals in that society want that good provided. The utility maximization entails an assessment of personal costs and benefits, stimulating *free rider* behavior. This evaluation of personal costs and benefits aligns with Schweizer et al.'s assertion (2009) that a public movement is characterized by the expectation that an individual must forego personal benefits for the interests of the larger community.

At its core, NIMBY-ism would be thus caused by selfish motives which in turn obstruct realization of societal goals. Using wind power to illustrate this, Wolsink (2000) points that in line with NIMBY principles, local residents on one hand, oppose a project to maximize their own utility but because they are in favor of wind power, they would be expected to welcome all turbines not built in their vicinity. However, Wolsink (2000) quantitatively concludes that data barely reveals citizens with both inclinations; in fact, people with NIMBY feelings are generally not in favor of wind power and their behavior is primarily grounded in their lack of support for wind turbines anywhere.

Wolsink (2000) further contends that by labeling public opposition as NIMBY, the wide range of public attitudes cannot be adequately encompassed and instead typifies resistance into the following four categories.

- *Resistance Type A*: Positive attitude towards the principle in addition to opposition to the implementation of the project in one's own neighborhood (NIMBY behavior).
- *Resistance Type B*: Negative attitude to a principle due to general opposition to the implementation of the project in any neighborhood (NIABY – Not In Any Backyard behavior).
- *Resistance Type C*: Positive attitude towards the principles which becomes negative as a result of discussion surrounding implementation of the project caused by evolving risk perceptions as part of the decision making process.
- *Resistance Type D*: Resistance on the grounds that some specific projects may be faulty without rejection of the principle as a whole. For example, in wind power development, opposition may be limited to wind farms on specific locations based on the impact it could have on the scenery and to a lesser extent, the interference or nuisance it might cause.

- *Visual Appeal*

In terms of nomenclature itself, the use of the word NIMBY while preferred by proponents is contentious among those who oppose planned developments.

Wolsink (2000) further emphasizes this point by drawing upon attitudes towards wind projects instead of wind power. He divides attitudes towards wind projects as the visual assessment of scenic value of wind turbines (VISUAL), interference factors - birds, nature, noise, shadow flicker (ANNOY), and the environmental benefits of clean energy (CLEAN) (Wolsink, Wind power and the NIMBY-myth: institutional capacity and the limited significance of public support, 2000). When examining these attitudes through statistical analysis, Wolsink found that only two of these affected wind power attitudes (WPATTIT) – the visual appeal of the turbines and to a lesser extent, the benefits of clean energy. In terms of resistance to wind projects (WTRESIST), both visual appeal and annoyance weighed in, with visual appeal being more significant. Finally, NIMBY behavior (NIMBY) and perceived self-efficacy (EFFIC), while contributory, have weak relations. As such, the visual appeal of the turbines becomes particularly salient since it contributes directly to resistance against wind projects and indirectly by determining attitudes to wind power.

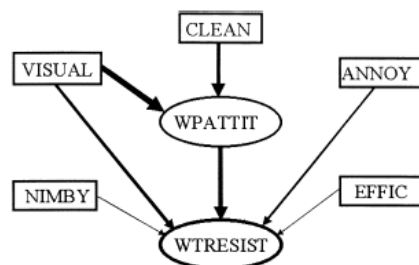


Figure 1: Direct and indirect impact of arguments and motives on resistance to wind turbine projects (Source: Wolsink, Wind power and the NIMBY-myth: institutional capacity and the limited significance of public support, 2000, p.7)

- *Equity and Fairness*

Much like Horst (2007), Wolsink (2007) also refers to a gap between public attitudes towards a principle and those towards a practice, exemplifying the same as public attitudes towards wind power and wind farms. However, rather than the selfishness inherent to NIMBY-ism, he emphasizes the role of equity and fairness instead (Wolsink, Wind power implementation: The nature of public attitudes: Equity and fairness instead of ‘backyard motives’, 2007).

Wolsink contends that instead of the egotism central to NIMBY-ism wherein individuals want to pass on their burden to others, they actually consider it unfair that others, or decision makers, shift the burden to them. Accordingly, at the core of public opposition issues is fair decision making that does not entail any perceived injustice. The perceived fairness in making decisions about siting facilities is, for example, strongly related to perceived environmental risk and core values on how society should take such decisions by incorporating all stakeholders.

- *Place attachment*

As an alternative to NIMBY-ism, disruption to place attachment and the theory of social representations could also be vital in understanding the nature of public opposition to infrastructure projects. (Devine-Wright & Howes, 2010)

2.2. Scope of Public Opposition

Based on available literature, the scope of NIMBY-ism includes the distance, the stage of development, and the people involved in the opposition.

- *Distance*

Wolsink (2000) suggests that concerns regarding specific project development are local in nature and not global. For example, for wind power, the type of landscape is integral to determining the scenic beauty ratings of turbines within the landscape. The characteristics of the selected site are thus vital in the development of public attitudes. Thus, on-site specific features are particularly important when shaping attitudes towards an infrastructure project.

At the same time, Horst (2007) identifies the need to determine what surveyed individuals identify as locations that they consider to be of great importance to them. In turn, this implies that academics must be cautious to not assume the possible geographic extent of concerns raised by individual residents within a specific locality (Horst, 2007). Traditionally, the ‘backyard’ in NIMBY has referred to some geographical catchment area for selfish behavior (Horst, 2007). This in turn implies that opposition to a proposed project is largely local in nature, due to limited information or impediments to exerting pressure when it comes to distant projects. However, Horst (2007) further contends that this administrative handicap may not suffice as an explanation especially given the presence of some non-local protestors suggesting that these concerns may in fact transcend local administrative borders.

- *Stage of planning*

Horst (2007) identifies differences in the temporal extent of NIMBY-ism, with regards to the development of a local project—before people are aware of the plan, during the planning phase and finally, after the project has been realized and is operational. Wolsink (2007) sees attitudes as developing in a U shape based on Horst’s temporal dimensions—positive when people are not confronted by a project in their neighborhood, critical after its announcement, and positive after some time reasonable time has elapsed after the project is operational.

Wolsink (2000, 2007) contends that the announcement of a project is when its impact is most emphasized. The number of those in favor of wind power development reaches a minimum when specific schemes are announced and publicly discussed.

This finds agreement in Horst (2007) who contends that the strongest opposition is prevalent during the planning phase – and that inherent difficulties to secure local planning permission have brought NIMBY behavior to the forefront of this rhetoric. As such, he advocates abandoning academic reference to the ‘before’ (when the project is still hypothetical) and ‘after’ phases of project development.

- *People*

In terms of the people encompassed within this opposition, Horst (2007) also points to the difference between active or passive support or opposition. In this case, active opponents of a development, including those who lobby and protest are at the crux of the NIMBY debate while passive opponents may not resonate with the same magnitude of strength or feelings within the premise of NIMBY behavior. This may be attributed to their acceptance of the *principle* of the project and therefore, make them less willing to actively make efforts to facilitate rejection of planning permission of the project by local authorities.

2.3. Institutional Factors

Wolsink (2000) argues that factors other than public attitudes can impede projects from being realized. He points to the discrepancy between broad support for wind power but not wind power *projects* and addresses the extent of public acceptance of a project. While this reflects Horst’s dichotomy of support *in principle* but not *in practice*, Wolsink contends that factors other than public attitudes could be formative instead suggesting the importance of

institutional factors in impeding planned projects from reaching fruition. For instance, the top down approach to project planning and development by assuming public acceptance or requesting it later (decide-announce-defend model) are obstructive to realizing certain infrastructure projects. Thus, institutional capacity, essential to realize infrastructure projects, is bolstered by collaborative planning (Wolsink, Wind power and the NIMBY-myth: institutional capacity and the limited significance of public support, 2000). Strong public support, while not sufficient, contributes favorably to siting policy and will thus be more favorable than top down planning. This again aligns with the contention by Schweizer et al. (2009) that a protest movement could be caused by perceived corruption or intransparency, overcoming which could result in legitimacy aligning with legality.

3. Background

3.1. German Energy Mix

The Total German Primary Energy Supply (TPES) in 2013 was 312,4 million tonnes of oil equivalent (Mtoe), showing a relative decline of -0,8% since 2003 (International Energy Agency, 2014) The TPES is forecasted by the Federal Government to further reduce over the next twenty years to 216,7 Mtoe in 2030 (International Energy Agency, 2013).

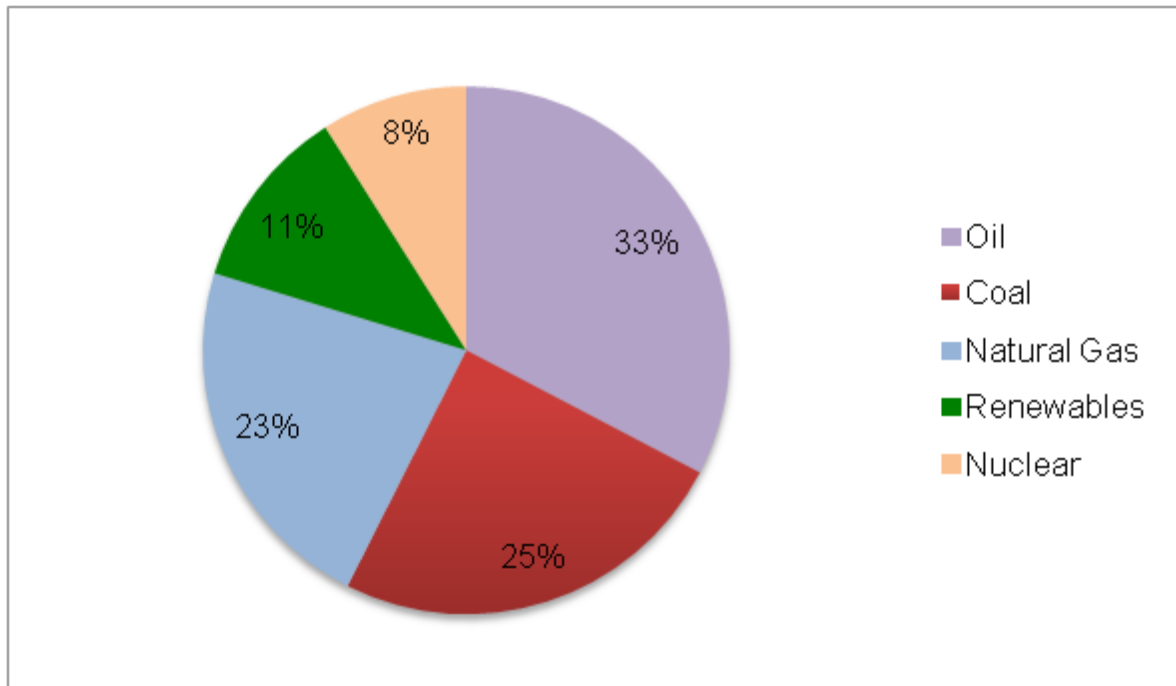


Figure 2: Germany Energy Mix (Source: Adapted from International Energy Agency, 2013)

As illustrated in Figure 2, oil contributes the most to Germany's TPES amounting to 33% in 2013. However, this value has decreased from 36% in 2003 and while the Government forecasts continued decline in oil's share in the energy mix, it is nonetheless going to remain the most significant source of energy at 28,2% of Germany's TPES in 2030 (International Energy Agency, 2013; International Energy Agency, 2014). In contrast to oil, the share of both coal and natural gas have remained relatively stable contributing 25% and 23% in 2011; the latter is expected to remain a significant source of energy forecasted to increase to 25% of TPES by 2030 (International Energy Agency, 2013, 2014). Renewables comprised approximately 11,9 % of TPES in 2013, with biofuels and waste constituting the most important renewable source contributing 9% (International Energy Agency, 2014). Since 2000, renewables have seen strong growth in their contribution to Germany's energy mix with a growth from 4% share in 2003 to 11,9 in 2013 (International Energy Agency, 2014).

According to the IEA, by 2030, their growth is expected to continue with biofuels at 21,6%, wind at 5,6%, solar at 3,2%, geothermal at 1,9%, and hydro at 1% (International Energy Agency, 2013). Finally, nuclear energy comprised 8% of Germany's TPES which reflects a decline of share of 5% (from 13%) since 2003 and expected to be phased out within the aegis of the Energy Package 2011 (International Energy Agency, 2014, p. 1).

Germany's Total Final Consumption (TFC) of Energy was at 221 Mtoe in 2012, which has been declining by 0,6% annually since 2002. In terms of use of energy by sector, the industrial sector (35%) is inevitably the largest end-user of energy followed by residential use (26%), transport (24%) and commercial (15%) (International Energy Agency, 2014, p. 1).

3.2. German Electricity Mix

Germany's gross electricity generation was 633,2 TWh in 2013 compared to 613,1 TWh in 2011. According to the AG Energiebilanzen e.V (2015, p. 1), the country's major electricity source was coal with an overall share of 44,6% (19,2% hard coal and 25,4% brown coal). The share of electricity generated by nuclear power plants declined from 22,2% in 2010 to 17,6% in 2011 and down to 15,4% in 2013. The share of natural gas decreased from 14 % in 2011 to 10,4 in 2013. Renewable energy sources, on the other hand, experienced a strong increase in the same time, with an overall share of 24,1% in 2013 (from 20,2% in 2011). (AG Energiebilanzen e.V, 2015, p. 1)

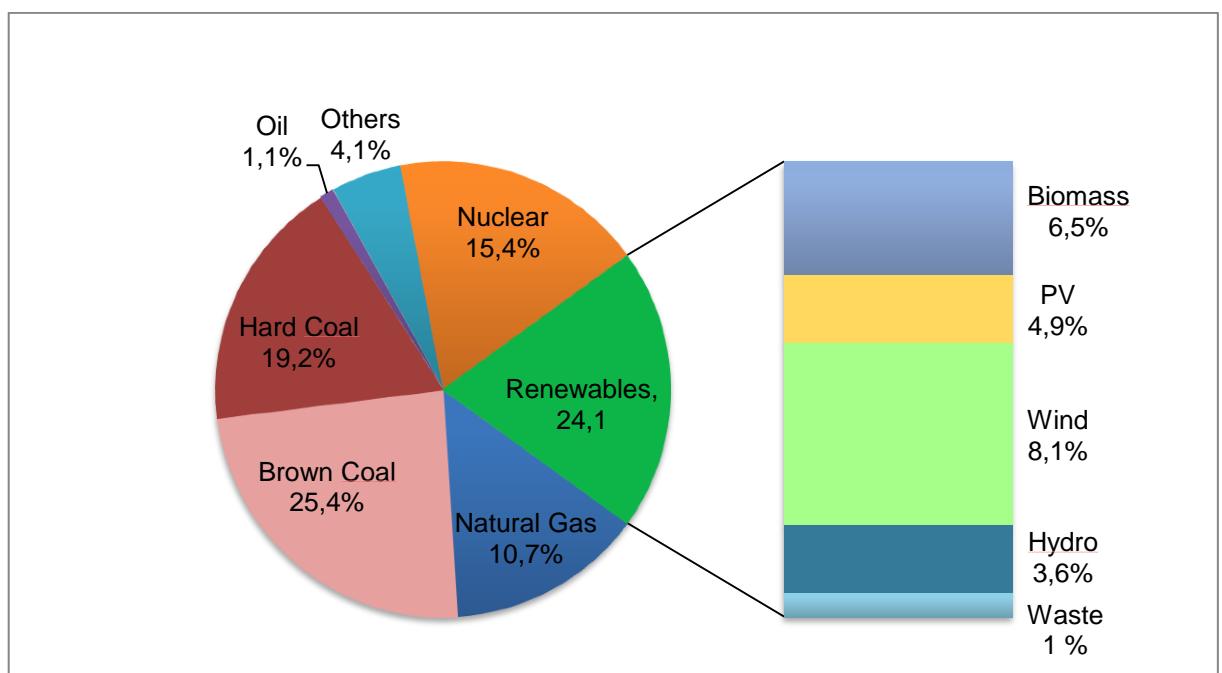


Figure 3: Gross Electricity Generation Germany 2013 (Source: AG Energiebilanzen e.V, 2015, p. 1)

3.3. Nuclear energy production in Germany

3.3.1. Historical overview and the shut down

Nuclear energy generation has been part of Germany's supply for more than six decades. Between 1955 and the late 1960s, the Federal Republic of Germany started founding a large number of institutions to promote research and the peaceful use of nuclear technology for electricity generation. A Ministry for Nuclear Affairs was established and the first academic institutes were soon provided with research reactors. It must be noted however, that from the beginning, the Federal Republic of Germany simultaneously banned any activity connected to the proliferation of nuclear weapons by releasing an official declaration. As a consequence, The Federal Republic of Germany could benefit from adequate international collaboration and it was able to build the first prototype reactors and develop a series of plans for a closed fuel cycle and the treatment and storage of radioactive waste (IAEA, 2013).

On the 31st of October, 1957, Germany's first nuclear reactor was put into service, a research reactor of the Technical University of Munich (DAtF - Deutsches Atomforum e.V, 2014 (b)). Few months later, the former Federal Ministry for Nuclear Affairs implemented the *Reaktorsicherheitskommission (RSK)* to maintain and ascertain the security of nuclear operations within the country. In 1960, the *Atomgesetz*, West Germany's first legislative basis for building and operating nuclear power plants, was adopted and the *Versuchatomkraftwerk Kahl*, an experimental-plant based on US American technology with a capacity of 16 MWe reached criticality (DAtF - Deutsches Atomforum e.V, 2014). The same year, the *Karlsruher Kernforschungszentrum* commissioned Germany's first domestically developed reactor, the *FR-2*. Few years later, Western Germany initiated the commercial use of nuclear power and commissioned reactors with up to 700 MWe capacity (I.E.A - International Energy Agency, 2013). In 1969, the *Kerntechnische Gesellschaft e.V (KTG)*, an association of nuclear scientist and experts, was founded. In 1971, Germany initiated the radioactive waste repository facility *ERAM Morsleben* and one year later, West Germany's nuclear industry earned international recognition by initiating the construction of the *Biblis A* power plant, the most substantial nuclear reactor known at that time. The *Biblis* reactor was put into service only two years later and became the world's first reactor with a capacity of 1200 MWe. At the same time ,

Siemens and AEG created the *Kraftwerk Union (KWU)* to develop and export the *Konvoi*, a 1300 MWe standardized Pressurized Water Reactor (DAtF - Deutsches Atomforum e.V, 2014). In 1972, the commercial reactors Stade, Würgassen and Niederaichbach started to feed electricity into the German grid. The same year, the *Kernforschungsanlage Jülich*, initiated the construction of a Thorium-high temperature reactor in Uentrop and a fast breeder reactor in Kalkar (DAtF - Deutsches Atomforum e.V, 2014). In the following years the reactors Biblis B, Neckarwestheim I and Brunsbüttel (1976), Isar 1 (1977), Unterweser (1978), Philippsburg 1 (1979), Grafenrheinfeld (1981), Krümmel (1983), Gundremmingen B, Gundremmingen C, Grohnde and Philippsburg 2 (all 1984) were commissioned (DAtF - Deutsches Atomforum e.V, 2014). Furthermore, experts accomplished a controlled nuclear fission in the THTR-300 Thorium high-pressure reactor in Hamm-Uentrop. Although Western Germany's early technological progress had highly depended on international support, including US American manufacturers such as GE/AEG, Western German technology had quickly become internationally renowned and was exported around the world from the early 1970s (DAtF - Deutsches Atomforum e.V, 2014 (b)).

However, the rise of nuclear power was not a uniquely Western German occurrence. In 1955, at the same time as the Federal Republic of Germany, the German Democratic Republic (DDR), with substantial support from the Soviet Union, also initiated activities aimed at the peaceful use of nuclear technology and founded the *Rosendorf Nuclear Physics Institute* (DAtF - Deutsches Atomforum e.V, 2014). In 1966, the first commercial nuclear power plant, the *Reihnsberg* reactor, was put into service and eight years later the Greifswald units 1-4 were commissioned (IAEA, 2013).

Along with the development of Germany's nuclear operations, rose an increasing criticism towards the use of nuclear energy in the country. In 1976, the first anti-nuclear demonstrations were held in Broksdorf and nuclear skepticism found growing support after the Three Mile Island accident in Harrisburg in 1979 (DAtF - Deutsches Atomforum e.V, 2014). On the 26th of April, 1986, a major nuclear accident occurred in the fourth unit of the Soviet nuclear power plant *Chernobyl* in the former Ukrainian Soviet Socialist Republic (DAtF - Deutsches Atomforum e.V, 2011). The latter

incident led to countrywide demonstrations against the construction of the reprocessing facility *Wackersdorf* and Germany's general engagement in nuclear operations (DAAtF - Deutsches Atomforum e.V, 2014 (b)).

In 1987, The Federal Republic of Germany introduced the *IMIS*, the Integrated System for Measuring and Assessing Environmental Radioactivity and two years later, the *Bundesamt für Strahlenschutz –BfS*, today's Federal Office for Radiation Protection, was founded. Even-though the Chernobyl accident had created broad resentment against nuclear power within the German population, the government commissioned the construction of two new reactors in 1989: Isar 2, Emsland and Neckarwestheim II (DAAtF - Deutsches Atomforum e.V, 2014). After the fall of the Berlin Wall, and with the reunification of the German Democratic Republic with the Federal Republic of Germany, Germany started an extensive inspection of the existing nuclear power plants which led to the decision to de-commission new power plants based on Soviet technology, namely *Rheinsberg* and *Greifswald*, and to stop the construction of those that had already been initiated (DAAtF - Deutsches Atomforum e.V, 2014). From this point on, no commercial nuclear reactors were commissioned. In 1995, the decommissioning of the Würgassen reactor was initiated and in 1998, the Alliance '90 – a coalition agreement between the Social Democratic Party of Germany and the Greens determined that Germany would slowly start phasing out nuclear energy (DAAtF - Deutsches Atomforum e.V, 2014). On the 14th of June, 2000, the German Federal Government and the German utilities entered into an agreement establishing on the one hand, limitations on nuclear energy generation with respect to the overall national supply, while on the other hand assuring the undisturbed operation of the existing nuclear power plants (*Vereinbarung zwischen der Bundesregierung und den Energieversorgungsunternehmen vom 14. Juni 2000*). Two years later, the agreement was incorporated in the updated *Atomgesetz*, the German Atomic Energy Act (DAAtF - Deutsches Atomforum e.V, 2014 (b)).

Changes were also occurring in other European countries and 2005 represented an important year for nuclear technologies throughout Europe. The Finnish government commissioned the Olkilouto 3 reactor, the first of a new generation of nuclear power plants (DAAtF - Deutsches Atomforum e.V, 2014 (b)). Simultaneously a broad union of States, including the European Union member Countries, the Peoples Republic of

China, the Republic of India, the Republic of Korea, the Russian Federation and the United States of America launched the *International Thermonuclear Experimental Reactor (ITER)* fusion reactor program in Cadarache, France (DAtF - Deutsches Atomforum e.V, 2014). In September 2010, the newly elected German government, led by the Christian Democratic Union of Germany (CDU) and the Free Democratic Party (FDP), approved the 11th Amendment of the Atomic Energy Act, determining the life span of a number of already existing nuclear reactors throughout the country. The activity of reactors older than 1980 was prolonged by 8 years, whereas that of reactors built after 1980 was extended by 14 years (BMUi, 2012).

3.3.2. The Shut Down

Until the 11th of March 2011, it was hard to imagine that Japan would play such a significant role in the nuclear energy-policy of Germany. The accident in the Fukushima Daiichi power plant following the tremendous earthquake that hit the country drew global attention to nuclear energy generation and inevitably raised questions connected to the safety of such operations (Pesch, Martinsen, Heinrichs, & Hake, 2012).

The first reaction of Germany's policy makers was to ask the Reactor Safety Commission (RSK) to examine and test the safety of the seventeen operating German nuclear power plants (BMUi, 2012). Based on these test's results and the recommendations from the RSK, the Federal Ministry for the Environment, Nature Conservation and Nuclear safety commissioned its technical support branch, the GRS – *Gesellschaft für Anlagen- und Reaktorensicherheit*, to reassess the risks of nuclear energy production. The resulting report (*Weiterleitungsnachricht-WLN*), in combination with the wide-spread disapproval of the public opinion, and recommendations from several organizations (such as the Ethical Review Committee for Safe Energy Supply – *Sichere Energieversorgung*) led the German Federal Government to take the decision to abandon industrial nuclear energy generation, and to do so as fast as possible (BMUi, 2012). The German Government decided to shut down 8 of the 17 nuclear power plants as a precautionary reaction to the Fukushima Daiichi accident. The German Bundestag accordingly enacted a three months moratorium to reevaluate the safety standards of all operating commercial power

plants in the country. The operational prolongations established in the 11th Amendment of the Atomic Energy Act were immediately suspended and the 7 plants older than 1981 and Krümmel KKK were temporarily decommissioned (Bredberg I. , Hutter, Kühn, & Dose, 2012). It is important to mention that the plants Brunsbüttel KKB and Krümmel KKK had already been in non-performance mode due to technical issues. In consequence, the power plants Biblis A, Biblis B, Isar KKI 1, Neckarwestheim GKN I, Philippsburg KKP and Unterweser KKKU were phased out and Brunsbüttel KKB and Krümmel KKK were not brought back into operation. (Bredberg I. , Hutter, Kühn, & Dose, 2012).

In the 13th amendment of the Atomic Energy Act of 2011, the German Bundestag decided with an overwhelming majority of 513 votes (compared to 79 no-votes and 8 abstentions) to abandon all operating nuclear power plant by 2022 (Deutscher Bundestag, 2011). Such an overpowering consensus had rarely been seen in the Parliament and it brought together almost all the major represented parties, including the governing CDU and FDP and the big opposition parties SPD and Bündnis 90' die Grünen (Zeit Online, 2011). Only one bigger political fraction, Die Linke, voted against the 13th Amendment. The former Minister for the Environment, Nature Conservation and Nuclear Safety, Dr. Norbert Röttgen, emphasized in a speech in front of the Bundestag the particularity of this seldom mutual consent, emphasizing that the agreement would represent a turn in the German energy-policy debate that had been ongoing for over 30 years (Zeit Online, 2011). At this point, it is important to note that the German Bundestag had decided an extension for the running life of German nuclear power plants in Autumn 2010 (Deutscher Bundestag, 2010). In fact, only few months before the Fukushima Daiichi accident, the German Bundestag had decided, in the course of the 11th Amendment of the Atomic Energy Act, to prolong the life time of the power plants older than 1980 by 8 years and the lifetime of the post-1980 plants by 14 years (Deutscher Bundestag, 2010; Deutscher Bundestag, 2010; Deutscher Bundestag, 2010(b)).

The German Bundestag passed the 13th Amendment of the German Atomic Energy Act on the 31st of July, 2011, four months after the Fukushima accident, and the

revision came into effect on the 6th of August, 2011. On the effective date of the legal validity of the Amendment, the eight nuclear power plants that had hitherto been phased off were permanently shut down. In addition, the Amendment determined that the remaining nine nuclear power plants were to be phased out by the year 2022 (Bredberg I. , Hutter, Kühn, & Dose, 2012). More precisely, the nuclear power plant Grafenrheinfeld KKG has been planned to be phased out by the end of the year 2015, Gundremmingen KRB B by the end of 2017, Philippsburg by the end of 2019, Grohnde, Gundremmingen C and Brokdorf by the end of 2021 and Isar 2, Emsland and Neckarwestheim by December 31st, 2022 (atw, 2012). The life span extension decided in 2010 and the additional electricity volumes added in 2010 were canceled. Additionally, the current legislation, since the 12th amendment of the act in September 2010, does not prescribe the commissioning of new commercial nuclear power plants (DAtF - Deutsches Atomforum e.V, 2014; Bredberg I. , et al., 2014).

In 2011, the gross electricity production of Germany's 17 nuclear power plants decreased by -23,2 % from 140,556 TWh (2010) to 107,971 TWh. The gross capacity of those power plants is 8.821 MW (net capacity: 8.433 MW). Therefore, Germany lost approximately 41% of their gross installed capacity. According to the International Atomic Energy Agency (IAEA, 2013), the 9 remaining German nuclear power plants had a gross capacity of 12.696 MWe and produced 97,141 TWh (net) in 2013. (Bredberg I. , Hutter, Kühn, & Dose, 2012; atw, 2012).

3.3.3. Current Status of the German reactors

Despite the initiated nuclear shut down and the reduction from 17 nuclear reactors to 9, Germany's nuclear capacity still remains one of the worlds' largest. Moreover, there are currently only twelve other countries with a higher numbers of operating, commercial nuclear reactors in the world: The United States of America with 100 reactors, the French Republic with 58 reactors, the State of Japan with 59 reactors, the Federal Republic of Russia with 33, the Republic of Korea with 23 reactors, the Republic of India with 21 reactors, The People's Republic of China with 22 operating reactors and 28 under construction, Canada with 19 reactors, the United Kingdom of Great Britain and Northern Ireland with 16 reactors, Ukraine with 15 and Sweden with 10 operating reactors¹ (DAtF - Deutsches Atomforum e.V, 2014 (b)). In fact, in 2013, Germany's gross capacity

¹ Status December 2013, According to the DAtF – Deutsches Atomforum e.V

accounted for 3,183 per cent, the net capacity for 3,192 percent and the gross production for 3,897 per cent of the global capacities or gross production². (DAtF - Deutsches Atomforum e.V, 2014)

In 2013, nine nuclear reactors with a gross capacity of 12.696 MWe were still in operation. This included seven Pressurized Water Reactors (PWR) with a capacity of 10.008 MWe and two Boiling Water Reactors (BWR) with a capacity of 2,688 MWe. As mentioned above, eight reactors, 4 PWRs (4.775 MWe) and 4 BWRs (4.046 MWe) were already in their final shut down process (Bredberg I. , et al., 2014). Furthermore, the German nuclear landscape counted 16 reactors under decommissioning, three reactors were already entirely dismantled and six projects were initiated, but never reached criticality. At this point³, no decommissioning process had been initiated for the eight reactors shut down in August 2011 (I.E.A - International Energy Agency, 2013; Bredberg I. , et al., 2014).

² Global gross capacity: 398.861 MWe, Global net capacity: 378.070 MWe, Global gross production: 2.364,16 TWh net (DAtF - Deutsches Atomforum e.V, 2014)

³ Status as of December 2013 (IAEA, 2013)

Table 1: Nuclear Power Plants in Germany 2013 (Bredberg I. , et al., 2014; atw, 2012; Bredberg I. , Hutter, Kühn, & Dose, 2012)

Power plant	Gross electrical capacity	Reference unit power	Location	First Grid connection	Status	Production		
						2010	2011	2013
Unit	MW (Gross)	MW (Net)				GWh (net)	GWh (net)	GWh (net)
Biblis A	1225	1167	Hesse (Bilblis)	25.08.1974	Permanent shutdown	4.675,88	2.111,28	0
Biblis B	1300	1240	Hesse (Biblis)	25.04.1976	Permanent shutdown	9.726,62	1.683,99	0
Brokdorf KBR	1480	1410	Schleswig-Holstein (Osterende)	14.10.1986	Operational (31.12.2019)	11.360,45	9.701,25	11.146,17
Brunsbüttel KKB	806	771	Schleswig-Holstein (Brunsbüttel)	13.07.1976	Permanent shutdown	0	0	0
Emsland KKE	1400	1329	Lower Saxony (Lingen)	19.04.1988	Operational (31.12.2022)	10.977,91	10.971,12	10.912,11
Grafenrheinfeld KKG	1345	1275	Bavaria (Schweinfurt)	30.12.1981	Operational (31.12.2015)	7.492,57	8.532,31	9.664,79
Grohnde KWG	1430	1360	Lower Saxony (Grohnde)	05.09.1984	Operational (31.12.2019)	10.782,44	9.609,19	10.420,06
Gundremmingen KRB B	1344	1284	Bavaria (Gundremmingen)	16.03.1984	Operational (31.12.2017)	9.460,79	10.320,08	9.647,36
Gundremmingen KRB C	1344	1288	Bavaria (Gundremmingen)	02.11.1984	Operational (31.12.2019)	10.394,76	9.454,97	10.015,72
Isar KKI 1	912	878	Bavaria (Essenbach)	03.12.1977	Permanent shutdown	6.285,18	1.561,10	0

					n			
Isar KKI 2	1485	1400	Bavaria (Essenbach)	22.01.1988	Operational (31.12.2022)	11.375,28	11.655,84	11.402,05
Krümmel KKK	1402	1346	Schleswig-Holstein (Geesthacht)	28.09.1983	Permanent shutdown	0	0	0
Neckarwestheim GKN I	840	785	Baden-Württemberg (Neckarwestheim)	03.06.1976	Permanent shutdown	1.910,34	188,66	0
Neckarwestheim GKN II	1400	1310	Baden-Württemberg (Neckarwestheim)	03.01.1989	Operational (31.12.2022)	10.180,30	10.807,79	10.218,74
Philippsburg KKP 1	926	890	Baden-Württemberg (Philippsburg)	05.05.1979	Permanent shutdown	6.448,68	1.415,29	0
Philippsburg KKP 2	1468	1402	Baden-Württemberg (Philippsburg)	17.12.1984	Operational (31.12.2019)	11.192,14	10.727,21	8.714,52
Unterweser KKU	1410	1345	Lower Saxony (Stadland)	29.09.1978	Permanent shutdown	10.698,9	2.369,34	0
Total	21517	20480				133.002,24	101.058,43	92.141,52

3.3.4. Organization and Structure of the German Nuclear Power Industry

Germany's basic law, the *Grundgesetz*, determines that the German Federal Government holds the legislative authority regarding the peaceful utilization of nuclear technologies and, on the other hand, allocates the execution of Federal law in this regard to the Federal Lands (Länder). However, the Federal Lands' executive power is subject to exceptions and controlled by the Federation. The *Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB)* has been assigned with the supreme authority for affairs regarding nuclear safety and radiological protection and is consequently responsible for the

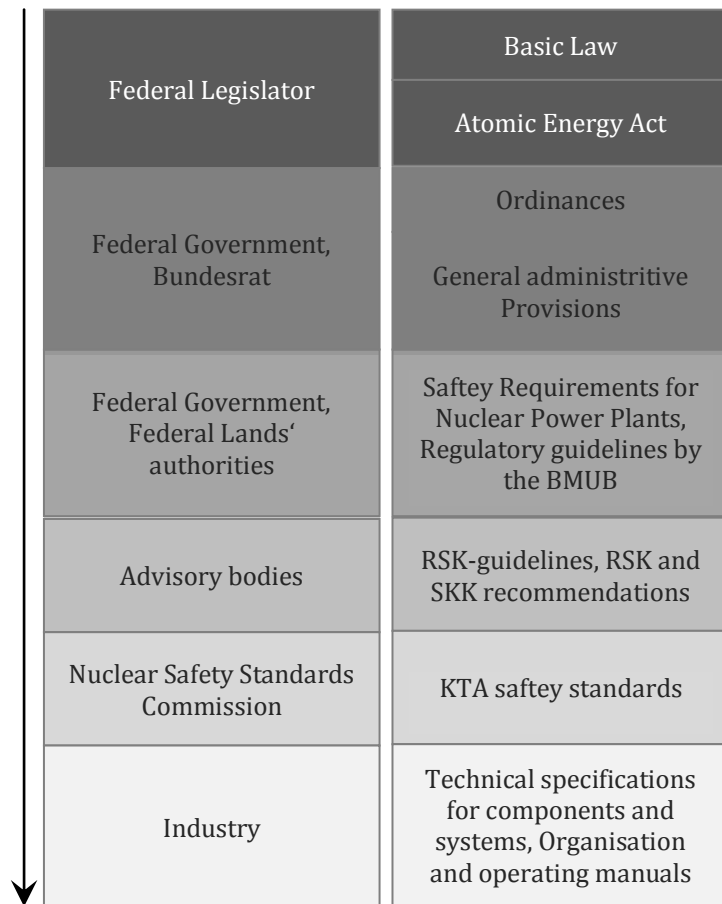


Figure 4: Hierarchy of the National Regulations and the Issuing Authorities (BMUB - German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2015)

supervision of lawfulness and expediency of the Federal Lands' related executive activities. The main federal legislative basis for nuclear regulation was constituted by the Atomic Energy Act of 1959⁴, which has since been changed and updated by thirteen amendments to this day. (BMUB - German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2015; I.E.A - International Energy Agency, 2013)

According to the Act on the Peaceful Utilization of Atomic Energy and the protection against its Hazards (Atomic Energy Act), the main purpose of the law is:

“(1) to phase out the use of nuclear energy for the commercial generation of electricity in controlled manner, and to ensure orderly operation up until the date of termination, (2) to protect life, health and real assets against the hazards of nuclear energy and the harmful effects of ionising radiation and to provide compensation for damage caused by nuclear

⁴ Atomgesetz from 1959

energy or ionising radiation, (3) to prevent danger to the internal or external security of the Federal Republic of Germany from application or release of nuclear energy or radiation, (4) to enable the Federal Republic of Germany to meet its international obligations in the field of nuclear energy and radiation protection (BfS - Bundesamt für Strahlenschutz, 2013, S. 3).“

In addition to the Atomic Energy Act, there are a number of generally binding federal regulations and laws to regulate and administer the peaceful use of nuclear technologies in Germany, which are as follows: the *Precautionary Radiation Protection Act*, the *Radiation Protection Ordinance*, the *Nuclear Licensing Procedure Ordinance*, the *Nuclear Financial Security Ordinance*, the *Repository Prepayment Ordinance*, the *Nuclear Reliability Assessment Ordinance*, the *Nuclear Safety Officer and Reporting Ordinance*, and the *Nuclear Waste Shipment Ordinance*. (IAEA, 2013)

The *Bundesamt für Strahlenschutz (BfS)*, the Federal Office for Radiation Protection, supports the *BMUB* with technical and scientific advice regarding radiation protection, nuclear safety and nuclear waste management. In addition, the Office assists the ministry in the execution of federal oversight and a number of administrative and representative tasks (BMUB - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2013). In order to assure independent, qualified and comprehensive evaluations, the BMUB is supported by the advisory commissions *Reactor Safety Commission (RSK⁵)*, the *Commission for Radiological Protection (SSK⁶)* and the *Nuclear Waste Management Commission (ESK⁷)* (BMUB - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2013; BMUB - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2012). These Commissions are aimed at providing the BMUB with unbiased and comprehensive recommendations and scientific comments and at promoting technical progress in the field of safety. It should however be noted that the members of the advisory commissions are assigned by the BMUB (BMUB - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2012). Furthermore, the Nuclear Safety Standards Commission (KTA⁸) defines precise safety

⁵ RSK: Reaktor-Sicherheitskommission

⁶ SKK: Strahlenschutzkommission

⁷ ESK: Entsorgungskommission

⁸ KTA: Kerntechnischer Ausschuss

standards for nuclear operations. This commission is affiliated with the *BfS* and represents five groups of stakeholders: operators, experts, manufacturers, federal- and state authorities and representatives of public interests. In fact, each of these groups is represented by seven votes and new standards have to be approved by twenty-eight members in order to be approved. This system had been set up to ensure that no stakeholder group, provided that they vote in unison, could be overruled (BMUB - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2013; IAEA, 2013).

As mentioned, in accordance with the Basic Law and the Atomic Energy Act, the Federal Lands are responsible for the execution of national laws and regulations regarding nuclear

power. Two of the utmost important tasks in this regard, are the licensing and supervision of domestic power plants. The Federal Land government may therefore nominate the responsible executive Federal Land authorities. The seventeen German reactors, including those shut down in 2011, are located in five different German Federal Lands, namely Baden-Württemberg, Bavaria, Hesse, Lower Saxony and Schleswig-Holstein (atw, 2012).

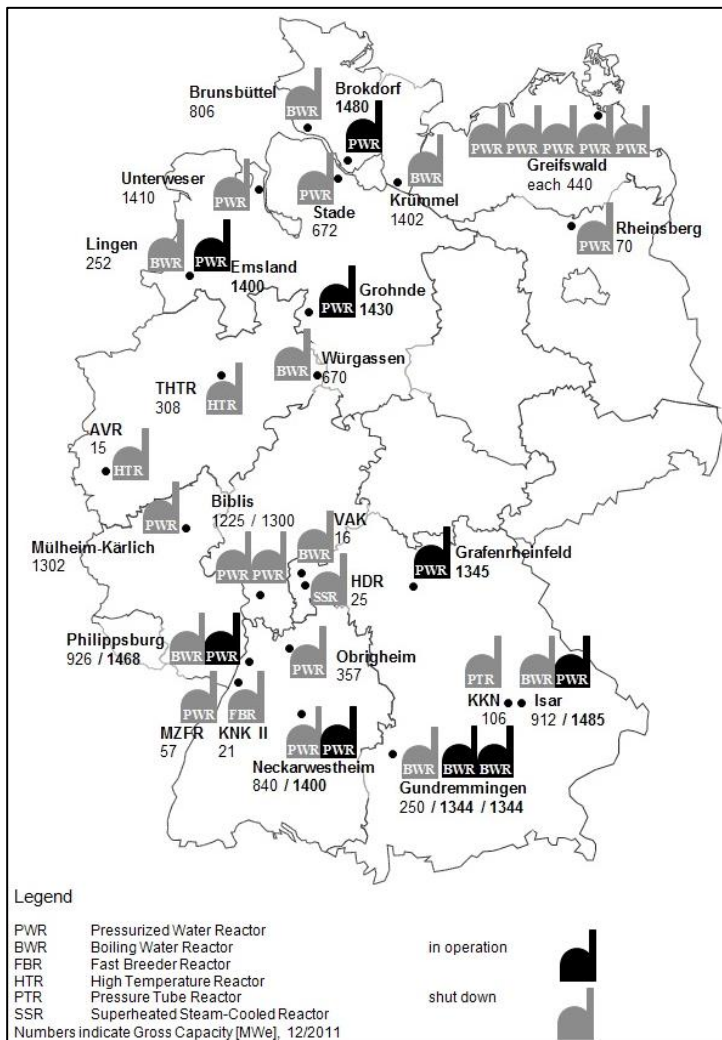


Figure 5: Status and Location of Germany's Nuclear Power Plants end of 2011- Retrieved from IAEA (2013, p. 65), based on Bredberg I. , et al., (2014)

Figure 5: Status and Location of Germany's Nuclear Power Plants end of 2011 and shows the geographical sites of both, the operational reactors and those which were shut down until 2013. The Federal Land of Baden-Württemberg has four reactors within

were shut down until 2013. The Federal Land of Baden-Württemberg has four reactors within

its borders, *Neckarwesteheim 1* and *Philippsburg 1*, both shut down in 2011 and *Neckarwesteheim 2* and *Philippsburg 2*, which are both still operational. The licensing authority⁹ and supervising authority have both been held by the *Ministry for the Environment, Climate Protection and Energy Sector of Baden Württemberg*. *Isar 1* and *2*, *Grafenrheinfeld*, *Grundremmingen B* and *C* are located in Bavaria and the licensing authority¹⁰ and supervisory authority are subject to the *Bavarian State Ministry of the Environment and Public Health*. The *Biblis A* and *Biblis B* reactors, both had been shut-down in 2011, are located in Hesse and are therefore under the authority (licensing and supervisory) of the *Hessian Ministry of the Environment, Energy, Agriculture and Consumer Protection*. In Lower Saxony, the operational reactors *Grohnde* and *Emsland* and the shut-down reactor *Unterweser* (2011) are regulated by the *Lower Saxon Ministry for Environment and Climate Protection*. Lastly, the *Ministry of Energy Transition, Agriculture, Environment and Rural Areas Schleswig Holstein* oversees licensing and supervision of the local reactors *Brunsbüttel*, *Krömmel* (shut-down in 2011) and *Brokdorf*. (IAEA, 2013)

3.3.5. Nuclear Reactor Design in Germany

Germany's remaining operational commercial nuclear reactors and those shut-down in 2011 can be subdivided into two main technologies, the Pressurized Water Reactor (PWR) and the Boiling Water Reactor (BWR). Today, there are seven PWRs and two BWRs in operation, whereas four PWRs and four BWRs had been shut down in 2011 (IAEA, 2013). In order not to go beyond the scope of this paper, the following chapter will be limited to these two fission based thermal reactor technologies, which are the only existing designs for commercial power generation in Germany. However, it is important to state that this only covers a part of today's nuclear reactor designs (Choppin, Rydeberg, & Liljenzin, 1995; DAtF - Deutsches Atomforum e.V, 2014).

Even though there has been significant progress in developing new technological approaches for nuclear power, the vast majority of the world's nuclear power plants in commercial service are based on fission of the *Uranium 235* (^{235}U) isotope. Obviously, ^{235}U is not the only fissile element¹¹; however, it is the most used nuclear fuel today (Bonin & Royer, 2014).

⁹ The licensing authority is held in agreement and cooperation with the Ministry of Finance and Economic Affairs and the Ministry of Interior of Baden-Württemberg (IAEA, 2013)

¹⁰ The licensing authority is held in agreement and cooperation with the State Ministry of the Economy, Infrastructure, Transport and Technology (IAEA, 2013)

¹¹ Examples for other fissile isotopes: ^{233}U (produced from ^{232}Th), ^{239}Pu (produced from ^{238}U) or ^{241}Pu

Natural uranium usually consists of 99,3% of ^{238}U and in consequence ^{235}U represents a minimal share of 0,7% (Narbel, Hansen, & Lien, 2013; Volkmer, Kernenergie Basiswissen, 2013). PWRs and BWRs usually need a minimum share of 2% ^{235}U ; consequently, natural uranium has to be enriched in processing plants by a complex procedure (Volkmer, Kernenergie Basiswissen, 2013). In order to ensure a controlled nuclear chain-reaction, a sufficient number of neutrons is needed (Volkmer, Kernenergie Basiswissen, 2013). During the fission process, a neutron hits the ^{235}U isotope and consequently transforms it into ^{236}U , which on the other hand fissions into two daughter products (for example: *Barium* (^{139}Ba) and *Krypton* (^{94}Kr), or *Cesium* ^{140}Cs and *Rubidium* ^{93}Rb), under the release of two to three neutrons (Volkmer, Kernenergie Basiswissen, 2013; Royer, 2014). This reaction¹² releases kinetic energy of approximately 195 MeV¹³ (Royer, 2014). The probability to capture the released neutrons highly depends on their kinetic energy. In general, the slower the neutrons are, the higher is the probability of further fission of ^{235}U isotopes. Therefore, the fast neutrons, often released with a kinetic energy between 0,1-2,0 MeV, have to be decelerated to thermal neutrons with less than 0,1 MeV (Volkmer, Kernenergie Basiswissen, 2013). In order to decelerate fast neutrons, moderator substances, such as *Hydrogen* (^1H), *Deuterium* (^2De), *Carbon* (^{12}C), *Beryllium* (^9Be), or *Uranium* (^{238}U) may be used. However, the energy transfer is in principal higher when the fast neutrons collide with light nuclei¹⁴ (Royer, 2014). In practice such moderators, which enable a fast slowdown with few collisions and a minimum absorption of neutrons, are chosen. The fuel and the moderator are either mixed, in so-called homogenous reactors or may be separated, in heterogeneous reactors (Volkmer, Kernenergie Basiswissen, 2013). The chain reaction in nuclear fission reactors, in order to be maintained, has to be controlled by neutron absorbers. Hence, thermal reactor design comprises regulation rods, allowing them to reach exactly the critical state.

Radiation is a consequence of nuclear break-up due to excess of energy or mass. Three different forms of radiation may be released:

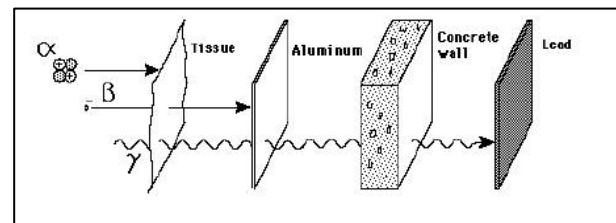


Figure 6: Insulation of Alpha-, Beta- and Gamma Radiation by different matters according to Bonin and Royer (2014, p. 7)

¹² $n + ^{235}\text{U} \Rightarrow ^{140}\text{Cs} + ^{93}\text{Rb} + 3n$ (or $n + ^{235}\text{U} \Rightarrow ^{140}\text{Cs} + ^{93}\text{Rb} + 3n$)

¹³ $n + ^{235}\text{U} \rightarrow ^{139}\text{Ba} + ^{94}\text{U} + 3n + E$

$E \approx 139 + 8,3 + 94 + 8,8 - 235 + 7,6 \approx 195\text{MeV}$ (Bonin & Royer, 2014)

¹⁴ *Hydrogen* (^1H), *Deuterium* (^2De), *Carbon* (^{12}C)

Alpha radiation (the release of 4_2H), Beta radiation (positron release (β^+) due to the transformation of protons into neutrons or the transformation of a neutron into a proton releasing an electron (β^-)) and Gamma radiation, an electro magnetic wave of high energy. In order to shield the outside from radiation, different matters are used (Royer, 2014). Whereas Alpha radiation is fairly simply to isolate, Beta radiation requires a barrier made of aluminum (${}^{13}Al$) or concrete and Gamma radiation a sufficient layer of lead (${}^{82}Pb$). In consequence, thermal reactors are equipped with barriers for radiation protection and the retention of radioactive matter. (Royer, 2014; Volkmer, Kernenergie Basiswissen, 2013; Narbel, Hansen, & Lien, 2013).

Both, the Pressurised Water Reactor design and the Boiling Water Reactor design are thermal reactors. Thermal reactors consist of five main components, which allow a controlled nuclear reaction: (1) Sufficient supply of fissile material, (2) substance for moderation, (3) Control Rods to capture neutrons, (4) a medium for heat transfer from the nuclear core to outside and (5) barriers for radiation protection and the retention of radioactive matter. (Volkmer, Kernenergie Basiswissen, 2013)

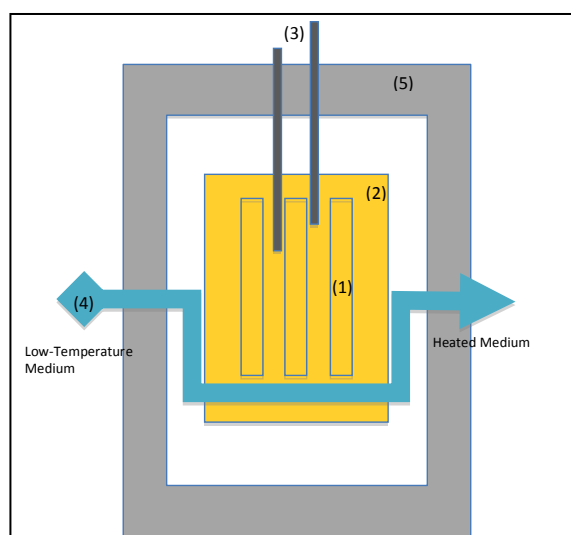


Figure 7: The Main Principle of Thermal Nuclear Reactors - Own Illustration based on (Volkmer, 2013, p. 39)

3.3.5.1. Pressurized Water Reactors (PWRs)

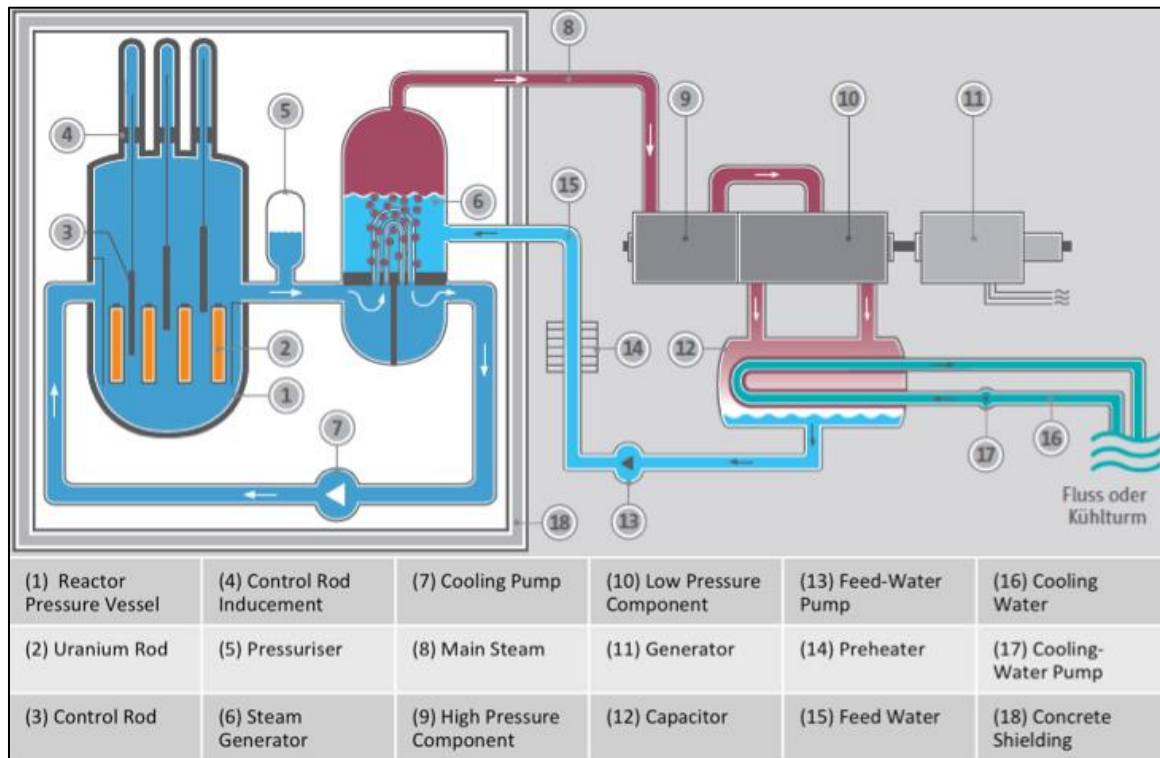


Figure 8: Example of the Brokdorf Nuclear Reactor – Retrieved from Volkmer (2013) with own translation

PWRs are, as BWRs, classified as *Second Generation* nuclear power plants and these two designs represent the vast majority of operational reactors in the world (Royer, 2014). In the case of Pressurized Water Reactors the moderator substance is hot highly pressurized water (H_2O), which is also used as the substance for cooling. In fact, the heat generated by the nuclear fuel elements is dissipated by highly pressurized water. Taking the Brokdorf-reactor as an example¹⁵, the system pressure is increased to 157 Bar and constantly regulated by a pressurizer. The water in the cooling circuit enters the core of the reactor with a temperature of 291°C and leaves it with 326°C. In the Brokdorf reactor, 67.680t of coolant is processed in each hour of operation. The main differences in the PWR design are the two separated circuits; one cooling the reactor's core with highly pressurized water, and a second, detached circuit generating steam. The heated, pressurized H_2O of the primary circuit gives off heat to the separated secondary circuit via pressurizers. It is important to note that only heat, no water is exchanged between the two circuits. Thus, the radioactive matter from the primary circuit is shielded off and cannot reach the turbines or the capacitor. As with other kinds of thermal power plants, the steam generated is used to power turbines in the generator,

¹⁵ Not all PWR are identical in technology, however the main technological concept for those reactors in operation in Germany does not differ significantly.

consequently transforming mechanical energy into electrical energy. In the case of the Brokdorf generator, a three-phase synchronous generator four pressurisers generate enough steam to power a turbine, which has a gross capacity of 1.480 MW. The capacitor liquefies the steam leaving the turbine. In fact, this requires massive amounts of H_2O . In order to cool the Brokdorf reactor, approximately 208.000 cubic meters of water are extracted from the river Elbe per hour of operation. After condensation the pre-heater increases the temperature to 218°C and the water is reverted to the steam generator. In order to guarantee shielding from radiation, a pressure vessel of 25 cm wall thickness of special steel coats the nuclear fuel elements, which is, together with the primary circuit, further encased by a double-walled containment (Volkmer, Kernenergie Basiswissen, 2013, pp. 50-51).

3.3.5.2. Boiling Water Reactors (BWRs)

Even though the design of a Boiling Water Reactor is very similar in most aspects to PWR-technology, it comprises only one single circuit with water. As the name implies, the water is heated to temperature of ebullition in the core of the reactor. After the generated steam is separated from the water, it is directly delivered to the turbine. In the case of the German Gundremmingen C reactor 7.477 tons of steam, at 286°C and under almost 70 Bar pressure, are processed per hour of operation. Since this design uses only one circuit and radioactive contaminant may reach the generator segments, the turbine house needs to be shielded off by the containment (Volkmer, Kernenergie Basiswissen, 2013, pp. 49-50).

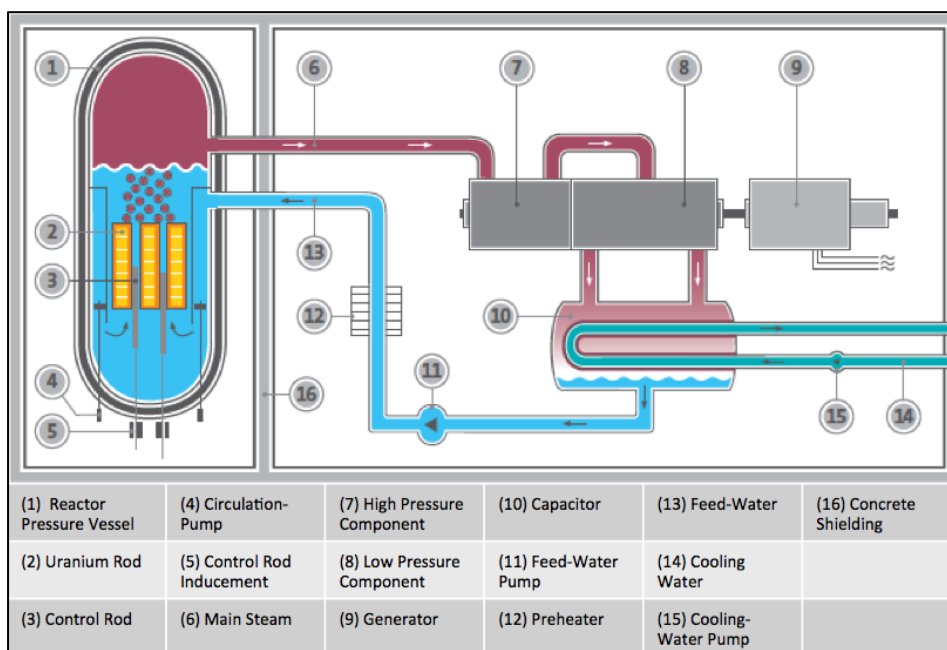


Figure 9: BWRs- Example of the Gundremmingen Block C Reactor – Retrieved from Volkmer (2013, p. 49) with own Translation

3.3.6. Safety standards in Germany

3.3.6.1. Germany's Fundamental Safety Concept

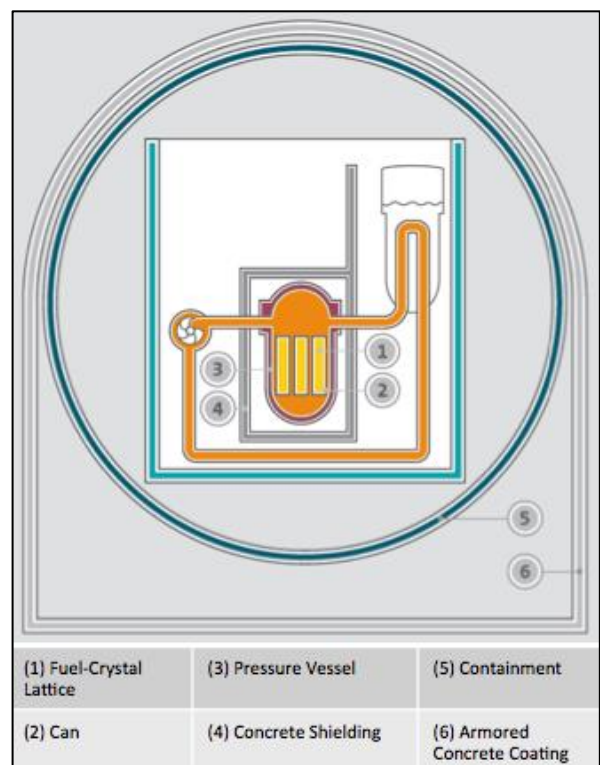
As already described in an earlier chapter, the use of nuclear technology is strictly bound to peaceful operations and the planning, construction, operation and decommissioning is strictly regulated. There are two very important concepts in place to ensure high safety standards.

First, the *Barrierenkonzept* determines that nuclear reactors have to be equipped with a number of protective barriers to avoid the leakage of radioactive matter and to shield radiation. Whereas, Alpha- and Beta radiation are sufficiently isolated by the surrounding cooling water, further measures are necessary to ensure the shielding of Gamma radiation. Hence, each German thermal reactor needs to have the following retaining layers: (1) crystal lattice surrounding the fuel rods to shield a major part of the fission products (2) metallic cans coating the fuel rods, (3) pressure vessels, (4) the concrete shielding of the core, (5) the reactor

containment and the armored concrete coating. In fact this multiple barrier concept reduces the remaining radiation to a minimum outside the reactor, and on the other hand protects the reactor from external impacts. (DAtF - Deutsches Atomforum e.V, 2013; Volkmer, Kernenergie Basiswissen, 2013)

Furthermore, in addition to this barrier design related concept, the German nuclear safety policy stipulates the concept of defence in depth by four security levels. According to the BMUB - Federal Ministry for the Environment Nature Conservation, Building and Nuclear Safety (1998), the aim of this framework is to conduct all necessary safety measures to avoid or reduce malfunction to the highest possible degree of implausibility and, on the other hand, to provide an adequate framework of countermeasures in case of incidents or accidents. Therefore, this framework postulates failure and assumes that, even though all due diligence may be applied, technical malfunction may occur (DAtF -

Figure 10: Reactor Safety Barriers in Germany – Retrieved from The German Atomic Forum (2013, p. 11) with own translations



Deutsches Atomforum e.V, 2013). In other words, risk of technical failure has to be taken into account, and in case of failure on one security level, the superordinate security level has to provide the adequate safety measures to absorb the consequences. Assuming the normal operating state, the measures of the first security level aim to reduce risk of failure by high technological standards and strict quality controls for components or modules used for construction, operation or maintenance of nuclear reactors (Volkmer, Kernenergie Basiswissen, 2013; DAfF - Deutsches Atomforum e.V, 2013). In addition, all workforce involved has to be regularly instructed and their performance reviewed. According to the German Atomic Forum (DAfF - Deutsches Atomforum e.V, 2013), this comprehensive supervising system has resulted in a low number of operational disorders and a consequently high availability of German reactors.

In case of abnormalities during operation, the second security level was designed to reduce the consequences of malfunction to a minimum. Therefore, the reactors' operating systems are equipped with a dense network of control- and monitoring systems to detect and counteract any malfunction. However, it is important to note that this state is still specified as normal operation. (BMUB - Federal Ministry for the Environment Nature Conservation, Building and Nuclear Safety, 1998; DAfF - Deutsches Atomforum e.V, 2013)

The third security level postulates the case of disturbance. During the planning- and construction process, Germany's fundamental safety concept has been designed to assume the most unfavorable circumstances and therefore determine several important principles in order to provide comprehensive safety measures to avoid negative consequences (DAfF - Deutsches Atomforum e.V, 2013).

First, the *Duplication-principle (Redundanzprinzip)*, determines that all safety installations have to be installed manifold and have to consist of identical independent subsystems. This principle ensures that, even if one safety installation fails, another identical installation provides a back-up system.

Secondly, the *Diversity-principle (Diversitätsprinzip)* requires a range of heterogeneously working systems for each individual safety measure.

Third, the *Segregation-principle (Entmaschung)* postulates that individual safety measures are subject to spatial separation; that they are particularly protected by their construction

technology and that all sub-systems are decoupled. In consequence, even if a safety system is threatened or non-functional due to fire or flooding, this principle helps to avoid the spill over to other installations (DAtF - Deutsches Atomforum e.V, 2013; I.E.A - International Energy Agency, 2013). According to the German Atomic Forum (DAtF - Deutsches Atomforum e.V, 2013), this principle is of utmost importance when comparing German nuclear reactors and the Fukushima-Daiichi reactor, since the latter had neither sufficient constructional protection, nor did the reactor design adhere to the spatial separation of emergency back-up generators from other safety measures. Another important standard is the *Fail-Safe-Principle (Fail-Safe-Prinzip)*, which determines that in particular emergencies, such as the black out of the electricity supply, reactors have to switch autonomously into a safe state. One of the greatest dangers in emergency situations has been the reliance on human decision-making under stressful conditions. To counteract potential incorrect decisions due to stress, all German reactors have to be equipped with automated control and communication systems (DAtF - Deutsches Atomforum e.V, 2013).

According to the *Principle of Automated Control and Communication Systems (Prinzip der Automatisierten Leittechnik)*, safety measures in case of an emergency have to be automated to a degree that no human interaction is needed within the first thirty minutes after a disturbance. Protection systems of German reactors monitor and control most important activities regarding the operation of reactors and have to automatically initiate safety measures when limits are exceeding certain margins (Volkmer, Kernenergie Basiswissen, 2013).

Furthermore, the *Principle of Autarchy (Autarkieprinzip)* implies that, in case of emergency, German reactors have to be able to rely on distinct and appropriate emergency power supply in order to maintain all necessary safety measures for a certain amount of time and without any external power supply (DAtF - Deutsches Atomforum e.V, 2013).

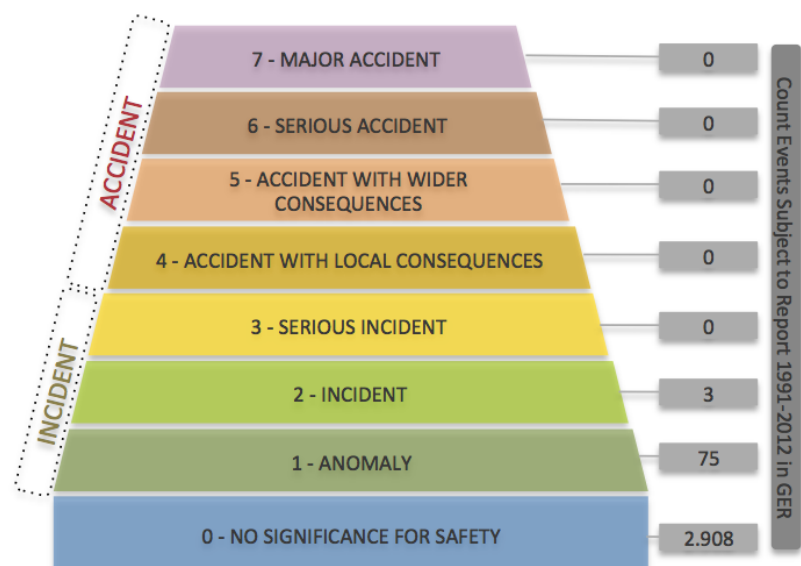
Finally, the *Quality-Control Principle* ascertains that during the planning-, construction- and operation- phases, inspections have to be conducted (BMUB - Federal Ministry for the Environment Nature Conservation, Building and Nuclear Safety, 1998; DAtF - Deutsches Atomforum e.V, 2013).

The fourth security level postulates specific and improbable incidents and comprises safety measures to minimize remaining risks. This comprises precautionary measures and accident

management in order to limit any accident's impact to the reactor. However, the concept of in depth defence acknowledges a certain residual risk of incidents, which is beyond the four security levels. According to the BMUB (1998), the likelihood for such accidents is extremely rare to practically impossible. In case of such major accidents, impacting surrounding areas, the policy framework determines measures for disaster control and civil protection. (BMUB - Federal Ministry for the Environment Nature Conservation, Building and Nuclear Safety, 1998; DAfF - Deutsches Atomforum e.V, 2013)

According to the binding Nuclear Safety Officer and Reporting Ordinance - AtSMV¹⁶ (BfS - Bundesamt für Strahlenschutz, 2013), plant operators are obliged to report incidents to their supervising authorities. Three major categories of reportable incidents are therefore distinguished: Category S (immediate), Category E (urgent) and Category N (normal) (BfS - Bundesamt für Strahlenschutz, 2013). Category N comprises all such incidents where at least one sub-safety system is out of order. Category E on the other hand, includes such cases where only the minimum necessary safety systems are performing. Category S incidents comprise those where less than the necessary minimum number of safety subsystems are operating and such cases have to be reported immediately (DAfF - Deutsches Atomforum e.V, 2013).

In addition, Germany introduced the International Nuclear and Radiological Event Scale (INES) in 1991 (DAfF - Deutsches Atomforum e.V, 2013). This system, designed by the IAEA, represents a voluntary and globally used common framework for reportable incidents and accidents regarding the use, transfer or storage of radioactive matter. According to the IAEA



(2014), the INES framework consists of a scale with eight

Figure 11: INES Framework according to the IAEA (2015, S. 1) and a Count of Germany's Events Subject to Report 1991-2012 according to the German Atomic Forum (2013, p. 27)

¹⁶ AtSMV: Atomrechtliche Sicherheitsbeauftragten- und Meldeverordnung

different levels, depending on an event's impact on: "(1) *people and the environment*, (2) *radiological barriers and control* and (3) *defence in depth* (IAEA - International Atomic Energy Agency, 2015)."

The eight different levels illustrate if there is no significance for safety (0) or if there is an incident (level 1-3) or even an accident (level 4-7) respectively (IAEA - International Atomic Energy Agency, 2014). Figure 11: **INES Framework according to the IAEA (2015, S. 1) and a Count of Germany's Events Subject to Report 1991-2012 according to the German Atomic Forum (2013, p. 27)** on the previous page shows a more detailed differentiation of the levels within the INES framework and the respective number of events that occurred in Germany between 1991 and 2012. During this time, 2.996 events were reported in line with both, the AtSMV and the INES framework (DAtF - Deutsches Atomforum e.V, 2013, p. 27). Out of these, 2.911 were graded to be Category N (normal), 72 Category E (urgent) and only 3 were classified Category S (immediate). Furthermore, the same events were categorized within the INES framework to be either with no significance (2.908), anomalies (75) and incidents (3). In conclusion, there have been no events, which could be classified as serious incidents or even accidents thus far (DAtF - Deutsches Atomforum e.V, 2013, p. 27; IAEA - International Atomic Energy Agency, 2014).

3.3.7. Chernobyl and Fukushima

The accident in unit 4 of the Chernobyl nuclear power plant remains to be known as the most serious accident in the history of peaceful use of nuclear technology (IAEA - International Atomic energy Agency, 2015). A more detailed analysis of the impact of the Chernobyl accident and its contribution to the development of anti-nuclear norms is assessed subsequently.

This chapter will briefly explain the main incidents and technological circumstances and compare it to the German nuclear landscape. On the 25th of April, 1986 the unit 4 RBMK 1000¹⁷ reactor was about to be shut down for inspections. During the shutdown process, the operator decided to conduct tests to ensure that emergency- and after cooling units would be supplied with sufficient electric power during the transition from a blackout of the external main power supply and the start-up of the emergency power aggregates (Kerner, Reinhard, & Weiß, 2011). In theory, the down-running turbo generators were supposed to supply enough

¹⁷ Reactor Bolschoi Moschtschnosti Kanalny 1000

rotational energy to the emergency cooling system until the emergency diesel generator sets would be in operation. However, this test's impact was considered to be limited to the reactor's electro-technical units, without any repercussion on the nuclear technology units (Kerner, Reinhard, & Weiß, 2011; NEA - Nuclear Energy Agency / OECD, 2002). In fact, the operating staff had not been informed sufficiently by the personnel conducting the test. According to an NEA (2002) report, the Personnel's safety and communication culture was inadequate and lacked essential precautionary measures. Furthermore, the authors argue that the RBMK 1000 design "*made the plant potentially unstable and easily susceptible to loss of control in case of operational errors*" (NEA - Nuclear Energy Agency / OECD, 2002, S. 10). Additionally, the team conducting the test ignored a number of operating regulations by avoiding safety devices. After a disturbance in the control system and a drop of the reactor output to approximately one per cent, the operating staff would have had to shut down the reactor immediately (Kerner, Reinhard, & Weiß, 2011). However, it was decided to increase the output to 200 MW of thermal power by extending the control rods. Further, the automatic shutdown signal, which is released by the shutdown of the last turbo generator unit, was actively disabled (Kerner, Reinhard, & Weiß, 2011). At 1:00 a.m., the reactor had been in a severe condition, including an over proportional burn-up of the reactor core, low power output with unfavorable power density and problems with the cooling system and the feeding water. In reaction to these problems, the operating staff violated multiple operating regulations (Kerner, Reinhard, & Weiß, 2011). Nevertheless, the testing team initiated the test. In consequence to the shutdown of the four main circulating pumps, the reactor temperature and its core void content increased significantly. Few minutes after the test was initiated, the reactor was shut down manually but the precedent reactor excursion resulted in a disproportional release of energy in the fuel assemblies and consequently a manifold of the output of the usual nominal capacity (NEA - Nuclear Energy Agency / OECD, 2002; Kerner, Reinhard, & Weiß, 2011). The surrounding graphite could not moderate the increase of energy released and, due to the following rise in pressure, the unit 4 reactor exploded. The reactor was almost completely destroyed and, due to insufficient safety barriers, radioactive matter and radiation were released (NEA - Nuclear Energy Agency / OECD, 2002) (Kerner, Reinhard, & Weiß, 2011).

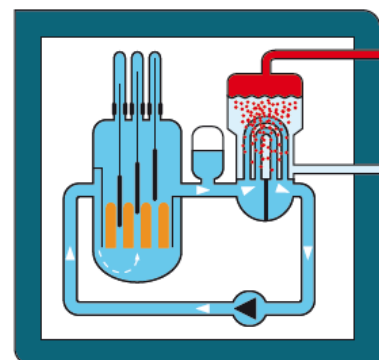


Figure 12: Multi-barrier Principle of German Reactors - Retrieved from DATF - Deutsches Atomforum e.V (2011)

There are a number of reasons why the Chernobyl accident, in the form in which it occurred, could not have happened in a German reactor (DAtF - Deutsches Atomforum e.V, 2011). As explained before, all German nuclear reactors are subject to the concept of multiple barriers to shield the reactor through different layers. This includes, most importantly, a compression proof and gas tight containment layer, which was not part of the RBMK 1000 reactor design (DAtF - Deutsches Atomforum e.V, 2011). In fact an adequate containment may have shielded radioactive matter and radiation from leaking. Second, German reactors are equipped with an automated regulating rods, allowing a interruption of the nuclear chain reaction within few seconds (DAtF - Deutsches Atomforum e.V, 2011). Third, German reactors use water as both a moderator and cooling substance. An increase of vapor lock therefore leads to a lower moderating quality for water, which leads to a efficiency drop and a stop of the nuclear chain reaction (Choppin, Rydeberg, & Liljenzin, 1995; DAtF - Deutsches Atomforum e.V, 2011).

The RBMK 1000 reactor on the other hand used graphite as a moderating substance and water as coolant. This self-energizing combination may lead to an increased vapor lock, which accelerates the nuclear chain reaction (DAtF - Deutsches Atomforum e.V, 2011). Lastly, the fuel assembly is located in one pressure vessel in German BWRs and PWRs, allowing fast emergency cooling. The Chernobyl reactor comprises approximately 3.400 fuel units separated in 1.700 coolant ducts (DAtF - Deutsches Atomforum e.V, 2011). Since the cooling channels were destroyed in the explosion of the reactor, the reactor core could not be flooded by the emergency cooling system. Furthermore,

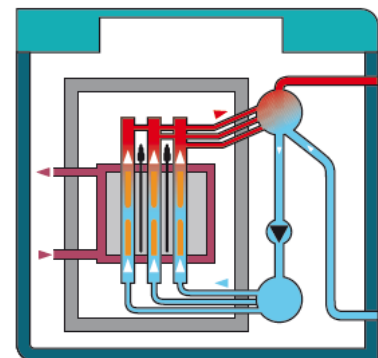


Figure 13: Chernobyl Reactor without Containment – Retrieved from (DAtF - Deutsches Atomforum e.V (2011)

it is important to note the concept of defense in depth, including the safety principles, had not been applied in the Former Soviet Union in this form¹⁸ (DAtF - Deutsches Atomforum e.V, 2011). This may have prohibited the initial test leading to the accident and would have provided thoroughly hierarchized safety measures (DAtF - Deutsches Atomforum e.V, 2011; Volkmer, Kernenergie Basiswissen, 2013).

¹⁸ Duplication-principle, Diversity-principle, Segregation-principle, Fail-Safe-Principle, Principle of Automated Control and Communication Systems, Principle of Autarchy, Quality-Control Principle

3.3.8. The Fukushima Daiichi Accident

Twenty- five years after the Chernobyl accident, Japan was in the spotlight of international attention. A disastrous earthquake, attributed a magnitude of nine in the Richter scale, led to a series of tsunamis¹⁹ with enormous consequences for the Japanese island of Honshu. In fact, the earthquake represents the country's most severe since the beginning of statistical records (DAtF, Deutsches Atomforum e.V, 2015).

In general, three conditions have to be fulfilled for tsunamis to occur. Firstly, the magnitude has to be at least 6,5 on the Richter scale. Secondly, the tectonic plates have to shift both, horizontally and vertically. Third, the seismic focus has to be relatively close to sea level. According to the GRS (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), 2015, pp. 6-7), all three conditions were fulfilled: an earthquake of magnitude of 9 on the Richter scale with a vertical shift of the tectonic plates of more than three meters only twenty-five meters under the seabed. Approximately 18.000 people lost their lives due to this natural disaster; 2.600 people are still reported missing and parts of the island's infrastructure were destroyed²⁰ (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), 2015, p. 3).

The power plant had been commissioned in the late-1960s and was the oldest nuclear reactor assembly operated by the former Tokyo Denryoku, today known as TEPCO²¹. The powerplant comprises six reactor units, ranging from BWR 3 to the BWR 5 series, and all six are equipped with containment vessels²². The unit one reactor was supposed to be shut-down by March 2011, however the supervision authorities extended the authorized life-cycle by ten years only in February 2011 (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), 2015).

In fact, the Fukushima Daiichi power plant, due to its proximity to the sea, has been equipped with protective barriers for tsunamis of 3,1-3,7 meters altitude. TEPCO reassessed this safety barrier concept in the years 2002 and 2008 and considered enhancing the barriers to hold tsunamis of 5,7 meters and up to 15 meters respectively. However, these reinforcement measures were not carried out, since the findings of the assessments were not considered affirmed (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), 2015, p. 7).

¹⁹ Gravitation waves triggered by earthquakes, volcanic eruptions and similar events

²⁰ Status as of September 2013

²¹ TEPCO - Tokyo Electric Power Company

²² BWR 3, BWR 4, BWR 5 refer to the type of BWR design. In Fukushima the reactor types are the following: Unit 1: BWR 3; Units 2,3,4 and 5: BWR 4; Unit 6: BWR 5

Today, there is no evidence that the earthquake had a direct destructive impact of significance on one of the reactors (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), 2015). At the time of the earthquake, 14:46 on the 11th of March, reactors 4-6 were shut down due to maintenance, whereas the reactors 1,2 and 3 were operational. In line with Japanese regulation, all operational reactors were automatically shut-down. However, due to the earthquake, the Fukushima Daiichi power plant was largely cut off from the power grid. In order to maintain the cooling of the fuel element storage and the reactor cooling system (the cooling has to continue after the shutdown due to afterheat), 13 emergency diesel power units were started (DAtF, Deutsches Atomforum e.V, 2015). Forty-three minutes later, at 15:27, the first larger tsunami-waves reached the Fukushima-Daichii plant and flooded parts of it and resulted in first technical failures. At 15:41, the largest gravitational wave, which is estimated to have had a height of approximately 14 metres reached the plant and disabled twelve of the thirteen emergency diesel power units. The protective barriers could not withstand a wave of such magnitude and the rooms containing the aggregates were not sufficiently sealed against floodings. The reactors 1,2,3 and 4 were flooded for several minutes and next to the emergency power units, control units and batteries were also destroyed. According to the German Atomic Forum (2015, p. 5), the power supply for the aftercooling was consequently disabled for the reactors 1,2 and 3 and for the cooling ponds of the reactors 1-4. On the 12th of March, the cooling circuit for reactor 1 was not further supplied with cooling substance, followed by the breakdown of the cooling system of reactor 3 on the 13th of March and reactor 2 on the 14th (DAtF, Deutsches Atomforum e.V, 2015). Safety measures to prevent the failure of the emergency cooling system did not work sufficiently and the fuel element claddings of reactors 1-3 overheated. The containment could not withstand the increase in pressure, which was due to chemical oxidations of the overheated claddings. According to the German Atomic Forum (2015, p. 5), the hydrogen which was newly formed from the oxidation, could leak out of the containment vessels of the reactors 1,2 and 3. Additionally, hydrogen leaking from the vessel of reactor 3 could spread within reactor 4 through a connected construction. On the 12th of March, at 15:36 the reactor 1 building was severely damaged by a hydrogen explosion, followed by explosions in reactor 3 on March 13th and reactor 4 on March 15th (DAtF, Deutsches Atomforum e.V, 2015). Due to a partial meltdown of the nuclear fuel rods and insufficient shielding by the containment vessels, radioactive matter and radiation were released. After different assessments of the events, the Fukushima Daiichi accident was classified as level seven on the INES scale on

April 12th. Three different agencies, namely the Nuclear and Industrial Safety Agency (NISA), the Nuclear Safety Commission (NSC) and the Japan Atomic Energy Agency (JAEA), calculated the amount of radioactive matter release from the Fukushima Daiichi plant. All three institutions concluded iodine equivalent numbers exceeding the value benchmarking level 7 accidents in the INES scale²³. According to the GRS (2015, p. 28), the INES scale considers accidents from 5×10^{16} Becquerel as major accidents (level 7) and the assessment of the NISA stated a value of $3,7 \times 10^{17}$ Becquerel and NSC and JAEA reported an estimation of $6,3 \times 10^{17}$ Becquerel.

Few days after the beginning of the Fukushima-Daiichi events on March 17th 2011, the German Bundestag requested the Federal Government to:

“... conduct a comprehensive review of the safety requirements for the German nuclear power plants. For this purpose, an independent expert commission is to be tasked with carrying out a new risk analysis of all German nuclear power plants and nuclear installations with consideration of the knowledge available about the events in Japan – especially also with respect to the safety of the cooling systems and the external infrastructure-as well as of other extraordinary damage scenarios; ... (RSK - Reactor Safety Commission, 2011, p. 2)”

The German Federal Government, in line with the Land governments of Baden-Württemberg, Bavaria, Hesse, Lower Saxony and Schleswig-Holstein authorized the RSK to conduct an in-depth review of all operational power plants in the country (BMUB - The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2014). On the one hand, tsunamis could be excluded as a threat for German power plants; however, according to Eric Royer (2014) from the French CEA²⁴, other natural catastrophes and man-made hazards could potentially represent a theoretical threat for those power plants located in Germany.

The RSK conducted the safety review and assessed the reactor design in Fukushima Daiichi, attributing it an *“inadequate design of these plants to withstand tsunami impacts”* (RSK - Reactor Safety Commission, 2011, p. 2). Furthermore, the commission stated that *“Obviously, installations and measured (sic) to prevent hydrogen explosions in the buildings (venting,*

²³ The iodine equivalent value helps to summarize the radiological impact of release nuclides

²⁴ CEA - Commissariat à l'énergie atomique et aux énergies alternatives

recombiners, leak tightness of the systems, barriers) were not effective or did not exist (RSK - Reactor Safety Commission, 2011, p. 2). ”

Based on their assessment of the Fukushima-Daiichi events the RSK created the “Catalogue of requirements for plant specific reviews of German nuclear power plants in the light of the events in Fukushima (Japan)” (RSK - Reactor Safety Commission, 2011, p. 2). The conclusions of the assessment were as follows (RSK - Reactor Safety Commission, 2011, p. 13):

“It follows from the insight gained from Fukushima with respect to the design of these plants that regarding the electricity supply and the consideration of external flooding events, a higher level of precaution can be ascertained for German plants.

The RSK has furthermore reviewed the robustness of German plants with respect to other important assessment topics.

The assessment of the nuclear power plants regarding the selected impacts shows that for the topic areas considered, there is no general result for all plants in dependence of type, age of the plant, and generation.

The existing plant-specific design differences according to the current state of licensing were only partially considered by the RSK. Plants that originally had less robust design were backfitted with partly autonomous emergency systems to ensure vital functions. In the robustness assessment performed here, this selectivity leads to evidentially high degrees of robustness.

The RSK has derived first recommendations for further analyses and measures from the results of the plant-specific review.

(...)”

3.3.9. The possibility of Thorium as an alternative

Thorium is a radioactive element similar to Uranium but is nonetheless different on two main accounts. Firstly, thorium is three times as abundant as uranium in the Earth’s crust and occurs as the easily exploitable ‘fertile’ ^{232}Th isotope in many countries (IAEA, 2005). Secondly, unlike natural uranium, which contains approximately 0.7% ‘fissile’ ^{235}U isotope, natural thorium does not contain any fissile material. As such, thorium and thorium-based

fuel in metal, oxide, or carbide forms, is used in combination with ‘fissile’ ^{235}U or ^{239}Pu in nuclear research and power converters for conversion to fissile ^{233}U , consequently enlarging the ‘fissile’ material resources. Thorium, however is not new technology but rather, has accompanied the nuclear age itself (Bryan, 2009). In the early years of developing nuclear technology, from the mid-1950s to the mid-1970s, there was considerable interest in the development of thorium fuels and fuel cycles, especially among countries that sought to integrate thorium fuels into their long-term nuclear program to offset limited uranium deposits. However, this initial enthusiasm waned in the face of discovery of new uranium deposits and their improved availability. Nonetheless, thorium-based fuels have met with renewed interest, according to the IAEA (2005) as a result of “the need for proliferation resistance, longer fuel cycles, higher burn up and improved waste characteristics.”

3.3.9.1. Rationale for Thorium-based fuel cycles

i. Safety

As Bryan (2009) elucidates, thorium fuel builds upon the tradition of Generation III reactors which use *passive safety* features allowing the laws of nature such as gravity and thermodynamics to prevent any possible runaway reactions, leakage, or other accidents by causing the reactors to shut down and removing the need for human intervention. Additionally, ThO_2 has higher thermal conductivity and lower coefficient of thermal expansion compared to UO_2 (IAEA, 2005). This, as Bryan (2009) points out is crucial in mitigating a possible meltdown scenario since thorium fuel does not burn as hotly as uranium allowing it burn longer and more thoroughly.

ii. Security of Supply

Thorium is widely abundant with an average concentration of 10 particles per million (ppm) in the Earth’s crust in many phosphates, silicates, carbonates and oxide minerals—an amount nearly triple that of Uranium and which has not been exploited commercially thus far (IAEA, 2005). The most popular source of thorium is monazite, a mixed thorium rare earth uranium phosphate present in many countries in beach or river sands along with heavy minerals such as ilmenite, rutile, zircon, silliminite, and garnet. Currently, the production of thorium is predominately as a by-product of rare earth extraction from monazite sand; the mining and

extraction of thorium from monazite is easier and significantly different when compared to the extraction of uranium from its ores (IAEA, 2005). Monazite sands can be mined by dredge mining—an environmentally unobtrusive mining technique that does not involve having to go underground and thus the operating and infrastructure costs are less than that of a uranium mining operation.

iii. Increased energy efficiency

In addition its abundance relative to Uranium, ^{232}Th is a better *fertile* material than ^{238}U in thermal reactors— ^{232}Th has three times higher thermal neutron absorption cross-section (7.4 barns) relative to ^{238}U (2.7 barns) (IAEA, 2005). The fissile ^{233}U , the number of neutrons liberated per neutron absorbed is greater than 2.0 over a wide range of thermal neutron spectrum, in contrast to ^{235}U and ^{239}Pu —as such the conversion of ^{232}Th to ^{233}U is relatively more efficient than the conversion of ^{238}U to ^{239}Pu .

iv. Proliferation-resistance of ^{232}Th - ^{233}U

Additionally, one of the reservations regarding nuclear energy is the simultaneous proliferation of nuclear weapon material generated as a by-product of the nuclear fuel cycle. It thus follows that public acceptance of nuclear energy, as a significant contributor of primary energy is largely contingent on a fuel cycle that is highly proliferation-resistant. Accomplishing this goal necessitates both a combination of administrative checks and boundaries, as well as mitigating production of any material in a quantity or quality sufficient enough to be of prospective military use (IAEA, 2005). Therefore, rectifying the fuel cycle itself to avoid residual material that can be used for the generation of nuclear weapons is integral to decoupling the prospective danger of nuclear weapon acquisition from the development of nuclear power. Thorium based fuels and fuel cycles have inherent proliferation resistance due to the formation of ^{232}U through reactions with ^{232}Th , ^{233}Pa and ^{233}U . The half life of ^{232}U is only 73.6 years; in addition, the daughter products also have a short half-life and ^{212}Bi and ^{208}Tl emit strong gamma radiations: 0.7-1.8 MeV and 2.6 MeV respectively. (IAEA 2005) As such, in thorium matrix fuel, instead of plutonium, ^{232}U is formed in the spent fuel; this ensures high proliferation resistance as a result of the high gamma radiation from the daughter products.

v. *Improved waste profile*

The current ‘once-through’ fuel cycle generates spent nuclear fuel contains lethal radioactive material, including nearly 1% plutonium and minor actinides such as curium, americium, and neptunium—all of which can be concentrated to produce nuclear weapons (Bryan, 2009). The waste from the thorium fuel cycle comprised ^{233}U . Bryan (2009) contends that while technology to capitalize on its ability to be reprocessed as a fuel in a closed thorium fuel cycle is not yet available, it is nonetheless difficult to make bomb materials as a result of its natural properties. ^{233}U contains isotopic ^{232}U , the decay of which generates bi products which generate gamma rays significant enough to

“fry electronics in any conceivable bomb-making mechanism, not to mention being fatal for any human being within several meters, making transport of weapons impossible” (Bryan, 2009).

Finally, the gamma rays could be easily detected through satellite surveillance. Bryan (2009) thus concludes that while bomb fabrication from ^{233}U is technically possible, its impracticality renders it close to impossible.

Moreover, as discussed, even though thorium based waste is highly radioactive, the half-lives of ^{233}U and its daughter products are shorter than the half-lives of the aforementioned transuranic waste (TUR) thereby minimizing problems of toxicity and decay heat. (IAEA 2005, pp. 10)

vi. *Elimination of enrichment phases*

Thorium does not require any conversion or enrichment. It occurs naturally as thorium dioxide (ThO_2) with no isotopic content. ThO_2 , which is not fissile, can be transported to the fuel fabrication facility where it can then be used to manufacture pellets, rods, and bundles, after which it is transported to the reactor (Bryan, 2009). Consequently, the infrastructure costs and transport risks that are inherent to uranium are mitigated.

3.4. Storage – the Achilles heel of Nuclear Power?

After nuclear fuel has been spent in the reactor, it is removed from the reactor and brought to a cooling pond. After the fuel has been stored there, it can be either brought to a final repository or be recycled in a fuel reprocessing plant. For part of the radioactive waste, the high active waste, adequate final storage facilities have to be provided. The construction of

storage facilities and processing plants is complex and costly. Germany's electric supply companies have currently set aside reserves of approximately 36 billion Euros (DAtF - Deutsches Atomforum e.V, 2014 (b)). High active waste represents approximately ten per cent of the overall waste in Germany, yet it contains approximately 99% of the radiation. The rest of the waste is classified as low-level radioactive waste and medium-level radioactive waste (DAtF - Deutsches Atomforum e.V, 2014 (b)).

The storage of high active waste has to be completely isolated from the cycle of matter of the biosphere. In Germany, all types of nuclear waste are to be disposed in deep geological formations, surrounded by host rock materials²⁵, to ensure low environmental impacts. The Gorleben central interim storage facility has been examined as a potential final storage facility in Germany. However, the German Federal Government decided in July 2013 to initiate a new site selection process by passing the Site Selection Law (StandAG)²⁶. The Federal Office for Radiation Protection (BfS) is currently in the process, with a high level of public attention and participation to find a suitable location (BfS - Bundesamt für Strahlenschutz, 2015).

²⁵ Such as salt, granite or tuff

²⁶ StandAG: Standortauswahlgesetz

4. Analysis

4.1. Security of Supply

4.1.1. Terminology: Dispatchable and Intermittent Generating Technologies

When discussing security of supply, a distinction must be made between dispatchable and intermittent generation technologies. Dispatchable technologies include most conventional generation technologies such as coal and nuclear which can be controlled by the system operator and be turned on or off “depending on their economic attractiveness at every point in time to supply both electricity and network reliability services” (Joskow, 2011, p. 238). This implies that the dispatchability refers to a given generation technology’s ability to increase or decrease output quickly on demand. Intermittent technologies, on the other hand, include sources such as wind and solar which supply electricity on an intermittent basis meaning that they could be unintentionally unavailable; for example, generation from these technologies could be affected by factors such as “wind speed, wind direction, cloud cover, haze, and other weather characteristics” (Joskow, 2011, p. 238). They can thus not be typically controlled or economically dispatched by system operators based on economic factors, as opposed to dispatchable technologies. Instead, system operators must respond to inherent variability in intermittent generation and utilize dispatchable generators to balance supply and demand continuously (Joskow, 2011, p. 238).

4.1.2. Changes in Base Load Generation

“Base load” refers to a category of demand for electricity encompassing the minimum amount consumed at all times over the year, which in the case of Germany is 35 to 40 GW (Agora Energiewende, 2013). Agora Energiewende (2013) argues that renewables are replacing the role of conventional base load power plants, such as nuclear and coal. The report further contends that by 2022, total load (base, mid and peak load) will be covered by renewables during many hours throughout the year, necessitating the use of fossil-fuel powered plants at times only when there is limited sun or wind. However, these conventional plants must adapt to the fluctuating patterns of wind and solar power and thus operate on a flexible basis.

However, this may be complicated in light of German’s nuclear phase-out and the concomitant goal of reducing carbon emissions. According to the World Nuclear Association

(2015), Germany would need to depend on approximately 25.000 MWe of base-load capacity should it wish to proceed with the nuclear phase-out and simultaneously reduce carbon emissions. One possible scenario is Germany's neighbours such as France, Netherlands, Denmark, Poland, Czech Republic and Switzerland, through increased nuclear capacity especially in France and requisite interconnection, being able to supply the required base-load capacity by 2020; however, this would lead to Germany being dependent on neighbours for electricity (which would be largely nuclear) (World Nuclear Association, 2015). While baseload capacity will have to be replaced as a result of the nuclear phase-out, the quantity of necessary base-load remains unclear (Rolle). Furthermore, from a cost perspective, according to the BCG (2014), part of the € 410 billion investment required in the German power sector will be needed to make conventional power plants more flexible as they shift from being baseload providers to what the BCG report identifies as 'peaker' plants needed only during times of peak demand. Furthermore, as discussed subsequently in the next chapter on Affordability, further integration of renewables would also have to address lower Energy Returned on Investment (EROI), especially when storage options have to be taken into account.

4.1.3. Grid Reliability

4.1.3.1. Generation Adequacy Standard

Germany currently has a surplus of capacity; however, this could be challenged as a result of the nuclear phase-out, especially in Southern Germany. Given bottlenecks in the transmission grid development between the North and the South, Southern Germany is facing resource adequacy issues in the context of the decommissioning of 5 GW of nuclear capacity in 2011 as well as the planned closure of an additional 3,869 MW; this could result in an overall negative balance of approximately 5.717 MW by 2018 (RAP, 2015).

4.1.3.2. Current SAIDI

The System Average Interruption Duration Index (SAIDI) is a measure of the average interruption time per electricity consumer, and is an internationally accepted metric to assess grid reliability. In 2013, Germany's SAIDI value for unplanned interruptions, excluding exceptional events, showed an improvement from 15,91 minutes in 2012 to 15,32 minutes in 2013 (Bundesnetzagentur, 2014).

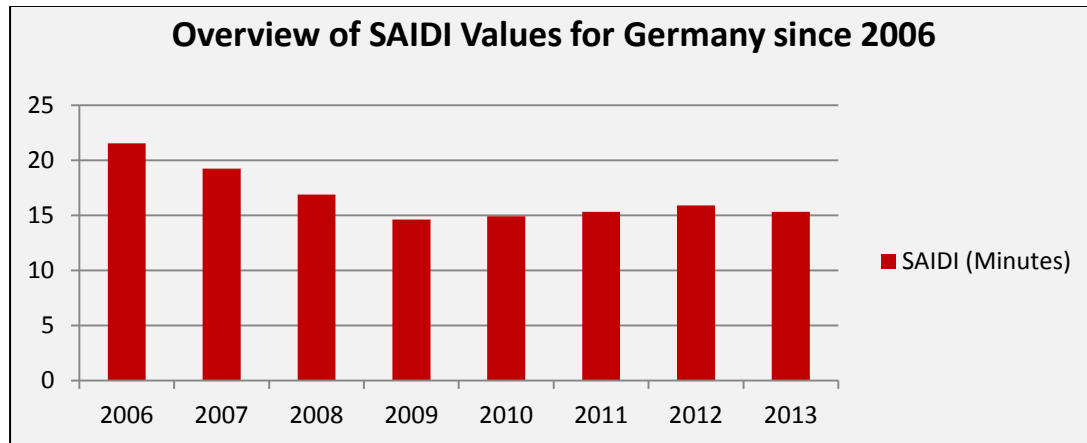


Figure 14: Overview of German SAIDI Values since 2006 (Prepared by authors based on data from the German Bundesnetzagentur)

Furthermore, assessed through SAIDI as a measure of reliability of service, German supply is more reliable compared to most other European countries (Figure 15). In 2012, for example, Germany's SAIDI score was the third best in Europe. Sopher (2015), however claims that even though Germany's commendable SAIDI figures validate the BMWi's assertion that Germany has managed to ensure one of the world's most reliable electricity supplies despite integrating 70 GW of intermittent wind and solar power with an overall share of 25,3% renewables, it does not adequately account for the impact of more renewables on future reliability. As an example of the same, a concern regarding reliability is grid congestion for both Germany and its neighbors due to Germany's increased integration of renewables. As a consequence of insufficient grid infrastructure to handle power production, power is diverted to neighboring countries (such as Czech Republic and Poland) resulting in unscheduled loop flows and consequent reduction in transmission capacity for these countries. According to Czech grid operator CEPS, power grids in these countries are stretched to their thresholds and are vulnerable to potential blackouts when output increases from wind turbines in northern Germany or the Baltic Sea; the Czech Republic for instance, intends on installing security switches near German borders to avoid overload (Bauerova & Andresen, 2012). As such, the importance of lines from the North to the South of Germany is emphasized to mitigate the risk of internal bottlenecks and unscheduled loop flows to neighboring countries.

Additionally, the input of intermittent renewables will also necessitate significant backup capabilities, particularly during winter. In 2012, the Bundesnetzagentur

contracted 2,6MV of reserve capacity, compensating these plants for their preparedness to generate power should the need arise; even so, the ENTSO-E calculated a negative reserve margin of -0.6% reflecting an excess of national demand relative to generation, causing greater reliance on imports (Sopher, 2015).

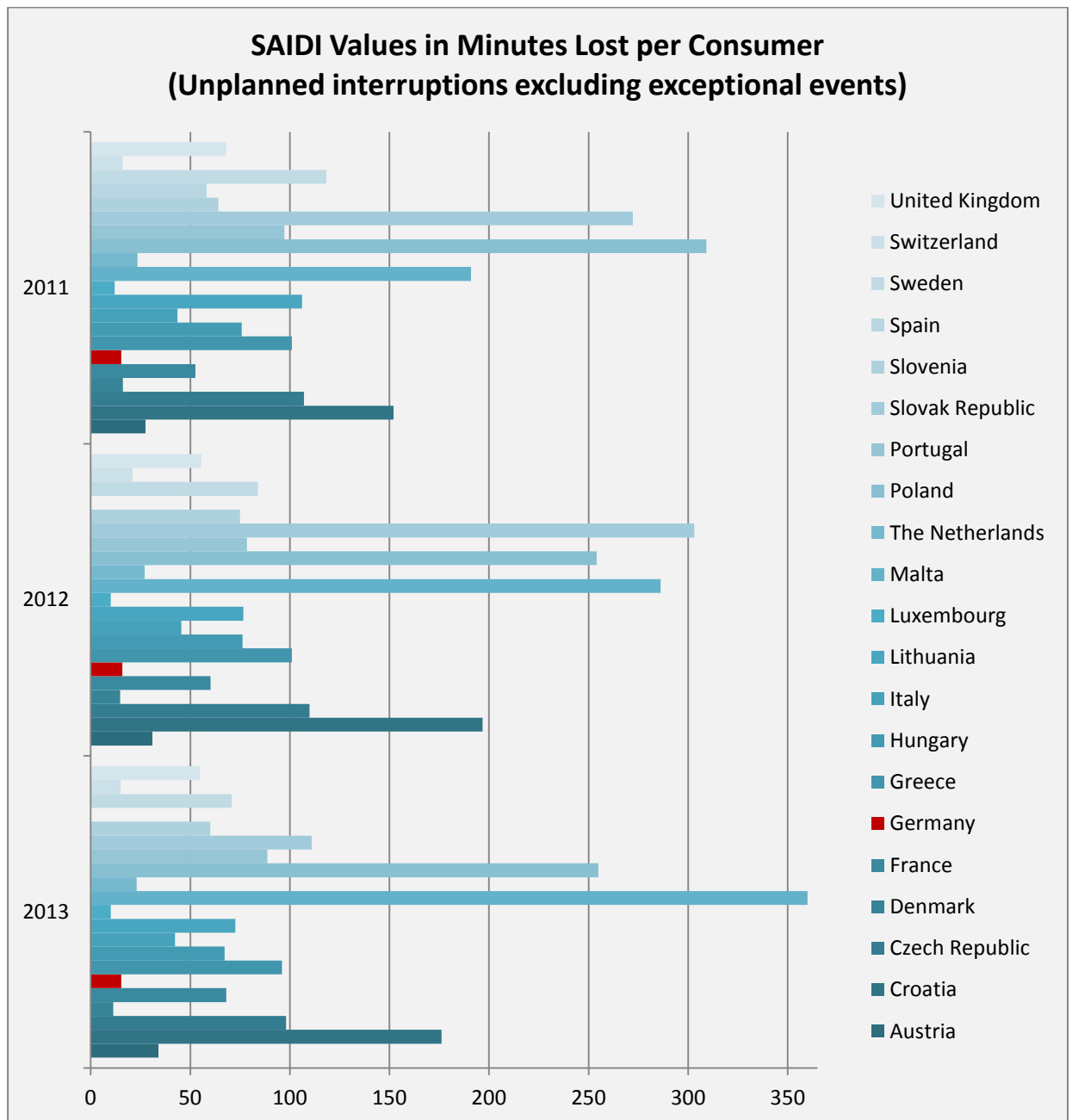


Figure 15: SAIDI Values (unplanned interruptions excluding exceptional events) based on data from CEER (Council of European Energy Regulators, 2015)

4.1.3.3. Smart Metering

A challenge that the Energy Transition must confront is the bi-directional integration of electricity from small and local renewables such as household PV panels. Excesses

should be absorbed into the system but when they fall short, the supply should come from the grid. As such, this sensitivity to the grid will necessitate modernization in the form of smart grids and smart meters to synchronize supply and demand (BMW_i). As of 2013, approximately 500,000 smart meters have been installed in Germany, but subsequent installation could face the following challenges according to RAP (2015):

- i) Meters that comply with new security standards have not been developed yet
- ii) Recommendations from a study by Ernst & Young (E&Y), commissioned by the BMW_i have not been integrated into a national level roll out plan. Among the recommendations, E&Y suggests that while smart meters are cost effective for new buildings or those undergoing a major renovation (defined by Directive 2010/31/EC on the Energy Performance of Buildings) and for final consumers with an annual consumption exceeding 6,000 kWh, small consumers should use *intelligent meters* instead within the normal replacement cycle for meters. Unlike smart meters, intelligent meters show end consumers their actual energy usage but do not communicate said information to utilities.
- iii) Finally, German law permits third parties (companies independent of Distribution Service Operators) to serve as metering operators and service providers, as long as the devices installed are compliant with regulatory standards.

4.1.4. Grid Extension

Gawel et al. (2014) advocate further development of grids and storage as complementary components of energy infrastructure to adapt to new needs of a more sustainable energy supply in the future. In doing so, the reserve capacity required in addition to the renewable capacity will be reduced, and the utilization of feature-dependent renewables such as solar and wind will increase. The authors propose that improved coordination between the expansion of generation and network infrastructure will facilitate this.

This belief by Gawel et al. (2014) is echoed in findings of The Boston Consulting Group (BCG). In their report, “Germany’s *Energiewende* – The End of Power Market Liberalization?” they consider grid extension as possibly the biggest obstacle for Germany’s energy transition, especially as it approaches its deadline for nuclear withdrawal by 2022. The BCG Report underpins this in the need to transmit wind generated power from Germany’s North to its industrial South as well as for the local integration of solar and wind

power. Projections by German transmission-system operators indicate that this would need an



Figure 16: Germany's new grids (Source: Reuters, 2015. Retrieved from: link.reuters.com/veg84w)

estimated 3500 km of new construction in new corridors as well as the enhancement of approximately 5000 km of transmission along existing routes (Gerbert, Rubner, Herhold, & Steffen, 2014). However, the Report claims that progress on grid extension lags behind with only 15% of planned projects having been completed by 2013 and the delaying of commissioning dates of 40% of reported projects, in spite of legislation to expedite planning and permission procedures, largely as a result of local resistance (Gerbert, Rubner, Herhold, & Steffen, 2014).

Four pieces of legislation exist which collectively form the basis for the coordinated, accelerated and transparent expansion of the grid (BMWi):

- i) *Energy Industry Act (EnWG)*: Ensures transparent and coordinated annual grid expansion planning for the German high voltage grid determined through a multi-stage process
- ii) *Grid Expansion Acceleration Act (NABEG)*: Seeks to ease the planning of grid expansion projects which involve many federal states or cross national borders— power line routes are centrally planned and approved by the Federal Network Agency after securing early public participation. Additionally, the Federal Network Agency has the onus of defining the specific route of the power lines. The shift of the planning responsibility from the state to federal level simplifies the process and overcomes fragmentation of responsibilities.
- iii) *Federal Requirement Plan Act (BBPlG)*: Identifies the priority expansion projects basis the Grid Development Plan and the Offshore Grid Development Plan

- iv) *Power Grid Expansion Act (EnLAG)*: in addition to the Federal Requirement Plan, lists other priority projects which are solely within the responsibility of the federal states

Additionally, concerns also exist regarding the vulnerability of large interconnected grids to solar flares²⁷. Predictions by NASA forecast that a future solar maximum could result in highly energetic solar flares and coronal mass ejecta; this in turn could cause significant damage to the power grid (Mills).

4.1.5. Developing Wind Energy

Another aspect of the integration of renewables is the development of both on- and offshore wind energy to reduce Germany's dependence on nuclear and fossil fuel power. Currently, wind power accounts for 8% of German power supply and the Federal Government intends to increase expansion of appropriate rural locations, replace older turbines with modern and more powerful turbines (repowering), and gradually expand wind power at sea called offshore wind power in the North and Baltic Seas (BMW_i). Gross (2011) however contends that offshore wind farms are also susceptible to delays because of protests, much like grid expansion; sunbathers at beaches in the North Sea and the Baltic do not wish to be inconvenienced by turbines which resultantly, have to be built at a minimum distance of 30 km from the shore.

Stegen and Seel (2013) contend that while wind firms are optimistic about the potential of new turbines and repowering, the same did not extend to offshore wind development. They are critical of the feasibility of the German government's target of achieving 10.000 MW offshore capacity by 2020 and 30.000 MW by 2030—attributed to higher costs for offshore wind farms and delayed grid expansion. Nonetheless, challenges exist for both onshore and offshore wind development.

For onshore development, they posit that the growth and expansion of onshore wind has resulted in prime locations, such as along the coasts of the North and Baltic Seas already being predominantly utilized. The next best alternatives are suboptimal and the extent to which they can be made more attractive using technological developments is debatable.

²⁷ The last solar storm occurred in 1859 when the sun experienced a high increase in sun spot activity and a sequence of intense solar flares; resultantly, a coronal mass ejection reached the Earth's atmosphere only 18 hours after the ejection (Mills).

However, even when new sites are found, they need to address public opposition, in the form of NIMBY-ism arising from health concerns, property value consequences, and aesthetic objections (Stegen & Seel, 2013). Resultantly, Germany also has strict regulations regarding the location and height of turbines to mitigate disturbances such as shadow flickering and acoustic emissions to the public around wind farms—these regulations are viewed as varying degrees of being restrictive by wind firms.

For offshore wind development, should Germany wish to reach its desired offshore capacity of 10,000 MW by 2020, Stegen and Seel (2013) estimate that it will have to erect approximately 1950 new 5 MW turbines or 1400 new 7 MW turbines over the next 7 years. However, given that Germany had only erected 68 turbines by the end of 2012 with few more not connected to the grid, offshore wind development will have to be expedited but it faces the following problems (Stegen & Seel, 2013). In addition to delayed grid integration, offshore wind farms are placed farther offshore than other countries; for example, German turbines must be situated approximately 40 km from the coastline, 17 km more than the European average (Stegen & Seel, 2013). Consequently, as a result of being farther into the sea, the turbines are more vulnerable to rougher weather. Secondly, offshore development is impeded by financing uncertainty due to low rate of return and the reluctance of banks to provide financing unless a grid connection exists.

4.1.6. Storage Capacities

As mentioned, Germany aims to accomplish a high share of renewables in its electricity mix: 50% by 2030 and at least 80% by 2050. At the same time, power generation facilities will have to be accordingly expanded to account for weather-related, diurnal, and seasonal fluctuations especially for wind energy and photo-voltaics (Schill, Diekmann, & Zerrahn, 2015). The German Energy Transition thus necessitates increasing flexibility in the electricity system to balance out electricity supply and demand. In addition to different generation, demand, and network based flexibility options, power storage could help in imparting this flexibility through different fields of application.

However, the nature of future power storage requirements is contingent on context. Assuming that other generation or demand based options can be at least partially developed, the expansion of power storage will not be an obstacle for the Energy Transition in the short to medium term (Schill, Diekmann, & Zerrahn, 2015). The underlying implication then is that

greater expansion of electricity generation from fluctuating renewables should be able to proceed without a significant increase in power storage, at least in the short term.

However, in the long term, the storage requirements could be different depending on different uncertainties. For example, an analysis by DIW Berlin takes into account the arbitrage value of storage as well as its contribution to providing control reserves and firm generation capacity (Schill, Diekmann, & Zerrahn, 2015). The study concludes that power storage requirements could increase significantly with concomitant high shares of renewables. Additionally, storage requirements would increase continually if, for instance, relatively even generation from offshore wind turbines or demand flexibility was not adequately developed. Furthermore, support for power storage could be useful in protecting the energy transition given the possibly additional storage required as a result of uncertainties regarding the development of demand or generation based flexibility options such as flexible power generation from natural gas or biomass. Moreover, given the German government's ambitious targets for climate and energy policy, a high share of renewables might have to be integrated sooner than expected thereby requiring investments in storage earlier than anticipated in current model calculations.

At the same time, however, despite the importance of storage and imports in enhancing reliability, fossil fuels remain a vital source of backup power to ensure grid reliability, both in the long and short run. However, Sopher (2015) claims that the increased influx of intermittent renewables is hurting these fossil fuel generators in three ways:

- i) These plants are tapped with a frequency lower than that of previous years
- ii) Lower wholesale prices as a consequence of increased renewables (with lower operating costs) also impede firm capacity providers from staying active
- iii) Market outcomes are becoming difficult to predict due to a combination of greater intermittency on the supply side and higher demand participation, energy efficiency, and macroeconomic impacts on demand.

4.3. Affordability

4.3.1. LCOE

One way to measure the costs of electricity generation is what is referred to as the LCOE, the Levelized Cost of Electricity. The LCOE concept allows the inclusion of physical and technological characteristics of different electricity generation sources. This unit-based comparison enables a broad evaluation of the competitiveness of different electricity generation technologies by attributing them different costs per kilowatt-hour over the estimated life cycle a plant (U.S Energy Information Administration, 2014). According to Narbel, Hansen and Lien (2013), a breakdown of the LCOE formula is recommended in order to examine the different physical and economic characteristics of generation technologies. Furthermore, this approach allows comparison of power plants with different cost structures; e.g. the comparison of fuel intense power plants with capital intensive technologies or dispatchable conventional power plants with variable renewable sources (Ueckerdt, Hirth, Luderer, & Edenhofer, 2012). Therefore, Narbel, Hansen and Lien (2013) propose a subdivided assessment of initial investments, operation and maintenance and fuel consumption. This approach allows a comparison of the distinct costs and may subsequently be accumulated to calculate the LCOE. There are different calculation methods for the LCOE; as such, it is important to note that the following examination is entirely based on an approach according to Narbel, Hansen and Lien (2013).

First, the *capital costs*, representing the initial investments are to be determined. Therefore, the cost c_p is multiplied by the so-called recovery factor R and further divided by the product of assessed time period H and the capacity factor f . In fact, the capacity factor is crucial to convert c_p , which is usually expressed as monetary units per installed capacity (monetary unit/MW), to a comparable unit cost (monetary unit/MWh). The capacity factor represents the quotient of the actual power generated and the maximum the power plant could theoretically generate within the same period H . This factor is very different for various electricity generation sources and may, depending on different geographical and technical aspects, range between 9% up to 95%²⁸ (Salvatore, 2014). Additionally, the life cycle of power plants can vary significantly. Therefore, the LCOE contains the capital recovery rate

²⁸ 9% for a low estimation of Solar PV thin film technology up to 95% according to Bloomberg New Energy Finance (Salvatore, 2014)

R ²⁹. In order to calculate the capital recovery factor, it is important to find an accurate estimation for both, the economic plant life cycle T and the discount rate r (Narbel, Hansen, & Lien, 2013).

Furthermore, operation and maintenance cost c_o represent all fixed costs. All those costs, even-though they may be very different by nature of origin, are summed up and divided by the product of the time period H and the capacity factor f . In addition, the result of this term will be multiplied by the levelization factor³⁰ l to factor in the discount rate, plant life cycle T and the escalation rate e .

The last term represents all costs connected to the consumption of fuel and variable operation and maintenance costs³¹. The fuel costs c_f are, as the operation and maintenance cost c_o before, multiplied by the levelization factor l and divided by the product of the time period H and the capacity factor f . This part of the LCOE equation can be of particular interest when evaluating different technologies regarding their dependence of fuel supply and their price volatility.

$$\text{Capital costs} \left[\frac{R * c_p}{H * f} \right] + \text{O\&M Costs} \left[l * \left(\frac{c_o}{H * f} \right) \right] + \text{Fuel costs} \left[l * \left(\frac{c_f}{H * f} \right) \right] = C_{LCOE}$$

As mentioned before, this separate breakdown can be very useful to detect more precise origins of the different technologies' costs, and on the other hand to benchmark different technologies based on a more holistic evaluation (Narbel, Hansen, & Lien, 2013). It is of utmost importance to note that the LCOE highly depends on the accuracy of the data and estimates used for the different parameters. Figure 17: Estimated Levelized Cost (EUR/MWh) for Electricity Generation Technologies Entering Service by 2019 (Based on E.I.A Data for the US) shows an overview of the most common electricity generation technologies, including a distinct breakdown of the *levelized capital cost* (*levelised c_p*), the *levelized fixed operation and maintenance cost* (*levelised c_o*) and the *levelized fuel and variable operation and maintenance cost* (*levelised c_f*). In order to compare technologies at a similar state of technology, this graph contains data based on the 2012 LCoE estimates of

²⁹ $R = \frac{r * (1+r)^T}{(1+r)^T - 1}$

³⁰ $l = \frac{r * (1+r)^T}{(1+r)^T - 1} * \frac{(1+e)}{(r-e)} * \left[1 - \left(\frac{1+e}{1+r} \right)^T \right]$

³¹ Narbel, Hansen and Lien included variable costs connected to operation and maintenance in the operation and maintenance cost c_o and not as part of the fuel costs c_f .

the U.S Energy Information Administration (2014), assuming this would be the technological stage of development of the different power plants potentially entering service by the year 2019³². The generation technologies, and the assumed capacity factors f , included are:

Table 2: Capacity Factors Benchmark According to the U.S Energy Information Administration (2014, p.6)

Plant Type	f (%)	Abbreviation
<i>Dispatchable Technologies</i>		
Conventional Coal	85	Conventional Coal
Integrated Coal-Gasification Combined Cycle	85	IGCC
Integrated Coal-Gasification Combined Cycle with Carbon Capture and Storage	85	IGCC with CCS
Natural Gas Fired Conventional Combined Cycle	87	NG-Conv. combined Cycle
Natural Gas Fired Advanced Combined Cycle	87	NG-Adv. Combined Cycle
Natural Gas Fired Advanced Combined Cycle with Carbon Capture and Storage	87	NG-Adv. CC with CCS
Natural Gas Fired Conventional Combustion Turbine	30	NG-Conv. Combustion Turbine
Natural Gas Fired Combustion Turbine	30	NG-Adv. Combustion Turbine
Advanced Nuclear	90	Advanced Nuclear
Geothermal	92	Geothermal
Biomass	39,5	Biomass
<i>Limited Dispatchability</i>		
Hydroelectric	53	Hydroelectric
<i>Non-Dispatchable Technologies</i>		
Wind – Onshore	35	Wind – Onshore
Wind – Offshore	37	Wind – Offshore
Solar PV	25	Solar PV
Solar Thermal	20	Solar Thermal

³² The data is based on the average LCOE numbers in the United States of America for the year 2012 and converted from USD to EUR at a rate of: 1USD=0,8789EUR (07.05.2105).

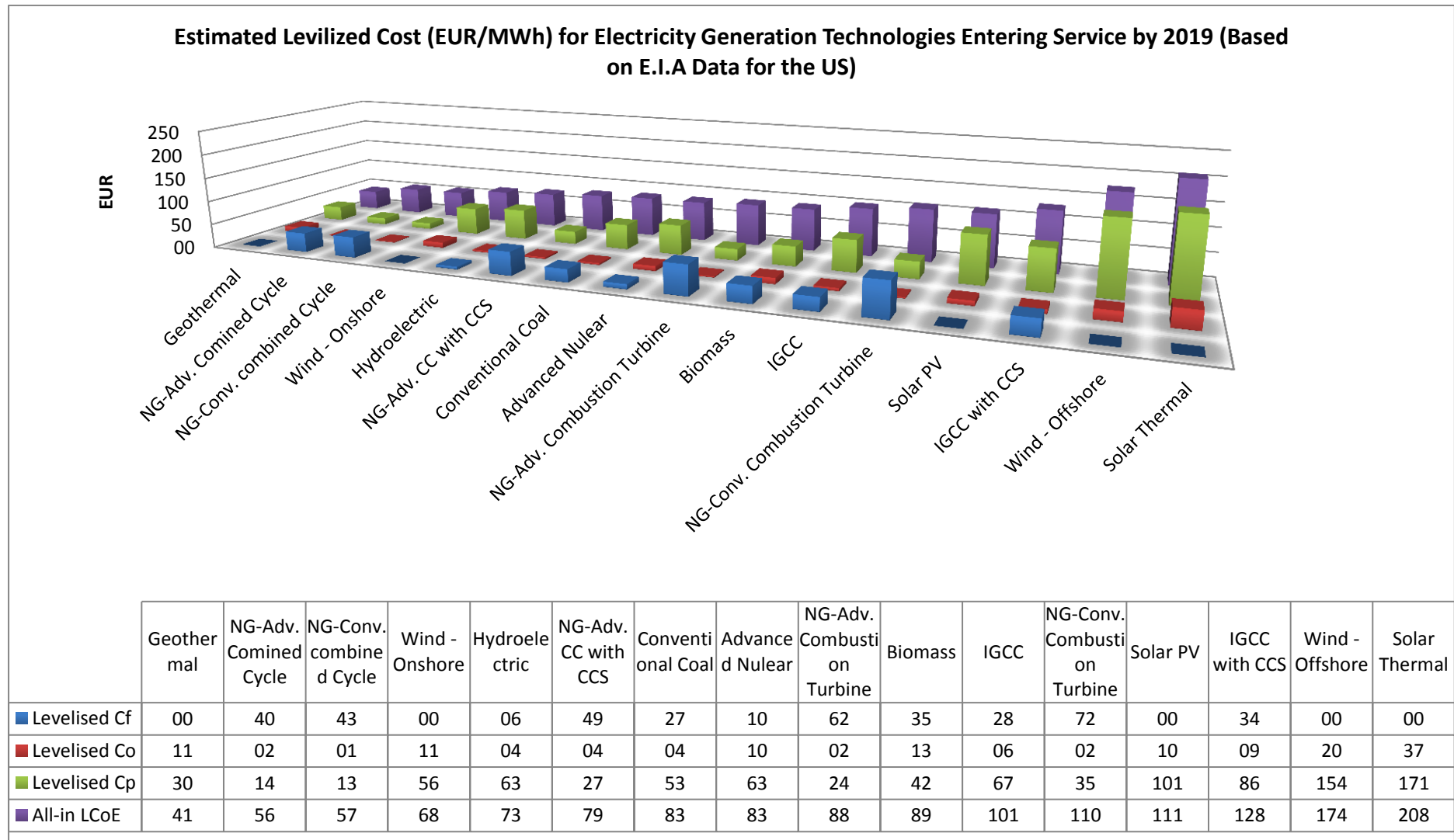


Figure 17: Estimated Levelized Cost (EUR/MWh) for Electricity Generation Technologies Entering Service by 2019 (Based on E.I.A Data for the US)

4.3.2. System LCOE and the issues of variability, uncertainty and location specificity

On the one hand, the LCoE concept represents an advantageous metric to benchmark different technologies by their economic competitiveness and on the other, the concept is highly sensitive to the accuracy of the assumptions used and contains severe deficits regarding other physical parameters. Thus, the LCoE metric misses to examine a large number of indirect costs of electricity generation (Ueckerdt, Hirth, Luderer, & Edenhofer, 2012). Therefore, it seems crucial to consider the concept more as one element for benchmarking, rather than a holistic and complete evaluation technique. First and foremost, the LCoE of one generation technology may vary significantly within different geographies and time periods, or may depend on the actual installed capacity of a power plant and its certain construction and operation technology. In fact, even within one country, the numbers may differ remarkably. Market and technology risks may influence the price of fuel or labor, and geographical differences or seasonal changes can directly impact on the capacity factor f (Narbel, Hansen, & Lien, 2013).

Figure 18: Minimum-, Average- and Maximum LCoE in the US based on Data from the E.I.A (U.S Energy Information Administration, 2014) illustrates the wide spectrum of LCoEs per electricity generation technology within the United States of America, showing the minimum LCoE, the average value and the maximum (U.S Energy Information Administration, 2014).

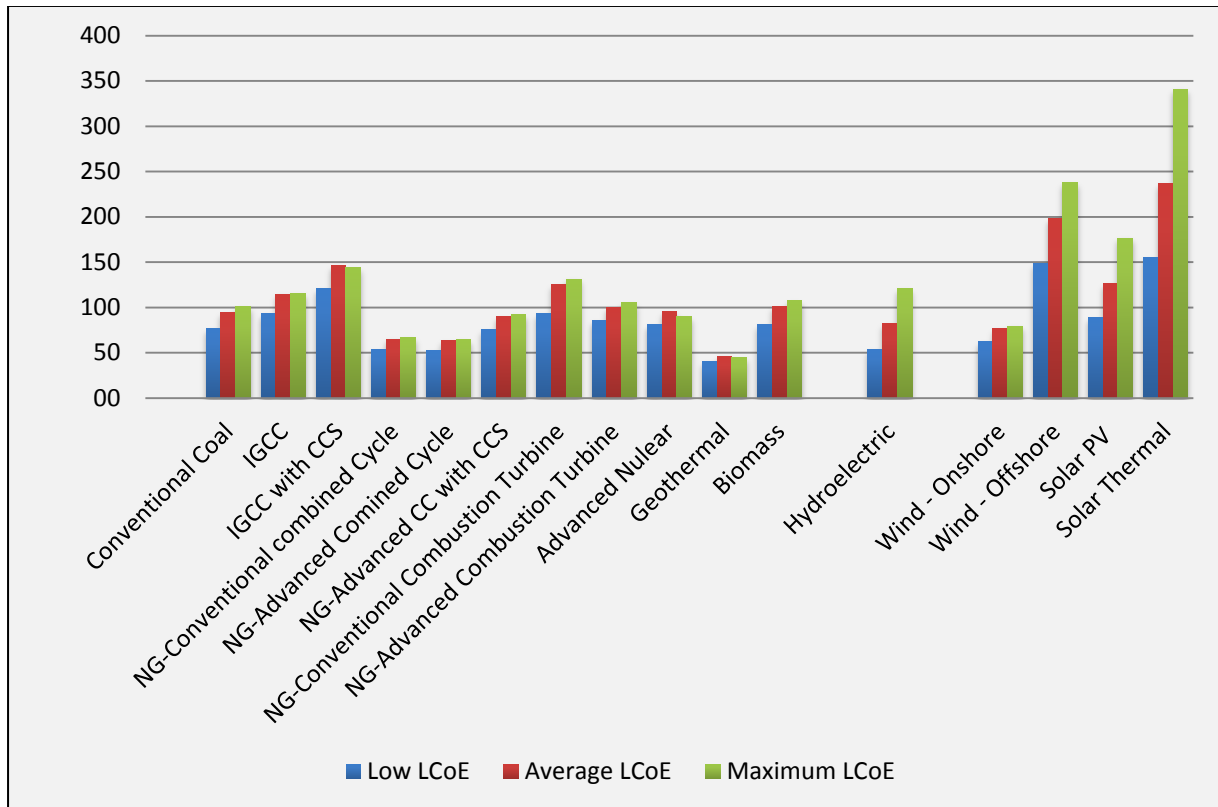


Figure 18: Minimum-, Average- and Maximum LCoE in the US based on Data from the E.I.A.³³ (U.S Energy Information Administration, 2014)

Furthermore, the LCoE metric does not contain parameters accounting for some important physical constraints of electricity generation and transmission, such as dispatchability or intermittency, nor does it include costs regarding the integration of power plants to the grid, in particular on a system level. As a consequence, the overall LCoE may draw a favorable picture for some technologies. Paul L. Joskow (2011) from the MIT Centre for Energy and Environmental Policy Research (CEEPR) argues that especially the LCoE comparison of intermittent and dispatchable electricity sources may lead to a biased metric regarding economic competitiveness. The author argues that this metric “is flawed because it effectively treats all electricity generated as a homogeneous product governed by the law of one price” (Joskow, 2011, S. 239). In fact, electricity demand and supply are often very volatile and electricity prices often vary significantly from hour to hour and season to season. The output profile of dispatchable conventional sources and variable renewable plants differs by nature. While dispatchable sources’ output is projectable, variable generating technologies’

³³ The data is based on the minimum, average and maximum LCOE numbers in the United States of America for the year 2012 and converted from USD to EUR at a rate of: 1USD=0,8789EUR (07.05.2105).

output is often difficult to foresee. Joskow (2011) argues that variable renewable plants are extremely sensitive to their location and weather conditions, i.e. the output profile of a solar power plant will highly correlate with the sun-hours and a wind-power plant will only generate electricity under the right wind conditions. Therefore, the output profiles of dispatchable sources and variable sources, and in consequence also their associated market value at the wholesale market, are difficult to compare. Thus, even-though a variable electricity source and a dispatchable electricity source may have a similar LCoE, their net economic value and profitability can vary significantly (Joskow, 2011). In consequence, Ueckerdt, Hirth, Luderer and Edenhofer (2012) of the Potsdam-Institute for Climate Impact research, state that the competitiveness of variably generating power plants' is only given when their market value, representing the marginal economic value³⁴, is equal or higher than their LCoE value. Further, the authors argue, these constraints of the LCoE analysis increase with the growing relative share of variable power plants in the electricity mix. In order to account for an increase of integration cost, they propose the concept of a so-called System-LCoE (*sLCoE*). According to Ueckerdt, Hirth, Luderer, & Edenhofer (2012), this concept allows benchmarking of different technologies not only by their generation costs, but also includes the indirect cost of integrating power plants to the grid system. The following models are largely based on the work of Ueckerdt, Hirth, Luderer and Edenhofer (2012)

$$sLCoE = LCoE + \Delta \textit{Integration}$$

$$\text{Where: } \Delta = \frac{d}{dE_v} * C_{int.}$$

Ueckerdt, Hirth, Luderer and Edenhofer argue that the marginal integration cost Δ can be seen as the increase of overall system integration costs $C_{int.}$ when variable electricity generation sources are marginally added E_v . As a result, the authors recommend, even though they acknowledge that there is no broadly accepted quantitative framework to measure integration cost, to include all such costs, which are indirect and linked to grid augmentation, storage and back-up facilities, balancing and even the requirements for higher flexibility of non-intermittent sources. (Ueckerdt, Hirth, Luderer, & Edenhofer, 2012, pp. 3-11).

³⁴ Assuming efficient and perfect market conditions.

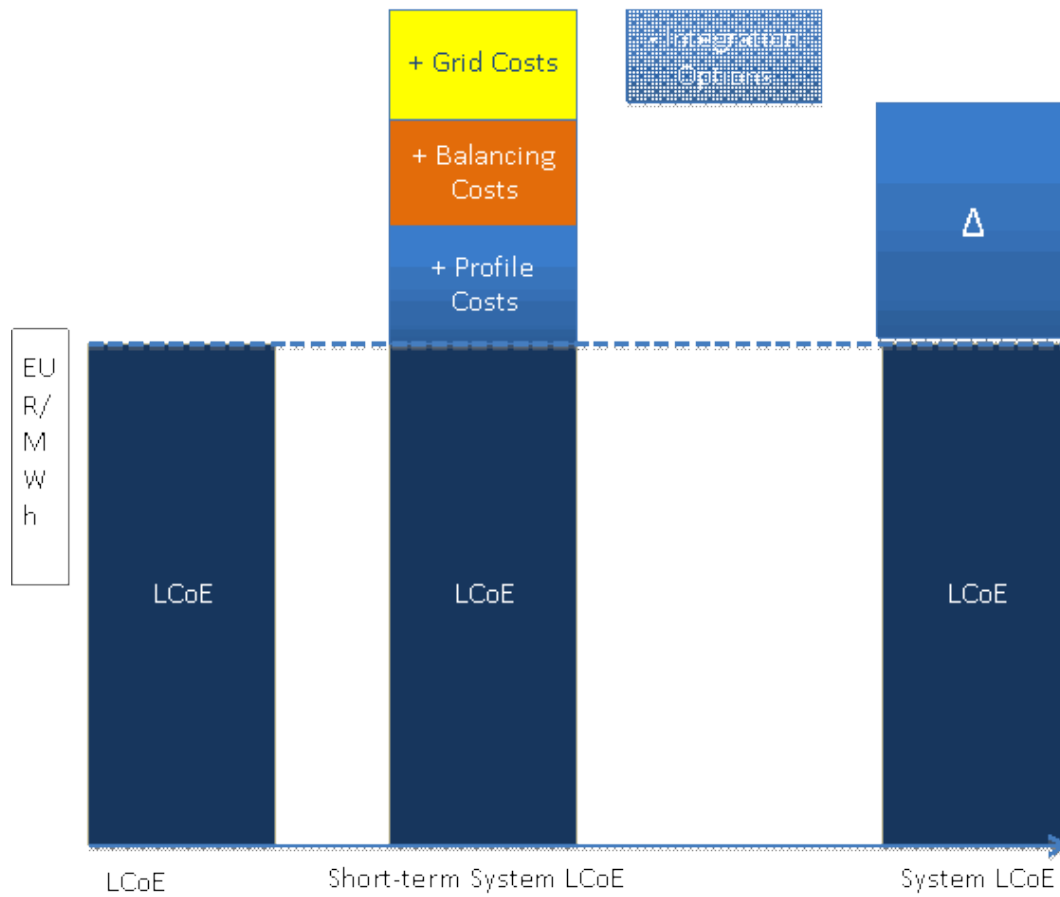


Figure 19: LCoE, System LCoE and the Drivers of Integration Costs; Graph Based on Ueckerdt, Hirth, Luderer, & Edenhofer (2012)

Figure 19 shows that integration cost can be subdivided into three parts: profile cost, balancing cost and grid cost. According to Lion Hirth (2012), these three components arise from three properties of electricity generation, namely: variability, uncertainty and location specificity. Whereas grid related costs may occur for any kind of power plants, profile costs and balancing costs are increasingly and particularly an issue when integrating variable renewable power plants, such as wind- and solar PV plants. However, it is important to note, that variability is not an exclusive occurrence of variable renewable electricity generation. In fact, even in a power system with solely conventional dispatchable sources, fluctuations in demand and supply would have to be managed (I.E.A - International Energy Agency, 2011). Profile costs are caused by the issue of variability - thus, integrating a higher share of variable renewable sources requires additional back-up infrastructure and potentially infrastructure for overload management. Furthermore, a higher share of variable sources may result in higher flexibility requirements for dispatchable power plants, and therefore decrease their full load

hours due to longer ramp-up/down periods (Hirth, 2012; Ueckerdt, Hirth, Luderer, & Edenhofer, 2012).

*Full load hour decrease + Back up capacity + Overprod. Mngmt = Profile costs*³⁵

Uncertainty, on the other hand, requires balancing services to react quickly to unforeseen intra-day changes of supply. Advanced forecasting tools, modern market design and limited use of curtailment measures can help to reduce such costs. However, since wind, sun-hours or tidal conditions are not perfectly predictable, intra-day balancing due to uncertain resource supply will remain an economic disadvantage of variable renewable electricity generation. According to Narbel, Hansen and Lien (2013), such costs may account for 0,7 Eurocent/kWh up to 4,7 Eurocent/kWh³⁶. Figure 20, for example, shows a comparison of Germany with Europe (EWIS) and I.E.A member countries.

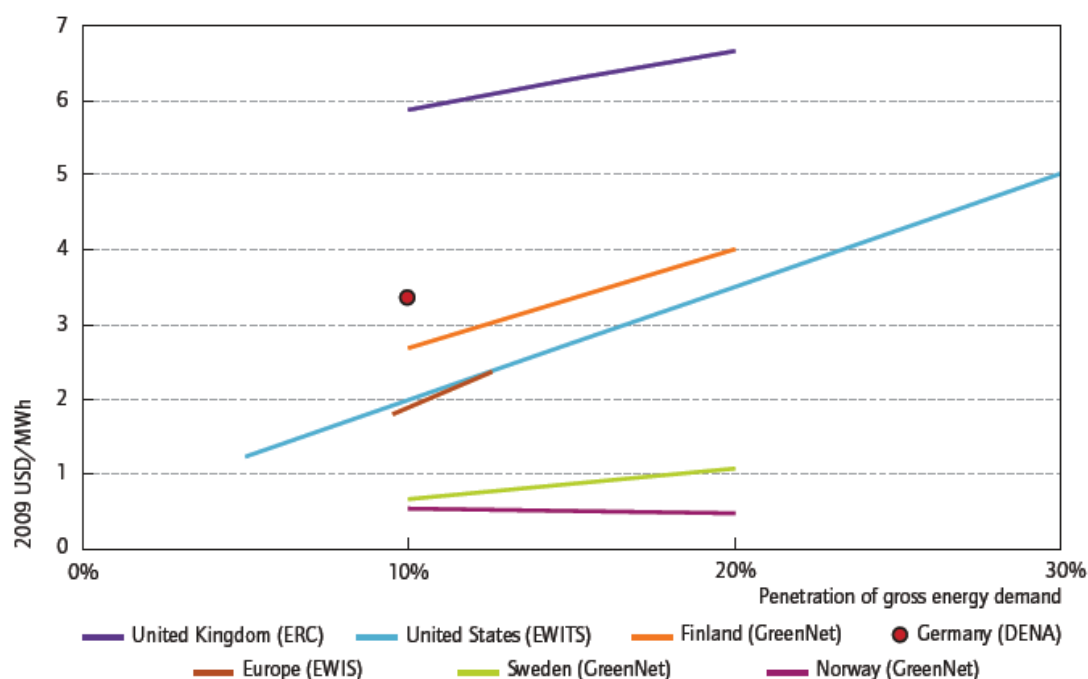


Figure 20: I.E.A Estimations for Wind Balancing Costs 2009; (Retrieved from I.E.A - International Energy Agency (2011, p. 85); I.E.A - International Energy Agency, 2009).

The third cost component of the integration costs is grid-connected expenses. These occur whenever a power plant is integrated into the grid and include transmission investments, and supporting infrastructure, e.g. for congestion services or increase of dispatchable power

³⁵ Ueckerdt, Hirth, Luderer and Edenhofer added the *flexibility effect* as a fourth cost component to the profile costs. For further information, please see (Nicolosi, 2012)

³⁶ 2008 Euro – 1\$/MWh-7\$/MWh

plants due to balancing requirements. Transmission investments usually represent the largest bulk of grid related costs and, as mentioned before, incur whenever power plant is connected to the grid. These costs depend on the location and the distance to the grid; therefore they can vary significantly from case to case. Furthermore, there may be additional grid expenses, when the grid design has to be changed or additional international transmission investments, import and export have to be undertaken to secure, due to the additionally integrated power plants (U.S Energy Information Administration, 2014). However, the focus in this section will be on the more direct nature of transmission cost, those investments required to directly connect the power plant to the grid. Figure 21: **Transmission Cost in EUR in the US per Technology (U.S Energy Information Administration, 2014)** shows the different average for transmission cost within the United States³⁷ (U.S Energy Information Administration, 2014). The green columns represent the estimates for variable renewable sources, the blue columns dispatchable technology and hydroelectric generation is considered to be partly dispatchable (U.S Energy Information Administration, 2014).

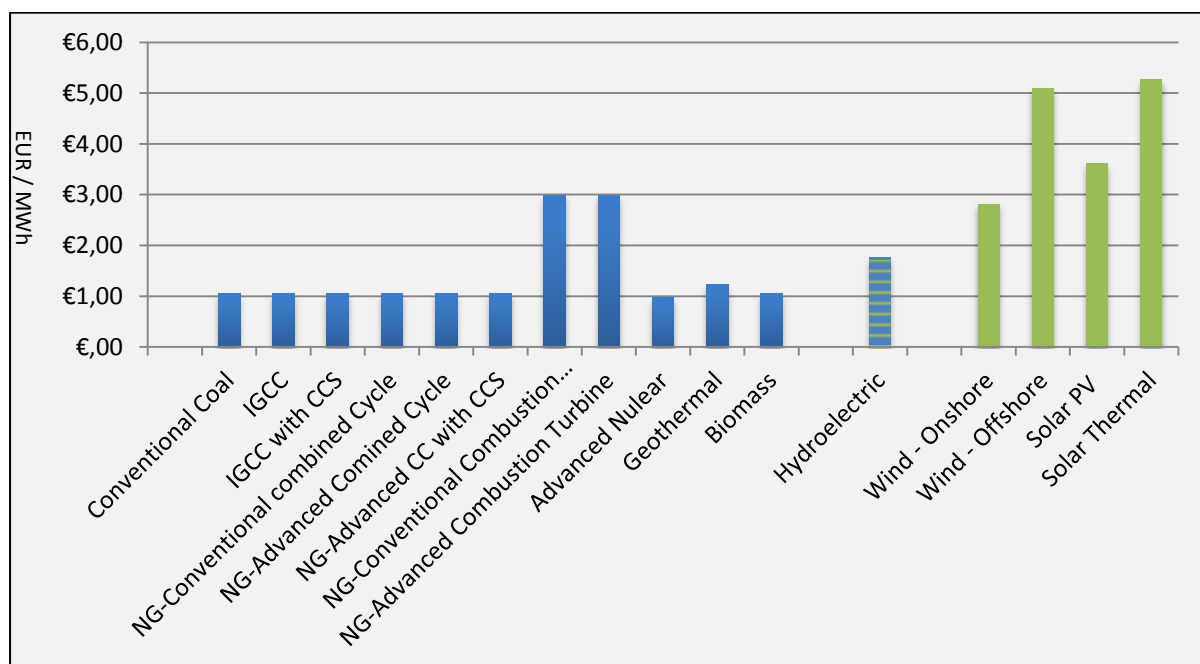
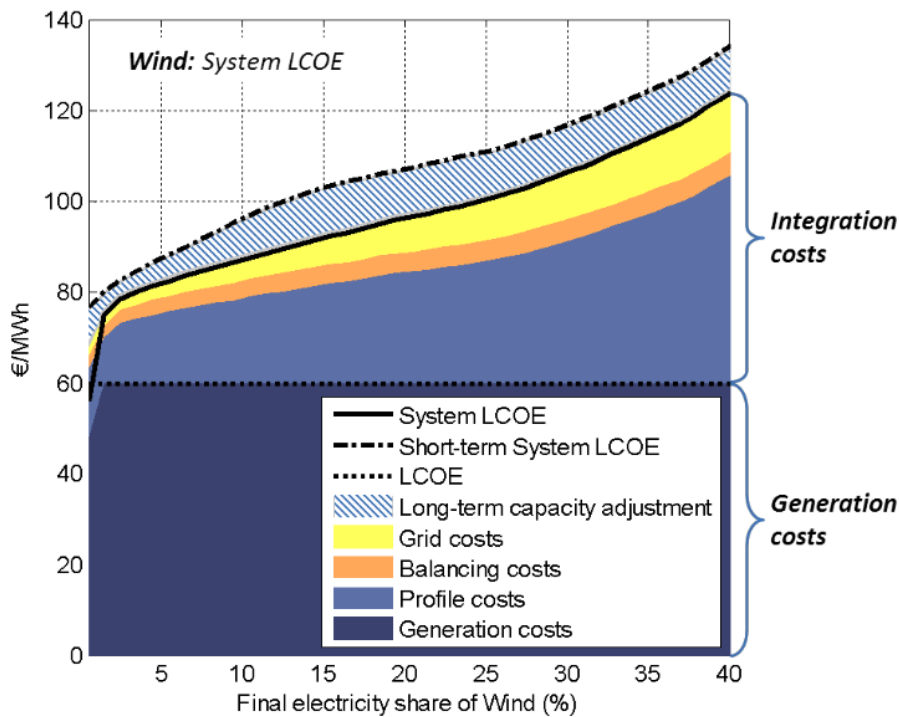


Figure 21: Transmission Cost in EUR in the US per Technology (U.S Energy Information Administration, 2014)

³⁷ The authors consider the US average an appropriate benchmark, due to the diverse geographical and climatic circumstances within the county



In conclusion, the graph below summarizes the different drivers of the System LCoE:

Figure 22: Example of the System LCoE for Wind in Europe (Retrieved from Ueckerdt, Hirth, Luderer, & Edenhofer (2012, p. 15))

This shows that, on the one hand, including integration costs into the LCoE metric may be very complicated due to the indirect nature of its components but on the other, it enables a deeper and more unbiased comparison of different technologies. This approach could become more and more important for Germany's energy transition, because a transparent evaluation of energy sources is essential to secure the economic- and environmental feasibility and to maintain a high level of security of supply (Ueckerdt, Hirth, Luderer, & Edenhofer, 2012).

$$sLCoE = LCoE + Profile\ Cost + Balancing\ Cost + Grid\ cost - LR\ adjustment$$

4.3.3. EROI

Much like the System LCOE, the EROI (The Energy Returned on Invested) is a parameter to assess and compare different energy supply techniques and is defined thus by Weißbach et al. (p.212, 2013): The EROI of a power plant (R) refers to the ratio of the usable energy (E_R) the plant returns during its lifetime to all the invested energy (E_I) needed to make the energy useful (Weißbach, et al., 2013).

Therefore:

$$R = \frac{E_R}{E_I}$$

It thus follows that to break even, the EROI should be 1; however, for a plant to be useful, it needs a surplus that can be utilized for such purposes (Morgan, 2014). Weißbach et al. (2013) posit that this minimum viable EROI for countries such as The United States of America and Germany is 7; building upon this, Morgan (2014) contends that an energy source with an EROI lower than this threshold value will not be able to sustain the energy needs of such complex societies.

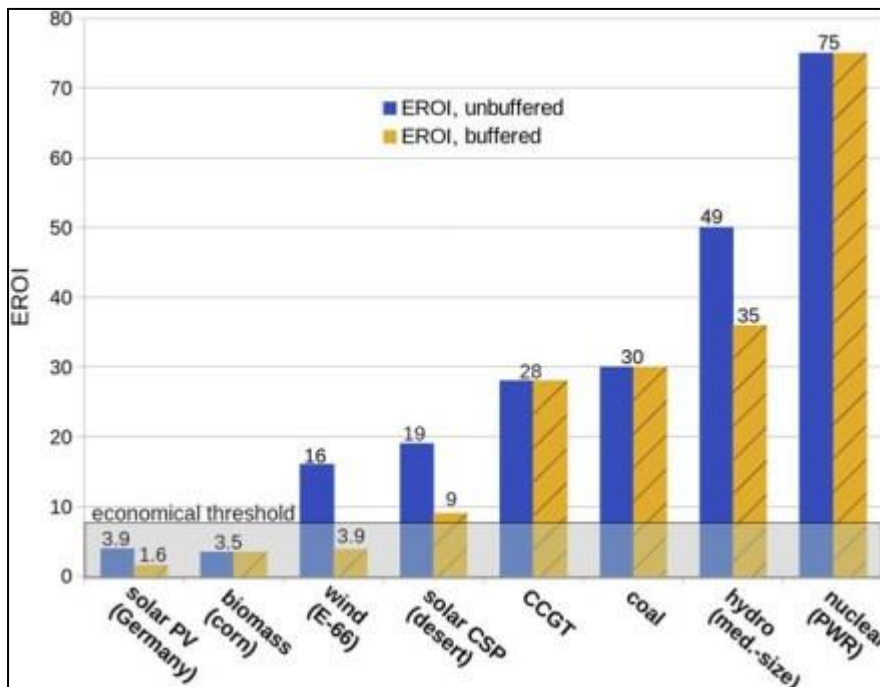


Figure 23: Energy Returned on Energy Invested with (buffered) and without (unbuffered) energy storage (Retrieved from Weißbach et al. (2013), p. 28)

Based on the findings in Weißbach et al. (2013) which account for different parameters such as construction, commissioning, production, maintenance, and decommissioning, illustrated in Figure 23 above, Morgan (2014) argues that nuclear (Pressurized Water Reactor), hydro (med.-size), coal, closed cycle gas turbines (CCGT), concentrating solar power (CSP) and wind have energy surpluses sufficient to support a developed industrial society based on their unbuffered EROI values (above the threshold value of 7). However, if storage is factored in, further investment is required, resulting in lower buffered EROI values. Weißbach et al. (2013) assumed hydroelectric energy storage to calculate the EROI; however, should a more energy intensive form of storage be required, the buffered EROI value is likely to drop further (Morgan, 2014). These results become salient when evaluating the incorporation of more renewable sources, which would need storage to be viable, to transition towards a low carbon system, which Germany is currently aspiring to accomplish within the premise of its *Energiewende*. Morgan (2014) identifies this as a catch-22 situation wherein overcoming intermittency of renewables by adding additional storage will reduce the net EROI below the threshold level required to sustain societal needs.

As can be seen however, discussion focused on the EROI is fairly recent. However, it provides an opportunity to assess the *Energiewende* from an energy based accounting, in addition to the economic based accounting inherent to the LCOE.

4.3.4. Electricity prices in European and international Comparison

In order to examine the development of electricity prices it is important to break the overall electricity price down into its different elements. Table 3 below shows the price breakdown for domestic users from year 2007 to 2014 and subdivides the overall price into the distinct components of *Energy and Supply*, *Network Costs* and *Taxes and Levies*, which includes the EEG surcharges. This distinction is crucial to examine the price development over time and to see which price components actually increased and which ones stagnated or even decreased over time. Furthermore, this table shows both: the percentage difference from 2011 (the initial year of Germany's nuclear shutdown) to 2014; and the change from 2007 to 2014 (European Commission- Eurostat, 2015).

Table 3: Price Breakdown for Domestic Users from 2007-2014 (Source: European Commission- Eurostat, 2015)

Breakdown: domestic user consumption class	Price-breakdown	2007	2008	2009	2010	2011	2012	2013	2014	Δ 2011-2014	Δ 2007-2014
Less than 1000 kWh	Energy & Supply	0,1067	0,1319	0,1291	0,1385	0,1305	0,1409	0,1389	0,1424	9,1%	33,5%
	Network costs	0,1246	0,1089	0,1122	0,1143	0,1159	0,1137	0,1214	0,1152	-0,6%	-7,5%
	Taxes & levies	0,1034	0,1072	0,1154	0,1197	0,1367	0,1482	0,1664	0,1760	28,7%	70,2%
	TOTAL	0,3347	0,3480	0,3567	0,3725	0,3831	0,4028	0,4267	0,4336	13,2%	29,5%
1000 to 2500 kWh	Energy & Supply	0,0747	0,0903	0,0904	0,0993	0,0908	0,0958	0,0976	0,0920	1,3%	23,2%
	Network costs	0,0727	0,0635	0,0658	0,0670	0,0689	0,0684	0,0728	0,0727	5,5%	0,0%
	Taxes & levies	0,0826	0,0854	0,0934	0,0991	0,1136	0,1244	0,1432	0,1534	35,0%	85,7%
	TOTAL	0,2300	0,2392	0,2496	0,2654	0,2733	0,2886	0,3136	0,3181	16,4%	38,3%
2 500 to 5 000 kWh	Energy & Supply	0,0661	0,0801	0,0798	0,0877	0,0807	0,0845	0,0866	0,0772	-4,3%	16,8%
	Network costs	0,0618	0,0540	0,0561	0,0570	0,0588	0,0587	0,0623	0,0668	13,6%	8,1%
	Taxes & levies	0,0826	0,0854	0,0934	0,0991	0,1136	0,1244	0,1432	0,1534	35,0%	85,7%
	TOTAL	0,2105	0,2195	0,2293	0,2438	0,2531	0,2676	0,2921	0,2974	17,5%	41,3%
5 000 to 15 000 kWh	Energy & Supply	0,0629	0,0724	0,0730	0,0815	0,0791	0,0783	0,0801	0,0744	-5,9%	18,3%
	Network costs	0,0558	0,0483	0,0502	0,0509	0,0530	0,0528	0,0560	0,0573	8,1%	2,7%
	Taxes & levies	0,0805	0,0832	0,0906	0,0968	0,1102	0,1231	0,1415	0,1510	37,0%	87,6%
	TOTAL	0,1992	0,2039	0,2138	0,2292	0,2423	0,2542	0,2776	0,2827	16,7%	41,9%
More than 15 000 kWh	Energy & Supply	0,0594	0,0690	0,0664	0,0727	0,0713	0,0732	0,0744	0,0710	-0,4%	19,5%
	Network costs	0,0526	0,0448	0,0451	0,0466	0,0487	0,0490	0,0520	0,0512	5,1%	-2,7%
	Taxes & levies	0,0761	0,0789	0,0868	0,0955	0,1071	0,1173	0,1355	0,1439	34,4%	89,1%
	TOTAL	0,1881	0,1927	0,1983	0,2148	0,2271	0,2395	0,2619	0,2661	17,2%	41,5%

Germany's electricity prices for domestic users are the second highest within the European Union (and the European continent). Only Denmark reported higher electricity prices for households. This is in fact not a new scenario; Germany already ranked second in this category semester 2 of 2011. However, whereas Denmark's electricity price for households stayed relatively stable from 2011 to 2014, Germany's domestic customers had to accept a price increase of overall 17,5% from 2011 (Figures 24 and 25)³⁸.

³⁸ DA: 2 500 kWh to 5 000 kWh

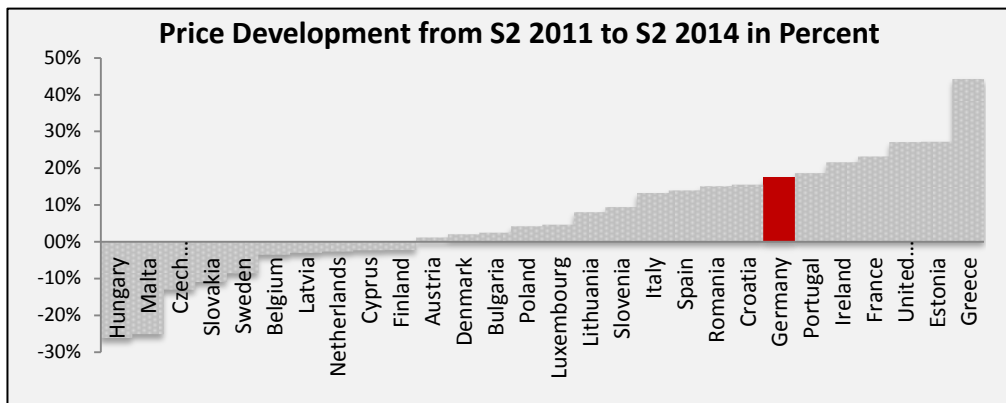


Figure 24: Price Development from S2 2011 to S2 2014 in % (European Commission- Eurostat, 2015)

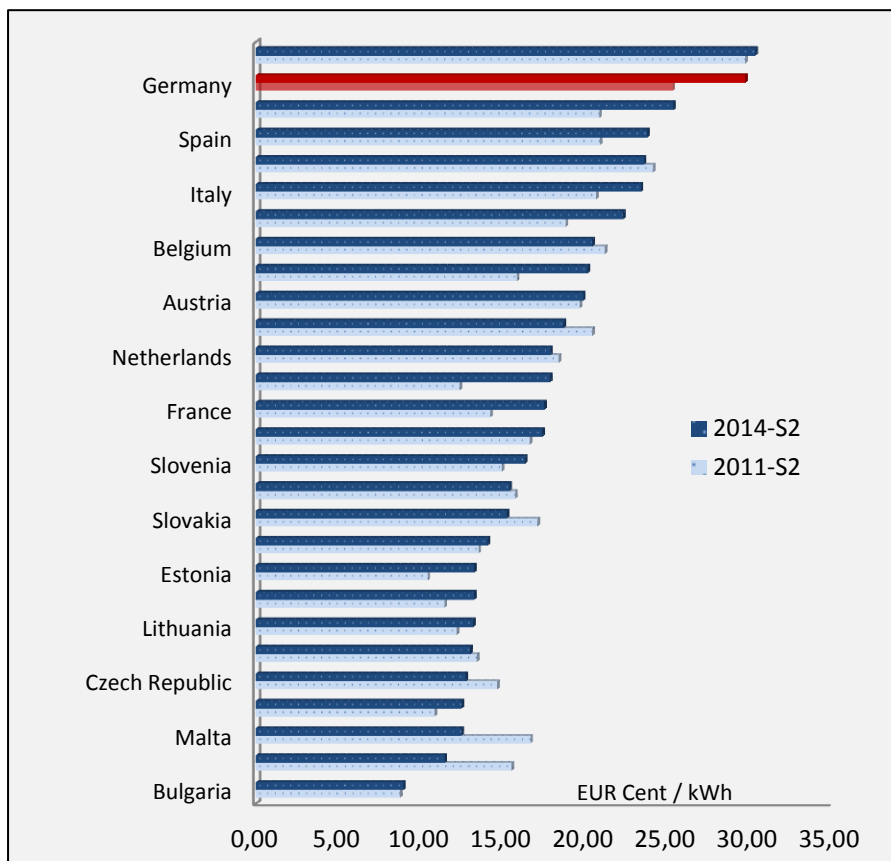


Figure 25: Comparison of Domestic User Prices in the EU – 2 500-5 000 kWh Semester 2 of year 2011 and Semester 2 of 2014 (European Commission- Eurostat, 2015)

One interesting trend here to observe is that costs for energy and supply (-5,9% to +9,1% depending on the customer class) and network costs (-0,6% to +13,6% depending on the customer class) changed moderately from 2011 to 2014 (I.E.A - International Energy Agency, 2013), yet taxes and levies increased drastically in the meantime, by minimum 28,8% to 37% for the DA 5 000-15 000 kWh (European Commission- Eurostat, 2015; I.E.A - International Energy Agency, 2013). This is illustrated in Figure 26 below.

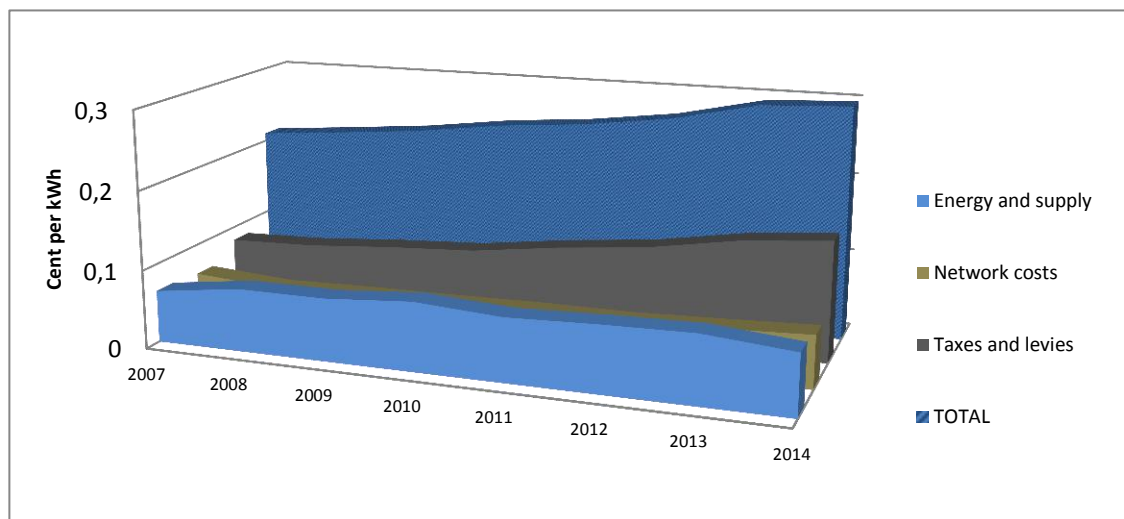


Figure 26: Price Development for Domestic Users - 2 500-5 000 kWh (European Commission- Eurostat, 2015)

4.3.5. EEG

The German Renewable Energy Act (EEG) and its precursor, the Feed-in Law, have been instrumental in deploying renewable energy-sourced electricity (RES-E) in Germany. However, with an increasing share of renewables in Germany's power supply, the EEG must be poised for stronger system and market integration. Firstly, RESE-generation should be adapted to demand; currently, operators receive the same price for any RES-E generated, irrespective of whether it is peak or off-peak demand. Secondly, costs to customers must be as low as possible while simultaneously not threatening the growth of renewables necessary to confront climate change (Langniß, Diekmann, & Lehr, 2009).

The EEG was established in 2000 and has since been amended with its most recent amendment coming into force in August 2014. The EEG is a feed-in tariff system which mandates distribution network operators (DNOs) to connect RES-driven power plants, purchase RES-E, and pay a fixed remuneration (cent per kWh) to the plant operator; the

remuneration is cost orientated and differentiated by technology and plant attributes among other characteristics (Langniß, Diekmann, & Lehr, 2009). The remuneration is fixed for 20 years for most technologies, allowing investors a modicum of security in planning and salvaging relevant costs. However, it decreases for new power plants every year (in accordance with a vintage approach) by a technology-specific degression rate reflective of technological developments and cost reductions associated with learning effects. Given that the degression rate is determined in advance, it directs plant manufacturers to expected cost reductions. Langniß et al. (2009) thus propose that the remuneration can be modeled thus:

$$p_{tvi} = p_{Ti}(1 - d_i)^{v-T} + k_i$$

p: Specific remuneration per kWh

t: Actual year of remuneration

v: Start of operation (vintage)

i: Technology category

k: Additional premiums for innovative technologies

d: Degression rate

Simplistically, by prioritizing access for renewable power to the grid, the EEG allows an operator of a RES power plant to deliver electricity to the DNO who in turn passes it on to the Transmission System Operator (TSO) who then passes it on to retailers. However, the commercial transfer of RES-E from the power generator to the consumer, as well as the payment from the consumer to the power plant is complicated as a result of two key challenges (Langniß, Diekmann, & Lehr, 2009).

- i. Given that intermittent sources such as wind and solar comprise half the power within the premise of the EEG, supply needs to match demand and appropriate mechanisms need to be instituted to allow for cost recovery in this service.
- ii. The German transmission grid is divided into four regions with each one run by a different operator. This necessitates a balancing mechanism between TSOs to guarantee equal distribution of both, amount of RES-E remunerated annually and simultaneous burdens, based on the electricity consumption in all four transmission grids.

As seen in Figure 26, however, the share of costs attributable to taxes and levies in the total price paid by domestic consumers has increased drastically. This has, in large part, been a result of the EEG Surcharge, paid by German electricity consumers to support investments in renewable energy production. According to the BMWi (2014), anyone generating electricity from solar, wind, hydro or biomass is paid a fixed price per kilowatt-hour (guaranteed for 20 years)—this electricity is then purchased by grid operators who subsequently sell it on the power exchange. The difference between the fixed price and the generally lower market price is distributed over electricity consumers and is known as the EEG surcharge (BMWi, 2015).

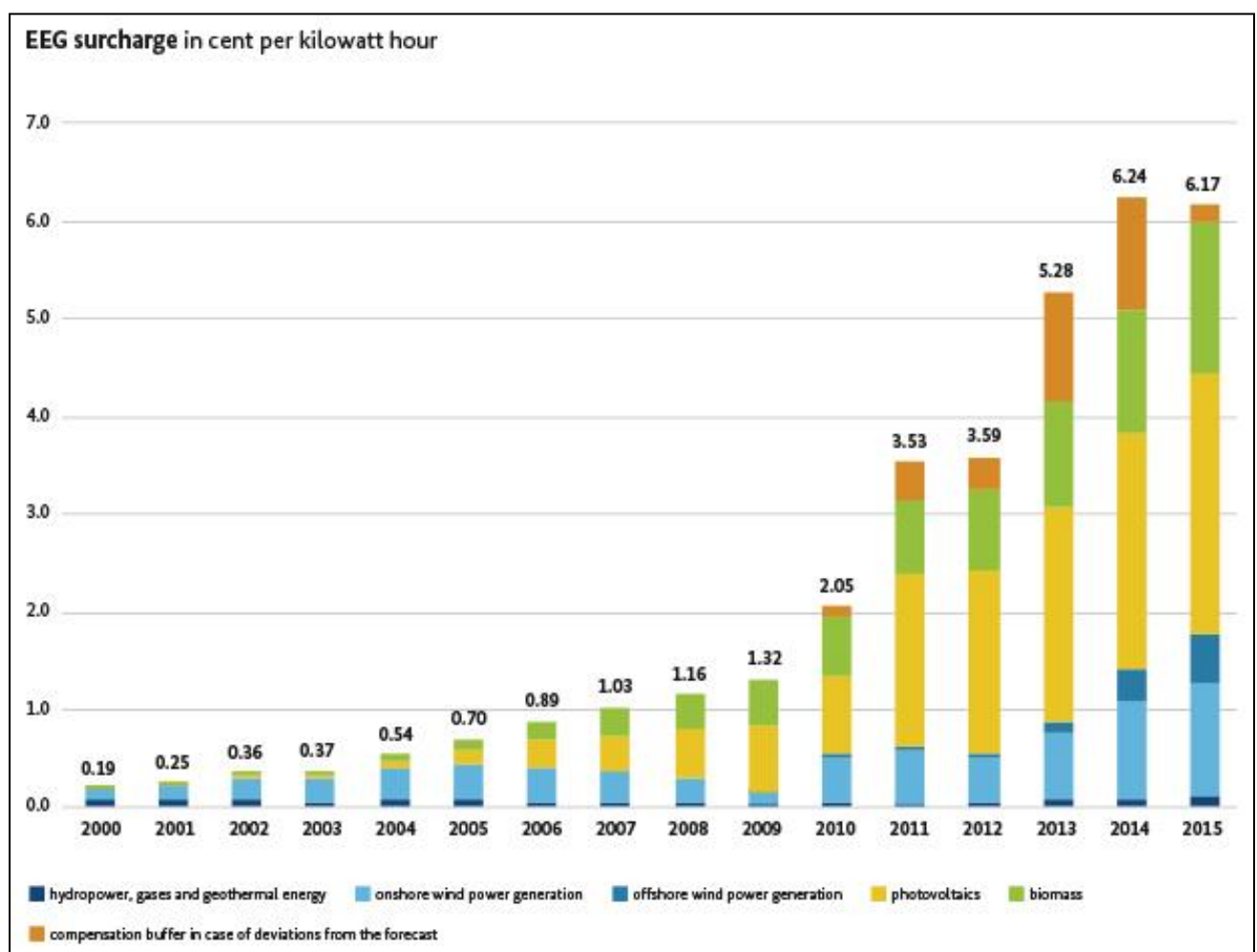


Figure 27: EEG surcharge in cent per kilowatt hour (Retrieved from: <http://www.bmwi.de/EN/Topics/Energy/Renewable-Energy/2014-renewable-energy-sources-act,did=677210.html>)

As seen in Figure 27 above, the EEG surcharge has increased progressively since 2000 necessitating stabilization of the costs of expanding the use of renewables such as biomass, PV, and wind. A study commissioned by Agora *Energiewende* and conducted by the Oeko-

Institut advances the notion that the surcharge paid by electricity consumers can be lowered if the exemption of industries within the purview of the EEG is limited to energy- and export-intensive industries (Oeko-Institut e.V., 2014). The report contends that large industrial consumers should also contribute to the costs of the *Energiewende*; these commercial consumers, prosumers, and rail operators have hitherto been exempt from the charge. In line with these findings, the amendment of the EEG in 2014 also sought to distribute the costs of finding renewables more equitably. The Special Equalization Scheme for electricity-intensive industries, which mandates exemptions and reduced EEG surcharges for electricity-intensive industries, was revised and made compliant with EU legislation; in the future, this exemption will be applicable to only electricity-intensive industries that compete internationally.

4.4. Environmental Sustainability

The Federal Republic of Germany straddles a precarious balance; it has embarked upon an ambitious climate and energy policy by transitioning away from the use of fossil fuels and phasing out nuclear energy. Like many of its other European counterparts, Germany seeks to accomplish a low-carbon system; however, in seeking to phase out nuclear energy by 2022, Germany will also be phasing out approximately half of its current source of carbon free electricity calling for a greater dependence on renewable sources of energy (Buchan, 2012, p. 2). Accomplishing the goals of this energy concept while simultaneously maintaining its position as a leading industrialized country thus poses an inevitable challenge for the country. This section of the thesis thus provides a background of Germany's current Energy Concept which guides its climate and energy policy.

4.4.1. The Energy Concept 2010

On September 28, 2010, Germany adopted an Energy Concept which according to The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMU) stipulated how Germany could best accomplish “an environmentally sound, reliable and affordable energy supply and for the first time mapped a road into the age of renewable energies.” (BMU, 2010) These goals, while ambitious nonetheless form the central tenets of Germany's long term energy policy. The key goals of the German Energy Concept of 2010 can be summarized in Table 4 below.

Table 4: The German Energy Concept, 2010 (Adapted from BMU (2011))

	Goal by 2020	Goal by 2050
Reduction in green house gas emissions	40 % (Relative to 1990 levels)	80 to 95% (Relative to 1990 levels)
Decrease in primary energy consumption	20%	50%
Energy productivity	Rise by 2.1% per year compared to final energy consumption	
Electricity consumption	Fall by 10% (Relative to 2008 levels)	Fall by 25% (Relative to 2008 levels)
Share of renewable energies in gross final energy consumption	18%	60%
Share of renewable in gross electricity consumption	35%	80%

Of particular significance is the long term positioning of the German Energy Concept which goes beyond the European Union's targets for 2020. However, to accomplish this transition in an economically efficient way, the BMU proposed the extension of the operating lives of nuclear power plant by an average of 12 years to bridge the transition from the status quo to the goals it envisioned in its Energy Concept.

4.4.2. The Energy Package 2011

After the nuclear disaster in Fukushima (Japan), Germany adopted measures in the summer of 2011 to gradually phase out nuclear power by 2022. Given the hitherto importance of nuclear power as a bridge power towards a more sustainable energy policy, the lack thereof necessitated higher energy efficiency and an accelerated transition to renewable sources of energy. Accordingly, in June and July 2011, the German government incorporated the following policies into its Energy Concept to 'supplement and accelerate implementation of the measures set out in the Energy Concept of September 2010' (BMU, 2011)

4.4.3. Greenhouse gas emissions

Germany has set itself very ambitious targets regarding decarbonization. In fact, Germany plans to decrease its emissions by eighty to ninety percent in 2050 in comparison to the 1990 benchmark. According to the German Institute for Economic Research (2015, p. 7), Germany represented the largest CO₂ emitting economy in the European Union in 2013, with an overall estimated CO₂ equivalent emission of 954,7 million tons. Even-though this number shows an overall decrease of already 23,5% from 1990, the short-term assessment shows a small increase from 2011 (952,4 million tons) to 2013 (Eurostat, 2015).

A recent report from the IAEA (2013, p. 12) compared the GHG emissions of different types of electricity generation source, both conventional generation technologies and renewables. The result indicated that even with CCS technology, fossil fuel plants remain high in GHG emissions, approximately 200g CO₂-eq.per kWh for coal and 150g CO₂.per kWh for natural gas. On the other hand, the renewables have demonstrated lower values regarding GHG emission, as the highest source, geothermal, has emissions being around 130g CO₂-eq.per kWh and the lowest one being run of river hydro nuclear with less than 10g CO₂-eq.per kWh. Nuclear energy generation was accounted with 14.9g CO₂-eq.per kWh (IAEA - International Atomic Energy Agency, 2013). Germany's energy mix, particularly such sources providing

base load supply, will have to shift towards cleaner technologies in order to achieve the long-run goal of a 85 to 90 % reduction in 2050.

Furthermore, it is important to state, that the emission of pollutants is not limited to CO₂. According to the European Environmental Bureau (EEB), greenhouse gases, in combination with heavy metals emitted by fossil fuel power plants, result in more than 18.000 deaths per year and lead to large number of chronic bronchitis cases within the European Union (European Environmental Bureau). The EEB further estimates the overall economic health cost to up to 43 billion Euros. In fact, these numbers are estimated to be significantly and over-proportionally higher for other parts of the world. Furthermore, according to the OECD (N.E.A - Nuclear Energy Agency/OECD, 2010, p. 35), no other energy chains cause more fatalities (in absolute numbers and per GW installed) than coal and oil.

4.5. Acceptance

4.5.1. The German Anti-Nuclear Movement

In the period from the mid-1950s to the end of the 1990s, Germany viewed the use of nuclear energy as a cost-effective and reliable supply of energy, legally enshrined in the German Energy Act enacted on the 23rd of December, 1959 (Blackmore, 2013). Strunz (2013) states that the conventional fossil-nuclear regime exhibited the following technological, political, and economic characteristics:

- i) *Technological*: Energy was primarily generated from nuclear power and fossil fuels in a centralized production structure and thereafter transmitted to consumers
- ii) *Political*: Subsidization and support from the state across the value chain
- iii) *Economic*: The major part of the German energy market was distributed among four big utilities; each of the ‘big four’ disposed of its own transmission network and competition was stymied as a result of regional separation of networks

Public rhetoric at this time focused on security of supply and affordability and this, combined with the positive feedback from the mutually reinforced technological, political and economic pillars of the regime made it very resilient for subsequent decades (Strunz, 2013). As discussed in the previous chapter as well, nuclear energy provided a reliable clean source for base load in addition to being viable when assessed through both EROI and System LCOE metrics.

Despite Governmental investment in nuclear development and building of reactors, demonstrations, protests and lobbying against it nonetheless existed (Blackmore, 2013). This opposition in the 1950s and 1960s was characterized by skepticism, even before they had learnt about the dangers of nuclear power (Uekoetter, 2012). This initial skepticism precipitated into a larger movement in the 1970s, culminating in mass demonstrations against different nuclear projects in subsequent decades.

Blackmore (2013) employs a social constructivist lens and posits that it was a combination of the Fukushima accident as well as a relevant political context that precipitated in Germany’s decision to abandon nuclear power. The move to shut down Germany’s older nuclear plants and phase out the remaining ones by 2022 was in stark contrast to the initially proposed extension of the lifespan of its nuclear reactors in 2010.

Anti-nuclear Norms

Blackmore (2013) considers anti-nuclear norms to be a “core reason” for Germany’s policy change. Drawing upon social constructivist literature, he contends that the German reaction to Fukushima was a combination of first, its anti-nuclear norms driven identity shaped by the country’s historical trajectory. Additionally, he also posits that anti-nuclear norms in isolation did not contribute to the Merkel’s change in nuclear policy; instead, the prevalent political climate at the time resulted in a populist move by the federal government. This is also in line with Linehan’s assertion that both, framing of the issue and the political opportunity inherent to the situation precipitated the decision for the nuclear shutdown (Linehan, 2013).

Employing a longitudinal analysis, Blackmore (2013) argues that it is vital to discern the cultural and institutional context of nuclear power prior to the German change in nuclear policy. Only analyzing Germany’s decision to abandon nuclear power and thus equating it to an anti-nuclear identity will not suffice.

Blackmore (2013) identifies members of the German anti-nuclear movement as norm entrepreneurs who succeeded in creating resonant frames which consequently mobilized opposition to nuclear power. These frames thus evolved into norms, thereafter institutionalized in government policy. In a similar vein, the norm entrepreneurs who started the anti-nuclear movement in the 1970s could also be seen as what Kitschelt (1986) identifies as collective and rational decision makers who both mobilized their followers and promoted their causes with the best available strategies. Blackmore (2013) exemplifies this by alluding to the first major anti-nuclear event to receive extensive attention in Wyhl on the 18th of February, 1975. Pursuant to this initial opposition, the norm entrepreneurs of the anti-nuclear movement succeeded in spreading the movement and in doing so, established resonant frames from the mid-1970s onwards (Blackmore, 2013). This anti-nuclear movement that thus evolved was characterized by its own expertise and understanding of the dangers nuclear power entailed (Uekoetter, 2012).

This ‘risk’ frame was further exacerbated by the Three Mile Accident in Pennsylvania, USA on the 28th of March, 1979—lending more credence to the anti-nuclear movement and in showing that an accident actually occurred, made the risk more credible. This ‘empirical credibility’ that the Three Mile Accident imparted to the movement bolstered it further and allowed the risk frame to resonate with German nationals, evident in the protest in Hanover

after the accident on the 31st of March, 1979 which was then the biggest anti-nuclear demonstration in Germany (Blackmore, 2013).

Nonetheless, the crescendo of the anti-nuclear movement's resonance was after the Chernobyl disaster on the 26th of April, 1986. Similar to Three Mile, Chernobyl illustrated the impact of nuclear risks on citizens and consequently, amplified the nuclear risk frame (Blackmore, 2013). Bedford and Snow (in Blackmore 2013) also argue that Chernobyl impacted the German anti-nuclear movement as a result of its *experiential commensurability*—the extent to which the frame can benefit by relating to the quotidian experiences of the targets it encompasses. In the aftermath of the accident, the German government took measures to protect citizens from radiation contamination from Chernobyl including, for example, closure of kindergartens and schools (Blackmore, 2013). By thus showing the direct effect of the accident on the day to day lives of German nationals, Chernobyl magnified the resonance of the anti-nuclear risk frame. Resultantly, the number of protests increased with a concomitant majority of Germans mobilized against German power (Rüdig in Blackmore, 2013).

Thus, the anti-nuclear movement, bolstered by Three Mile and Chernobyl, strengthened the anti-nuclear frames and made it resonate with broader public ideas of society—this allowed for new ways of discerning issues, and consequently functioned as norms.

This risk frame was also instrumental in the phase of institutionalization of anti-nuclear norms. After 1990, the anti-nuclear movement focused on the issue of nuclear waste. In May 1998, the German Environment Ministry announced that nuclear transports had been leaking radiation which exceeded allowed limits—consequently, nuclear transport was banned and the fact that the Government had been aware of this for the last decade damaged the reputation of the then ruling CDU/CSU-FDP coalition (Blackmore, 2013). Even though the radiation levels were not likely to cause harm, the possibility that nuclear radiation could directly affect German nationals added more credence to the anti-nuclear frame and amplified its resonance.

Even when Merkel decided to reverse the SPD/Green coalition's decision and instead extended the lifespan of reactors by 12 years on average by parliamentary majority, the norms still persisted. While successful in parliament, the change in policy was not supported by most Germans causing more protests. The phase-out by 2022 was ratified by 85% of

parliamentarians, passed by a majority of 513-79 in the lower house of the Bundestag (Davies, 2011). Conversely, in a report from the European Commission, a non-negligible portion of citizens (24%) opposed the lifetime extension of existing nuclear plants (European Commission, 2010). For instance, in April 2010, nearly 120 000 people formed a 120 km long chain between the nuclear plants of Krümmel and Brunsbüttel making the strength of the German anti-nuclear norms evident (Blackmore, 2013).

Political Climate

Blackmore's (2013) position that it was not just anti-nuclear norms that culminated in the *wende* regarding nuclear energy, finds resonance in Kitschelt's idea of it being facilitated by a nation's political opportunity structure (Kitschelt, 1986). Kitschelt (1986) defines a political opportunity structure as:

“Consisting of specific configurations of resources, institutional arrangements and historical precedents for social mobilization, which facilitate the development of protest movements in some instances and constrain them in others” (Kitschelt, 1986).

Further, Kitschelt (1986) expounds on this role of political opportunity structures by identifying three possible means of influencing the capacity of social movements to engage in protests.

Firstly, mobilization is contingent on the “coercive, normative, remunerative and informational resources” that a movement can deploy from its setting in its protest (Kitschelt, 1986). He exemplifies this by identifying the vitality of non-violent resources in protests in Western democracies. This further underscores the importance of anti-nuclear norms — and the inherent opportunity to both collect and disseminate information and resources — in broad mobilization (Kitschelt, 1986). As such, the political context is inextricably linked to the norms that it fosters or constrains. In the German context, the original anti-nuclear movement transforming into one that framed nuclear power as a risk illustrates this role of this information dissemination. The risk of nuclear power could serve as a locus for these opposition movements to converge on.

Secondly, the access of these movements to the public realm and consequently political decision making is in turn influenced by institutional rules, including electoral laws and rules concerning interaction between the government and interest groups (Kitschelt, 1986). On one

hand, these rules shape the demands of social movements that are hitherto not accepted political actors and on the other, could catalyze the institutionalization of new groups and claims. During the inception of the Anti-Nuclear movement, it had little access to the political system to demand policy changes. Consequently, the Government maintained a pro-nuclear position through the 1970s and early 1980s; however, this only provoked demonstrations and protests by the anti-nuclear movement (Blackmore, 2013). Notwithstanding this limited access to the political structure, attempts to demand nuclear policy change subsisted in the Bundestag—for example, after successful state elections, the Greens were voted into the Bundestag in March 1983. The Greens who were, in part, a consequence of the anti-nuclear movement persisted to bolster the anti-nuclear cause. In fact, the anti-nuclear activists of the 1970s who vehemently opposed nuclear in Germany were the precursors to the Green Party (Davies, 2011). By securing access to the political structure, the anti-nuclear views were now represented by a political entity which increased both its credibility and its political opportunities (Blackmore, 2013).

This was further institutionalized when the elections of September 1998 brought a coalition led by the SPD and the Greens to power. In 2000, the SPD-Greens coalition concluded an agreement to phase-out nuclear power which Blackmore (2013) attributes to the risk frame. He argues that the anti-nuclear norms that characterized German identity at that point influenced the Government's behavior to a certain extent.

Finally, the appearance or disappearance of other social movements could alter the opportunities which a social movement encounters to mobilize protest (Kitschelt, 1986). The political climate is underscored by Strunz (2013) wherein political changes in 2011 caused the transition from a fossil-nuclear regime to one based on renewables (Strunz, 2013). Following Kitschelt's (1986) line of argument, this could be seen as the appearance of a pro renewable social movement. The political context, both domestic and within the EU, fostered the emergence of a renewables-based regime and positioned it as a viable political, technological, and social alternative. The resilience of the fossil-nuclear regime was weakened by an alternative in an RES based regime, which caused a spillover of political changes in the economic and technical pillars (Strunz, 2013). Pursuant to the emergent significance of the environmental movement in German politics, RES-support policies were started in 1991 and thereafter extended in 2000. This bolstered technical developments and greater decentralized production; resultantly, the share of energy generated by renewables

increased from 4 to 23% in the period between 1996 and 2012 (Strunz, 2013). Unlike conventional sources of energy, the inherent decentralized and small scale energy production from renewables threatened the big four oligopoly. This was exacerbated by the liberalization of the EU electricity market—and the consequent empowerment of consumers and separation of the hitherto bundled production and transmission. As such, Strunz (2013) contends that growing competition in the energy market and the weakened positive feedback for large-scale energy production made the fossil-nuclear regime less resilient.

Until 2011, however, proponents of the nuclear regime succeeded in preventing a regime shift on the grounds that doing so would threaten security of supply; the big four and their political allies thus continued to view nuclear an essential bridging technology (Strunz, 2013). This resilience was exemplified in the Chancellor Merkel led Conservative Government's decision to reverse the earlier phase out nuclear power by the coalition of the Social Democrats and the Green Party (Strunz, 2013).

The reversal of this decision after Fukushima was also motivated politically, as argued by Blackmore (2013) given impending elections in Germany at the time. For instance, there were several core regional elections in March 2011 including the CDU stronghold of Baden-Württemberg which faced stiff competition from the SPD and the Greens. The premier of Baden-Württemberg, Stefan Mappus from the CDU had supported Merkel's decision to postpone the closure of nuclear power plants. Baden-Württemberg also owned a 45% stake in Energie Baden-Württemberg which operated four reactors in the region and assured a safety assessment of the reactors after Fukushima (Linehan, 2013). The pre-election polls placed Mappus's coalition at par with the SPD-Greens, making the competition close (Linehan, 2013). Blackmore (2013) thus argues that the national response to Fukushima would directly impact the regional candidates of the ruling coalition, and could thus have affected Merkel's decision for the nuclear shutdown. In fact, 71% of the German population was of the opinion that the decision was a tactical positioning in light of the impending state elections (Umfrage: Wähler strafen Union für Atomkurs ab, 2011).

Fukushima

Even before Fukushima, 53% of Germans were of the opinion that nuclear risks were being underestimated and recorded a 60% risk perception (European Commission, 2010). At the same time however, 51% of Germans were of the opinion that nuclear power plants can be

operated in a safe manner; this figure was however, below the EU average of 59% (European Commission, 2010). Contrarily, 70% of Germans recorded high levels of disbelief in the safe management of radioactive waste (European Commission, 2010).

The Fukushima Daiichi accident highlighted the anti-nuclear movement's position regarding risks of nuclear energy and allowed a chance for it to strengthen its message. This was emphasized in several protests following the earthquake. On the 12th of March, ca. 60.000 people formed a 45 km long human chain between Stuttgart and the Nekarwestheim nuclear plant. This was followed by protests at the national level by nearly 110 000 people on the 14th of March. Fukushima thus, much like Three Mile and Chernobyl, increased the resonance of the anti-nuclear movement's risk frame and imparted more empirical credibility by showing that the risk of nuclear power could be real (Blackmore, 2013).

At the same time however, Blackmore (2013) argues that the accident held little relevance to Germany, which was not as prone to natural disasters—accordingly, it could be contended that while Fukushima made the nuclear threat more credible, it did not bolster its relevance or salience for Germans. Wittneben (2012) however, argues that Germans feel a cultural proximity to Japan insofar as both countries had to reconstruct their infrastructure and identity post World War II and pride themselves with quality engineering and efficiency (Wittneben, 2012). As such, they believed that if an accident of that nature could occur in Japan, it could be a possibility for Germany as well though from a safety control lens, rather than one of Germany being susceptible to natural disasters.

However, the German Nuclear Power industry is structured in a way to enforce checks and balances. As discussed in Chapter 4.3.4. Organization and Structure of the German Nuclear Power Industry, through both organizational and legal measures, Germany has safety as a key priority. For instance, the BMUB is supported by different commissions including the Reactor Safety Commission, Commission for Radiological Protection (SSK) and the Nuclear Waste Management Commission (ESK) to secure an independent and comprehensive overview of technical progress relevant to safety. Furthermore, the Nuclear Safety Standards Commission (KTA) stipulates exact standards for nuclear operations, in accordance with the BfS and by incorporating different stakeholders—operators, experts, manufacturers, federal- and state authorities, as well as representatives of public interest—ensures that no stakeholder group can be overruled. In the case of nuclear, institutional factors that Schweizer et al.

(2014) believe could negatively affect public acceptance were robust and allowed for public opinions to be heard in addition to making safety a cornerstone of German nuclear policy.

Linehan (2013) complements Kitschelt and states that Fukushima provided a political opportunity for anti-nuclear dissent to be vocalized and the German response was in turn dictated by the permeability of governing institutions (Linehan, 2013). She deconstructs how Germany's electoral system provided for proportional representation, making it easier for newly formed groups to enter the system as was the case with the Greens; through their entry, the Greens were able to consolidate their position as a background player until Fukushima allowed them to gather sufficient attention and an electoral breakthrough in Baden-Württemberg.

Drawing upon a resilience framework, Strunz (2013) views the Fukushima Daiichi accident as an exogenous disturbance that initiated the regime shift from nuclear to renewables. The decision for a nuclear phase out after Fukushima had severe implications for the fossil-nuclear regime along all three axes—technological, political, and economic (Strunz, 2013).

- i) *Technological*: Firstly, the plummeting drop in nuclear power's share necessitates substitution of the remaining share from other sources (Strunz, 2013). Feed-in from nuclear has higher stability than feed-in from RES; Strunz (2013) thus contends that the decision for the phaseout forced energy providers and transmission operators to adapt within a restricted time-frame and thus connotes a break up of technological path dependency.
- ii) *Political*: The decision to phase out nuclear also represented a triumph of opponents of nuclear power in Germany made particularly salient by the fact that the decision was made by a Conservative Government which was a proponent of nuclear power.
- iii) *Economic*: In Germany, the introduction of nuclear had been heavily subsidized. This allowed big utilities to reduce their up-front capital costs, but at the same time capitalize on the benefits of their soon to be depreciated plants. (Strunz, 2013) However, the phase-out deprived the big four of their most profitable technology assets and consequently, also reduced their political leverage.

The acquiescence of the Federal Government to public opinion is also evidenced in findings by Richter et al. (2013) who find that the government decision to phase out nuclear resulted in an increase in reported levels of happiness – as a result of positive effects on general life satisfaction and reduced worries about the safety of nuclear power plants.

4.5.2. From a Fossil Fuel-Nuclear to a Renewables Regime

In addition to understanding the technical, legal, and economic nuances of the *Energiewende*, Zoellner et al. (2008) contend that wide public acceptance and a concomitant transfer of consciousness into quotidian life are vital to accomplishing Germany's carbon reduction goals. An Acceptance Study by RWE points to the fact that the major impediment to successfully fulfilling the Energy Transition will be societal and not technical in nature (RWE AG, 2012). Whereas Germany seems confident to realize the Energy Transition from a technical perspective, the real challenge will rest in the country's ability to adopt a culture of dialogue and participation. The study also finds that there is a certain cognitive dissonance among the German population; Germans are, for the most part, in favor of the *Energiewende* and the support of citizens remains intact as illustrated in a survey conducted by the IG BCE (Industriegewerkschaft Bergbau, Chemie, Energie) trade union (RWE AG, 2012). That said though, as outlined by Horst (2007), there is a difference between acceptance in principle and acceptance in practice. The Acceptance Study indicates that despite being in favor of the *Energiewende*, understanding regarding the actual relationships, requirements, and consequences remain limited in German society.

The study further claims that contemporary Germans are more willing to take a critical stand on projects and voice their concerns openly, relative to previous generations; in this context, participation and co-determination become essential in the public agenda (RWE AG, 2012). This increased willingness to protest is accompanied by a concomitant lack of trust in the government and corporations. Regarding the government, most Germans are of the opinion that they do not have much influence on governmental action; in a survey conducted by a weekly magazine 'Stern', 79% of respondents responded in the negative when asked if they had a say in Germany and similarly, 94% of Germans were of the opinion that they themselves did not have much say in governmental action according to another survey by the Friedrich-Ebert-Stiftung foundation (cited in RWE AG, 2012). According to another survey by the Bertelsmann Stiftung foundation, a similarly negative opinion is found in German

opinions regarding large corporations which are perceived as guilty of lobbyism, greed and being “out of touch” (RWE AG, 2012).

In results from data from a survey conducted by the Erhebung der Gesellschaft für Konsumforschung (GfK) in September 2014, the results regarding acceptance of the *Energiewende* were as follows (BDI, 2014).

Table 5: Acceptance of the *Energiewende* (Adapted and translated by the Authors from BDI *Energiewende Navigator* 2014)

Indicator	Prompt	% of sample who ‘Agree’ or ‘Somewhat Agree’			
		2011	2012	2013	2014
Relevance of the <i>Energiewende</i> for the population	The <i>Energiewende</i> is central for the future development of Germany	-	86,3	83,6	86,3
Acceptance of the <i>Energiewende</i> in the population	Aggregated value of the following four statements: i. I know the essential objectives of the <i>Energiewende</i> ii. I support the implementation of the <i>Energiewende</i> iii. The implementation of the <i>Energiewende</i> is currently on track iv. The costs of the <i>Energiewende</i> in Germany exceed the benefits	-	55,3	55,0	54,6
Acceptance of major projects in the population	In order to implement the <i>Energiewende</i> , I am ready to take its negative impact on my environment into account	-	50,0	47,8	45,3
Acceptance of electricity price increases	In order to implement the <i>Energiewende</i> , I am ready to purchase electricity at higher prices	23,9	18,0	19,1	-

The results of these studies indicate that the role of public acceptance in Germany is much nuanced. On one hand, the public is accepting of the overall project with a majority agreeing that it is relevant to the German population. At the same time, acceptance levels of both

major projects and electricity price increases vary with, the former having decreased and the latter having increased according to the aforementioned assessment by the BDI (2014).

Furthermore, the studies also emphasize that public opinion in Germany is also focused on a lack of integration or awareness as indicated in studies by ‘Stern’ magazine and the Friedrich-Ebert-Stiftung foundation discussed earlier. To this end, it is essential to understand the nature of public opposition to infrastructure projects and the nature of civic participation.

Much like Blackmore (2013) attributes the origins of the anti-nuclear movement to norm entrepreneurs, Strunz (2013) identifies the importance of institutional entrepreneurs, who advocated sustainability and support for renewables, in constructing a political and technological alternative to the fossil-nuclear regime. However, public acceptance is vital should the RES regime be expected to remain resilient.

Strunz (2013) argues that without support from civil society, the energy transition could result in major public resistance since citizens would accrue the current costs of the transition with benefits reaped only by future generations. These costs include monetary as well as aesthetic and environmental costs. For instance, NIMBY-ism related to the expansion of transmission lines and RES facilities (for example, biogas) have been observed and public acceptability is contingent on the German public participating and benefiting from the transition (Strunz, 2013). In fact, when polled regarding energy issues (and the use of nuclear energy in particular), a majority of Germans (36%) preferred to be consulted and heard directly in the decision making process (European Commission, 2010).

According to Zoellner et al. (2008) the economic consideration of the respective renewable energy system, discerned as a positive cost-benefit analysis by the individual, is the strongest predictor for reported acceptance (Zoellner, Schweizer-Ries, & Wemheuer, 2008)³⁹. While it must be noted that representative perceptions cannot be drawn from the four case studies examined, the paper nonetheless emphasizes the role of social processes in determining future planning processes. In fact, a survey conducted by the Forsa Institute and published by WINGAS GmbH, costs and climate protection had the highest priority among German citizens (Forsa, 2014).

³⁹ The study presents the results from a survey which is part of a 3 year project funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

76% of Germans polled that electricity and energy must continue to remain affordable for all, up by two percentage points from the previous year (Forsa, 2014). A majority of 62% emphasize that energy supply must be secure and reliable at all times (Forsa, 2014). Finally, in terms of sustainability, 43% considered environmentally friendly energy generation a priority, down by two percentage points from the previous year. Nonetheless, public opinion is also in favor of energy efficiency and greater integration of renewables lower fossil fuel combustion, in turn causing a positive effect on local air quality and human health (Kemfert, Opitz, Traber, & Handrich, 2015).

4.5.2.1. Acceptance of Changes in Affordability

Zoellner et al. (2008) provide an academic background to findings from the survey conducted by the Forsa Institute, wherein affordability had the highest priority among the German public. The authors contend that the influence of the economic costs increases with the personal relevance of economic and financial issues; for instance, public attitudes could be shaped by assumptions regarding the creation of new jobs or decreasing costs of renewables in the long run (Zoellner, Schweizer-Ries, & Wemheuer, 2008),

Strunz (2013) contends that expenses related to integration of renewables have increased causing household electricity prices to rise as well. If the transition is not implemented in a cost-effective manner, it could lead to lower public acceptance and social imbalances. Gawel et al. (2014), however attributes the public opinion regarding costs and market prices of renewables vis-à-vis conventional sources to the neglect of future price development. Gawel et al. (2014) argue that the current market prices are not commensurate with the relevant costs to the national economy, representing a possibility for the market to maintain fair technological competition regarding the most favorable manner to generate energy. Furthermore, they contend that the additional costs for renewable energy (costs beyond those achieved on the power exchange) will drop significantly as a result of the exchange prices, which in the mid-term will be oriented on the long-term marginal costs of the conventional power plants still producing electricity and will increase after excess capacity is disposed off. Additionally, a stronger EU emissions trading system would also rectify the distorted exchange prices.

At the same time, increased use of renewables and greater energy efficiency have facilitated an expected decrease in import of fossil fuels, in turn reducing the exposure to volatile prices

of fossil fuels (Kemfert, Opitz, Traber, & Handrich, 2015). Kemfert et al. (2015) also posit that this relates directly to energy security and less vulnerability imposed by energy imports.

Gawel et al. (2014) calls for a more holistic and objective debate on the cost of the renewable energy expansion which the authors claim is currently focused primarily on the power sector, consumer prices, and the impact of the EEG levy on prices – thereby, limiting the role of socioeconomic and other real challenges to the energy policy. The authors highlight that in addition to power, the heat and transportation sectors are also vital to the energy transformation. Additionally, regarding the price of electricity, Gawel et al. (2014) argue that a more objective assessment needs to be undertaken including other external costs such as environmental and special benefit dimensions (for example, the learning curve effects of technological developments). Moreover, every form of subsidy for an energy carrier should be considered including financing channels other than the price of electricity.

4.5.2.2. Acceptance of Changes in Security of Supply

Building on Gawel's (2014) claim for a more holistic analysis, this section of the thesis assesses literature on the costs associated with changes in security of supply. Strunz (2013) argues that the resilience of the transmission grid is essential for the transformation of the complete energy system. Given the focus on security of supply in German energy policy, the *Energiewende* should not weaken the system's overall performance, especially in terms of reliable supply. Blackouts or intentional emergency shutdowns of parts of the grid would challenge public trust in a renewables based regime (Strunz, 2013). This is also reflected in scepticism with the energy transition, wherein 64% of German citizens believe that the energy transition will not succeed as planned and it could cause bottlenecks, disruptions, and downtimes (Forsa, 2014).

Praktiknjo (2013) builds upon acceptance of supply security and blackouts by assessing the costs of blackouts for private households, especially in the context of the German government's goals of increasing the share of renewables and the nuclear phaseout. Based on analysis of data from the Economic Surveys of Private Households, "Einkommens- und Verbrauchsstichprobe" (EVS). The author contends that supply security failures in the form of blackouts are expensive to residential consumers (Praktiknjo, 2013). Additionally, he also asserts that a majority of the German population does not accept lower security of supply in favor of a renewable system in the energy sector. Praktiknjo (2013) concludes that the Willingness to Accept (WTA) and Willingness to Pay (WTP) based outage costs increase

with the duration of the interruption.⁴⁰ However, the average outage costs which are represented by the Value of Lost Load (VOLL) decrease with the interruption's duration. Given that the overall costs increase and average costs decrease, the author thus concludes that marginal outage costs must be decreasing with an outage's duration—which in turn, means that on average, each additional time period of an outage is less costly than previous time periods. As such, during a blackout, there must be certain fixed costs that are constant regardless of the outage's duration, which the author attributes to instant data losses in the context of private households.

Furthermore, he assesses the specific share of four areas of inconvenience on total outage costs, the observations from which are summarized as follows:

Table 6: Share of areas of inconvenience on total outage costs adapted from Praktijnjo (2013)

Spoilage of Food	Increases with the duration of power interruption from 5% (15 minute blackout) to 27% (4 day blackout)
Absence of heat and hot water supply	Increases with the duration of power interruption from 9% (15 minute blackout) to 27% (4 day blackout)
Data losses and reconfiguration of electrical devices	Highest share on outage costs (in average) for short interruption durations, but decreases with enduring outage duration from about 62 (15 minutes blackout) to 17% (4 days blackout)
Limitation of household activities for the duration of the power outage	More or less constant for durations between 15 minutes and 4 days

Additionally, it must be noted that for small consumers such as private households, security of supply is shared (Lieb-Dóczy, Börner, & MacKerron, 2003). As a result of technical reasons (high costs for provision of real-time meters and switches), no individual interruptions occur; instead, neighbors are affected as well and thus, in the case of low demand for energy relative to capacity, physical security of supply is non-rivalrous insofar as a consumer's consumption of security does not reduce another's security, even if they consume more (Lieb-Dóczy, Börner, & MacKerron, 2003). However, in the occurrence of limited capacity, an increase in consumption could make an interruption more likely,

⁴⁰ Praktijnjo (2013) defines WTP as the maximum amount of money an individual would be willing to pay to avoid outages and WTA as the minimum money an individual would be willing to accept as a compensation for an outage. The VOLL (Value of Lost Load) is the average cost per unit of unserved electricity to consumers due to power outages i.e. the average loss of consumer surplus (CS) per unit of electricity consumption (EC).

4.5.2.3. Acceptance of Major Infrastructure Projects

In the study conducted by Zoellner et al. (2008), the only statistically significant predictor for public acceptance for PV solar and wind energy was ‘economic estimation’. While changes in landscape were discerned as the second best predictor, the results nonetheless did not reach statistical significance in the sample. To reiterate however, the findings are limited to the four case studies assessed and can thus not be generalized.

A key challenge that the BCG report finds is local resistance among communities, including senior municipal and state-level policy makers (Gerbert, Rubner, Herhold, & Steffen, 2014). For example, Pegnitz in northern Bavaria has experienced opposition to development of power lines; one of the three main power lines meant to transport wind power from the north to the south would pass through Pegnitz and local residents are concerned that this would destroy the landscape, devalue property and cause potential health concerns (Nienaber, 2015). This is exacerbated by the decision of the Bavarian premier, Horst Seehofer, the Christian Social Union (CSU) to succumb to public opinion and revoke his support for grid expansion. However, this is not an isolated incident and protest groups have formed throughout the country after the federal network agency presented its master plan to construct three high-voltage direct-current transmission lines from north to south. For instance, in 2014 villagers in Bavaria protested against a similar plan by the network operator Amprion and an attempt to construct a similar high voltage-line through the state of Schleswig-Holstein by power company TenneT also failed to win substantial support (Eddy, 2014).

4.5.2.4. Discrepancies in Perceived Justice

A disparate distribution of the costs of the *Energiewende*, reflected in changes in affordability, security of supply, or siting of infrastructure projects, could lower public acceptance, when viewed through the lens of perceived justice. Zoellner et al. (2008) highlights the importance of perceived justice. The authors underscore the impact of perceived justice along all three temporal dimensions suggested by Wolsink (2007) – opposition is likely to increase if people feel excluded from the planning and decision making processes; if operating companies do not pay sufficient attention to public relations during the implementation phase; and if, the operating communities do not engage with the local communities after the project is completed through for example, community festivals or guided tours (Zoellner, Schweizer-Ries, & Wemheuer, 2008). This underscores a cooperative relation between the operating company and the public. An Acceptance Study by RWE (2012) also echoes the belief that

citizen participation should be incorporated as a component of project planning from its inception; this would not only save time but also facilitate higher planning security when progressing with the project.

The criticality of involving the public in the planning phase, suggested by Wolsink (2007) is also highlighted by Gawel et al. (2014). Given the scope and magnitude of the restructuring that the German *Energiewende* necessitates, it is vital to justify to the public that the overarching policy framework is appropriate and that no unneeded costs are being borne by the national economy (Gawel, et al., 2014). Concomitantly, alignment on the goals of the reforms needs to be attained before the beginning of the reforms. An example of doing so would be greater involvement of technocrats. An Acceptance Study commissioned by RWE contends that in addition to the political sphere, project managers from the corporate sphere should do a better job at clarifying the goals of their projects to the people (RWE AG, 2012).

Simultaneously, instruments to implement the project should be continually adapted to unforeseen challenges and required measures. Accordingly, less than optimal routes of development should not be stabilized or rigid; instead, a review, especially of the EEG, should be welcomed (Gawel, et al., 2014).

The difference between legality and legitimacy is also at the forefront of understanding the *Energiewende*. Gawel et al. (2014) argue that the discussion of costs and the utility of the *Energiewende* should not be limited to their relevant *amounts*, but instead to their distribution to individuals, groups, and regions. In line with Wolsink (2007) and Zoellner et al. (2008), Gawel et al. (2014) also contend that the distribution of the costs of the *Energiewende* should be transparent and fair. The authors qualify this, using the EEG-levy exemptions as an example of the inherently wide and contentious exceptions for industry from the financing of the expansion of renewables by all consumers of electricity.

4.5.2.5. Institutional Factors to Empower the Public

Zoellner et al. (2008) underscore the vitality of the procedural perspective on social processes, especially accounting for perceived justice by the public. In line with Horst (2007) and Wolsink (2000, 2007), For example, in one of the case studies, Region A situated in a former mining area in East Germany, civil participation was allowed by the Mayor in obligatory meetings held by local authorities. In doing so, the Mayor made an exemption to the German municipal codes of the federal states (*Gemeindeordnungen der Länder*) which do not allow

civilians who attend the meeting to participate in the debate (Zoellner, Schweizer-Ries, & Wemheuer, 2008).

Zoellner et al. (2008) contend that public participation in the decision making process needs to be considered in advance, exemplified in the decision on the location a planned renewable project. Successful implementation is also characterized by expressed involvement of local authorities.

Gawel et al. (2014) emphasize the nature of Germany's federal system in facilitating opportunities for development of innovative solutions adapted to decentralized technologies. The role of community self-management, in turn, allows the institutional basis for active local energy policies. At the same time, the authors contend that the success of the *Energiewende* is contingent on optimizing the overall system and keeping the overall costs as low as possible. Addressing the need to consider location-related consequences, the authors advocate efficacious coordination at all levels (national, state, regional, and municipal), as well as space- and process- related management.

Simultaneously, honest communication is essential to acceptance for the German *Energiewende*. The RWE Acceptance Study (2012) finds that in allowing society to address conflicts in a proper manner, greater acceptance could be accomplished among citizens. Through expert interviews conducted in the study, the report finds that German people are in fact ready to accept restrictions that impact their own lives as long as transparent communication, substantive justifications, and opportunities to address impact on individuals exist. The Study finds that experts are in consensus over the fact that current processes of citizen involvement are not working, and need reform.

The German Federal Government has taken remedial measures that recognize the need for transparency and dialogue, as well as seek the endorsement of the public. The BMWi recognizes that while there is a large majority in favor of the energy reforms, there nonetheless exists a certain lack of acceptance for infrastructure projects (BMWi). Accordingly, since January 2015, the BMWi has been supporting public dialogue on grids to address the specifics of each case and the interests of all those affected. The initiative for public dialogue has a regional approach with a focus on municipalities where an especially strong need for communication and discussion is observed. Additionally, from Spring 2015, new citizens' bureaus for matters pertaining to grid expansion will be instituted as local

points of contact for the public (BMW). These bureaus will have the responsibility of not only providing information to the public on a case by case basis, but also channeling feedback from the public to relevant authorities. Simultaneously, different events such as conferences, information markets, and discussion evenings are intended to be rolled out to provide the public an opportunity to get together, address any concerns and find amenable solutions. Finally, an internet based platform is to be established to disseminate information on the initiative and allow more ways for the public to get involved including the possibility of an online forum to engage in an online debate and share their perspectives.

5. Discussion

As thus illustrated, social acceptance is pivotal to understanding the context for both the Merkel Government's decision for a nuclear shutdown, as well as possible impediments to successfully integrate more renewables within the missives of the *Energiewende*. This section thus seeks to compare both public movements based on previous discussion of both, the Anti-Nuclear movement as well as German acceptance of the new renewables regime.

Both movements reflect a difference in legality and legitimacy, underlying the fact that even though policies and legislative action, mandated by law are present, they may not necessarily be accepted by the public. In the case of the Anti-Nuclear movement, safeguards were institutionalized, for instance in the checks and balances inherent to the structure of the German Nuclear Power Industry; for instance, the Nuclear Safety standards Commission (KTA) is tasked with defining precise safety standards for nuclear operations and is structured to incorporate different stakeholders with a voting structure that ensures no stakeholder group can be overruled. Furthermore, the German Fundamental Safety Concept further emphasizes the institutional importance placed on safety. Specifically, the Segregation Principle ensures that even if a safety system is threatened or non-functional due to fire or flooding, its spillover to other installations is prevented. In the case of the Fukushima Daiichi reactor, it had neither sufficient constructional protection, nor did a design that adhered to the spatial separation of emergency back-up generators from other safety measures. Even with robust security principles in place (discussed in Chapter 3.3.6 Safety standards in Germany), public opinion calling for the nuclear shutdown illustrates that while legal, they were not deemed legitimate as vanguards for public safety. The ultimate alignment of legality with legitimacy was attained only when the nuclear shutdown was ratified by the German Parliament. Similarly, the plans for grid expansion have been enshrined in the Energy Industry Act (EnWG), Grid Expansion Acceleration Act (NABEG), Federal Requirement Plan Act (BBPIG), and the Power Grid Expansion Act (EnLAG). However, subsequent development continues to face public opposition.

Notwithstanding this incongruence between legality and legitimacy, public attitudes towards the nuclear shutdown and towards increased integration of renewables are largely different.

As discussed, Wolsink (2000) stated that public attitudes are not adequately encompassed by NIMBY-ism, but are instead encompassed within four types (as discussed in Chapter 2.1, Understanding NIMBY-ism). The German anti-nuclear movement started as a movement that evolved from Resistance Type C to Resistance Type B, within the typology of resistance movements suggested by Wolsink (2000). Resistance Type C movements are characterized by positive attitudes that become negative as a consequence of discussion regarding implementation of the project. In the case of nuclear development in Germany, it started as an initially resilient regime, with positive attitudes among the public, strengthened through the mutually enforced pillars of technology, politics, and economics (Strunz, 2013). Technologically, energy was generated centrally by nuclear and fossil fuels; economically, the market was distributed among the 'big four'; and finally, politically, the state subsidized and supported the regime through the entire value chain. Concomitantly, public acceptance was focused on affordability and security of supply, in turn bolstering the resilience of the three-pillared fossil fuel-nuclear regime. However, the transition from positive attitudes towards an initially relatively benign negative perception in the early 1950s and 1960s, as a result of initial skepticism and not deep knowledge of the possible negative consequences of nuclear energy. However, the change from a Type C to a Type B movement (general opposition to a principle in any neighborhood, Not In Any Backyard (NIABY) behavior) occurred with exacerbated perceptions of risk. The accidents at both, Three Mile Island and Chernobyl provided empirical credibility to initial skepticism; the latter in particular, as a result of Chernobyl's geographic proximity to Germany also made the possible risks associated with nuclear more relatable. The precipice of the Anti-Nuclear movement was the Fukushima Daiichi accident. In addition to empirical credibility, much like the accidents at Three Mile and Chernobyl, the accident at Fukushima caused greater opposition to nuclear, including large scale protests such as the 45 km long human chain between the Stuttgart and the Nekarwestheim nuclear plant. Thus, an initially benign opposition evolved into a Type B opposition to nuclear across Germany, rather than being limited to a figurative *backyard*.

In contrast, public attitudes towards renewables fall within a combination of Type A (NIMBY behavior with positive attitude towards the project as long as it is not implemented in one's own neighborhood) and Type D (Resistance of some specific projects without rejection of the principle as a whole). As evidenced in different studies, including an Acceptance Study by RWE, the BDI Navigator, and the Forsa Institute, there is broad

acceptance among members of the German public for the *Energiewende*, in principle with 86% voting in favor of it being relevant for the German population (BDI, 2014). However, the difference between acceptances *in principle* versus *in practice* is highlighted in public resistance towards major infrastructure projects, particularly the development of the transmission grid and both on- and offshore wind farms. As noted by Strunz (2013), the resilience of the grid is the lynchpin of the resilience of the emergent renewables regime in Germany. As discussed in Chapter 4.1 on ‘Security of Supply’, development of the transmission grid is essential to both transmit wind power from Germany’s north to the country’s industrial south, and integrate solar and wind power locally. However, progress on grid development is delayed with only 15% of planned projects having been completed by 2013 (Gerbert, Rubner, Herhold, & Steffen, 2014), in large part due to local resistance as seen in the protests in Bavaria and Schleswig-Holstein. Similarly, public resistance to wind farm development has been characterized as opposition to possible changes in the landscape, aesthetic value alteration, and public disturbance evidenced particularly in the case on onshore wind farm development in the North and Baltic Seas. As such, even though a majority of Germans at 62% in a study by the Forsa Institute (2014) polled in favor of energy supply being secure and reliable, they oppose instruments essential to realize this security, such as expansion of the transmission grid and on-shore wind farm development. Furthermore, rather than being nationalized, the *backyard* of these movements is limited to geographic areas that are directly affected by the progress of these infrastructure projects, such as Bavaria where opposition to grid expansion has been particularly strong. In doing so, the movement tends to reflect NIMBY tendencies insofar as the German public supports the *Energiewende* and its tenets, including secure supply of energy, *in principle* but opposes it *in practice* if there is any disturbance to individual locations.

At the same time, while resistance to infrastructural projects is largely localized, acceptance of changes in affordability is more national. In the case of the anti-nuclear movement, the perceived risk of nuclear energy and resonance of the same in the German public took precedence over the affordability of nuclear energy, foregoing that instead for greater integration of renewables. As discussed in the LCOE Analysis of different energy sources in Chapter 4.3, LCOE metrics cause a bias in favour of economic competitiveness of intermittent and dispatchable sources of energy. In contrast, when taking the system LCOE into account, profile and balancing costs are increasingly an issue, particularly in the case of

integrating solar and wind power. Additionally, when taking dispatchability into account, nuclear has a lower transaction cost relative to renewables.

In the case of public acceptance of the *Energiewende*, the situation is different. While not currently large enough to be classified as a NIABY movement that culminated in the Merkel Government's decision to abandon nuclear energy, changes in affordability nonetheless possess the ability to increase public resistance to the *Energiewende*. When polled regarding which tenet of the *Energiewende* was of most importance, affordability was ranked highest relative to security of supply and sustainability (Forsa, 2014). As analyzed in Chapter 4.3 on Affordability, German electricity prices for domestic users are second highest in the European continent (and the EU) with an overall increase of 17,5% from 2011. Even though costs for energy and supply and network costs changed only moderately, taxes and levies increased between minimum 28,8% to 37% for the DA 5 000-15 000 kWh (European Commission- Eurostat, 2015; I.E.A - International Energy Agency, 2013). However, in line with Gawel's (2014) claim for a more comprehensive analysis, there are also costs associated with less reliable supply of power, through blackouts or intentional emergency shutdowns. While Germany has an impressive System Average Interruption Duration Index, grid reliability is nonetheless threatened by possible resource inadequacy in the South (due to impediments in transmission grid development), inadequate flexibility options including energy storage, and limited penetration of smart meters. In this scenario, as concluded by Praktijnjo (2013), supply security failures, in the form of blackouts, could be expensive to private households and a majority of the German population would be less willing to accept lower security of supply for a more renewables-based energy regime. In addition to the monetary costs, intangible inconveniences also affect private households including spoilage of food, absence of heat and hot water supply, data losses, and limitation of household activities.

Another factor, while common to both, the Anti-Nuclear movements and public acceptance of the *Energiewende* is the role of the Government. In the case of the Anti-Nuclear movement, the shutdown was framed in a political context that was favorable to it. Kitschelt's assertion (1986) regarding the importance of a favorable political climate is underscored in the fact the Merkel Government's decision for the nuclear shutdown came at a time of impending elections; growing public resistance would have limited the political opportunities for the initially pro-nuclear stance of Merkel's Government. As such, the decision to abandon

nuclear was largely reactionary to mounting public opposition at a time when it had to be acquiesced to. Additionally, as noted in Kitschelt's (1986) second proposition regarding mobilization of public opinion, access to political decision making is vital. The lack of political access to the norm entrepreneurs of the Anti-Nuclear movement allowed the Government to maintain a pro-nuclear stance through the 1970s and 1980s, in turn causing greater opposition to it.

In contrast, the German public is more vocal about its opinions now and more willing to engage in protests in parallel with growing distrust of the Government. As such, instead of a reactionary decision as was the case with the nuclear shutdown after Fukushima, the Government should be cautious and incorporate a more participatory model to implement the *Energiewende*. Given possible resistance to changes in security of supply and affordability, as well as opposition to planned infrastructure projects, the public could perceive a lack of justice and transparency especially if the allocation of related costs is not done equitably. The German Government has naturally progressed in a direction towards this model of implementation by establishing public dialogue initiatives especially for grid development; citizens' bureaus; local engagement through conferences, information markets, and discussions; and online engagement. However, these initiatives are nascent at best and provide opportunities to be harnessed further to better engage the German public.

6. Conclusion

Based on available literature and a comparison of the anti-nuclear movement to currently prevalent public attitudes in Germany, the importance of public acceptance in implementing subsequent steps of the *Energiewende* is incontrovertible. While the *Energiewende* is a complex topic, this thesis has strived to provide a comprehensive assessment of public attitudes, both before and after the Merkel Government's decision for the nuclear phase-out.

As discussed, the anti-nuclear movement in Germany was largely driven by scepticism against nuclear energy which then evolved into anti-nuclear norms and eventually an anti-nuclear Germany identity. This movement then found fruition after the Fukushima Daiichi accident which made the perceived risks related to nuclear energy more resonant among members of the German public. A combination of these risks along with impending elections for the ruling coalition played a large part in the Merkel government's decision for a nuclear phase-out by 2022. Much like social pressure was formative in the nuclear shutdown in Germany, public acceptance continues to play a crucial role in the future trajectory of the *Energiewende*. Public resistance to infrastructure projects essential to the *Energiewende*, such as expansion of the transmission grid and development of on- and offshore wind farms, has met with resistance, largely attributed to the NIMBY (Not In My Backyard) phenomenon. However, rather than NIMBY-ism, ideas of perceived justice and equity are crucial to bolstering public acceptance of the *Energiewende*. Particularly, the costs for the *Energiewende* must be distributed in an equitable manner to overcome perceived injustices. For example, rising prices for domestic consumers could face greater opposition in the future should the EEG not be adequately reformed to distribute the surcharge in a balanced manner.

At the same time, many contradictions in the *Energiewende* become apparent. Looking ahead, this paper proposes that the following questions must be addressed when implementing the *Energiewende*.

- *Given the importance placed on affordability by the German public, how will Germany address continuing higher prices for domestic consumers?* The System LCOE analysis indicates that profile and balancing costs are of increasing importance when integrating renewables such as wind and solar. At the same time, the EEG surcharge to finance investments for renewables is not distributed evenly between

industry and consumers and the share of taxes and levies in domestic consumer prices has increased. Germany thus straddles a precarious balance between maintaining its international competitiveness and fuelling greater integration of renewables, while trying to stabilize domestic consumer prices.

- *How will Germany address the seemingly incompatible goals of reducing its GHG emissions and simultaneously increasing its share of renewables?* As it stands, fossil fuels will play a key role as back-up and given adverse health and environmental repercussions of fossil fuel combustion, these two goals will be difficult to accomplish and increase public opposition at the same time. This is exacerbated by the phase-out of nuclear energy, which provided a carbon-free and reliable bridging technology for the energy transition.
- *How will Germany address the need for greater storage to account for intermittent sources, such as solar and wind?* While there is considerable research and development in progress, storage continues to be an opportunity that needs to be further harnessed should Germany wish to successfully integrate more renewables. Concomitantly however, this would imply a lower EROI as discussed earlier, and as argued by authors such as Morgan (2014) and Weißbach et al. (2013), values lower than the threshold required to sustain an industrialized society such as the one Germany has. Furthermore, possible supply security failures as a result of the lack of flexibility options, have associated costs which the German public would be less amenable to accepting in favour of a renewables based regime.

Thus, the public must be engaged adequately when addressing these possibly contentious questions. A key channel of strengthening public acceptance is increased transparency by Governmental institutions. Corrective action has been taken in this direction, evidenced in the amendment of the EEG in 2014 as well as more avenues for public participation in the planning of the expansion of the transmission grid. Nonetheless, many public engagement initiatives have yet to be realized and there exists sufficient opportunity for the Government to strengthen its engagement with the German public and overcome the currently perceived notion that they are not sufficiently involved in decision making processes by the Government.

Works Cited

- AG Energiebilanzen e.V. (2015, February 27). *Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern*. Retrieved from <http://www.ag-energiebilanzen.de/>: http://www.ag-energiebilanzen.de/#20150227_brd_stromerzeugung1990-2014
- Agora Energiewende. (2013). *12 Insights on Germany's Energiewende*. Berlin: Agora Energiewende.
- atw. (2012). Kernkraftwerke in Deutschland - Betriebsergebnisse 2011. *International Journal for Nuclear Power*, 1-7.
- Bauerova, L. M., & Andresen, T. (2012, October 26). *Bloomberg Business*. Retrieved from Windmills Overload East Europe's Grid Risking Blackout: Energy: <http://www.bloomberg.com/news/articles/2012-10-25/windmills-overload-east-europe-s-grid-risking-blackout-energy>
- BDI. (2014). *BDI-Energiewende-Navigator 2014*. Bundesverband der Deutschen Industrie e.V.
- BfS - Bundesamt für Strahlenschutz. (2013, August). Act on the Peaceful Utilisation of Atomic Energy and the Protection against its Hazards (Atomic Energy Act). *Act on the Peaceful Utilisation of Atomic Energy and the Protection against its Hazards (Atomic Energy Act) - Edition 08/13 (bilingual)*. Salzgitter, Germany.
- BfS - Bundesamt für Strahlenschutz. (2013, May). Erläuterungen zu dem Meldeverfahren und den Meldekriterien für meldepflichtige Ereignisse gemäß Anlage 1 der AtSMV. (05/2013). Salzgitter, Germany.
- BfS - Bundesamt für Strahlenschutz. (2015). *The Site Selection Law – A fresh start in the search for a repository site for heat-generating radioactive waste*. Retrieved May 10, 2015, from <http://www.bfs.de/en/endlager/publika/standag>
- Blackmore, D. (2013). Abandoning Nuclear Power: A Social Constructivist Analysis of Germany's Response to Fukushima. *Journal of Politics & International Studies*, 9, 44-87.
- BMU. (2010 йил 28-09). *The German government's Energy Concept Long-term strategy for future energy supply*. Retrieved 2014 from <http://www.bmub.bund.de/en/service/publications/downloads/details/artikel/the-german-governments-energy-concept-long-term-strategy-for-future-energy-supply/>
- BMU. (2011). Retrieved from The Energy Concept and its Accelerated Implementation: http://www.bmu.de/english/%20transformation_of_the_energy_system/resolutions_%20and_measures/doc/48054.php.
- BMUB - Federal Ministry for the Environment Nature Conservation, Building and Nuclear Safety. (1998, August 18). *Bekanntmachung der Leitfäden zur Durchführung von Periodischen Sicherheitsüberprüfungen (PSÜ) für Kernkraftwerke in der Bundesrepublik Deutschland*. Retrieved from http://www.bfs.de/de/bfs/recht/rsh/volltext/3_BMU/3_74_1.pdf
- BMUB - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. (2012, October 1). *Atomrechtliche Behörden, Gremien und Organisationen*. Retrieved April 2,

2015, from <http://www.bmub.bund.de/>: <http://www.bmub.bund.de/themen/atomenergie-strahlenschutz/nukleare-sicherheit/atomrechtliche-behoerden-gremien-und-organisationen/>

BMUB - Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. (2013, October 15). *Safety Standards of the Nuclear Safety Standards Commission*. Retrieved April 2, 2015, from <http://www.bmub.bund.de/en/topics/nuclear-safety-radiological-protection/nuclear-safety/legal-provisions-technical-rules/safety-standards-of-cta/>

BMUB - German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. (2015). <http://www.bmub.bund.de/en/>. (N. C. Federal Ministry for the Environment, Producer) Retrieved April 2, 2015, from <http://www.bmub.bund.de/en/>: <http://www.bmub.bund.de/en/topics/nuclear-safety-radiological-protection/nuclear-safety/legal-provisions-technical-rules/>

BMUB - The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety. (2014, March 10). *Developments in Germany following the nuclear disaster in Japan*. Retrieved April 12, 2015, from <http://www.bmub.bund.de/en/topics/nuclear-safety-radiological-protection/nuclear-safety/response-to-fukushima/overview/>: <http://www.bmub.bund.de/en/topics/nuclear-safety-radiological-protection/nuclear-safety/response-to-fukushima/overview/>

BMUi. (2012). *German Action Plan for the implementation of measures after Fukushima Dai-ichi reactor accident*. Berlin: BMUi - Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

BMWi. (2014). *The energy transition: key projects of the 18th legislative term*. Federal Ministry for Economic Affairs and Energy.

BMWi. (2015, March 26). *Cost-effective, plannable and market-focused: the 2014 EEG reform*. Retrieved from Energiewende direkt: <http://www.bmwi-energiewende.de/EWD/Redaktion/EN/Newsletter/2015/01/Meldung/eeg-reform.html>

BMWi. (n.d.). *Energy - Grids and Grid Expansion*. Retrieved from Public Dialogue: <http://www.bmwi.de/EN/Topics/Energy/Grids-and-grid-expansion/public-dialogue.html>

BMWi. (n.d.). *Energy - Grids and Grid Expansion*. Retrieved from Electricity Grids of the Future: <http://www.bmwi.de/EN/Topics/Energy/Grids-and-grid-expansion/electricity-grids-of-the-future,did=667666.html>

BMWi. (n.d.). *Energy - Renewable Energy*. Retrieved from Sun, Wind & Co.: <http://www.bmwi.de/EN/Topics/Energy/Renewable-Energy/sun-wind-co.html>

BMWi. (n.d.). *Federal Ministry for Economic Affairs and Energy*. Retrieved from Energy of the future - An overall strategy for the energy transition: <http://www.bmwi.de/EN/Topics/Energy/Energy-Transition/overall-strategy.html>

Bonin, B., & Royer, E. (2014). *Physics and Economics of Nuclear Energy. Physics and Economics of Nuclear Energy - HEC Energy and Finance Certificate*. Paris: CEA - Commissariat à l'énergie atomique et aux énergies alternatives.

- Bredberg, I., Hutter, J., Kühn, K. P., & Dose, J. (2012). *Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2011*. Salzgitter: Bundesamt für Strahlenschutz.
- Bredberg, I., Hutter, J., Kühn, K., Niedzwiedz, K., Philipczyk, F., & Dose, J. (2014, November). Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2013. Salzgitter, Germany.
- Bryan, A. C. (2009). Thorium as a Secure Nuclear Fuel Alternative? *Journal of Energy Security*.
- Buchan, D. (2012). *The Energiewende - Germany's Gamble*. Oxford Institute for Energy Studies.
- Bundesnetzagentur. (2014, 08 22). Retrieved from Zuverlässigkeit der Stromversorgung auf konstant hohem Niveau:
http://www.bundesnetzagentur.de/cln_1411/SharedDocs/Pressemitteilungen/DE/2014/140822_Stromversorgung.html?nn=265778
- Choppin, G., Rydeberg, J., & Liljenzin, J.-O. (1995). *Radiochemistry and Nuclear Chemistry* (2 ed.). Oxford, United Kingdom: Butterworth-Heinemann Ltd.
- Council of European Energy Regulators. (2015). *CEER Benchmarking Report 5.2 on the Continuity of Electricity Supply - Data Update*. Brussels: CEER.
- DAtF - Deutsches Atomforum e.V. (2000, June 2000). Vereinbarung zwischen der Bundesregierung und den Energieversorgungsunternehmen vom 14. Juni 2000. *Vereinbarung vom 14. Juni 2000*.
- DAtF - Deutsches Atomforum e.V. (2011, April). Deutsche Sicherheitstechnik im Vergleich zum Tschernobyl-Reaktor. Berlin, Germany.
- DAtF - Deutsches Atomforum e.V. (2013, November). Sicherheit ist das oberste Gebot. Berlin, Germany.
- DAtF - Deutsches Atomforum e.V. (2014 (b), December). Kernenergie und Kerntechnik in Deutschland und weltweit.
- DAtF - Deutsches Atomforum e.V. (2014). Kernenergie in Zahlen 2014. Berlin, Germany: DAfF - Deutsches Atomforum e.V.
- DAtF - Deutsches Atomforum e.V. (2014). *www.kernenergie.de*. Retrieved March 11, 2015, from <http://kernenergie.de/kernenergie-en/history/index.php>: <http://kernenergie.de/kernenergie-en/history/index.php>
- DAtF, Deutsches Atomforum e.V. (2015, March). Der Reaktorunfall in Fukushima Daiichi. *Folge fehlerhafter Auslegung und unzureichender Sicherheitstechnik*. Berlin, Germany.
- Davies, L. L. (2011). Beyond Fukushima: Disasters, Nuclear Energy, and Energy Law. *Brigham Young University Law Review*, 1, 1937-1989.
- Deutscher Bundestag. (2010). *Entwurf eines Elften Gesetzes zur Änderung des Atomgesetzes / Gesetzesentwurf der Fraktionen der CDU/CSU und FDP*. Deutscher Bundestag. Cologne: H. Heinemann GmbH und Co.

- Deutscher Bundestag. (2010(b), October). *Laufzeitverlängerung von Atomkraftwerken zugestimmt*. Retrieved June 18, 2013, from <http://www.bundestag.de>:
http://www.bundestag.de/dokumente/textarchiv/2010/32009392_kw43_de_atompolitik/index.html
- Deutscher Bundestag. (2011, 6). *Bundestag beschließt Atomausstieg und Energiewende*. Retrieved 06 18, 2013, from <http://www.bundestag.de/>:
http://www.bundestag.de/dokumente/textarchiv/2011/34938007_kw26_de_energiewende/index.html
- Devine-Wright, P., & Howes, Y. (2010). Disruption to place attachment and the protection of restorative environments: A wind energy case study. *Journal of Environmental Psychology*, 30, 271-280.
- Eddy, M. (2014, February 5). *The New York Times*. Retrieved from Germany's Clean-Energy Plan Faces Resistance to Power Lines: http://www.nytimes.com/2014/02/06/business/energy-environment/germanys-clean-energy-plan-faces-resistance-to-power-lines.html?_r=0
- European Commission. (2010). *Europeans and Nuclear Safety, Special Eurobarometer 324*. Brussels.
- European Commission- Eurostat. (2015, April). *Eurostat - European Statistics*. Retrieved April 15, 2015, from <http://ec.europa.eu/>:
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_204_c&lang=en
- European Environmental Bureau. (n.d.). Retrieved from
<http://www.eeb.org/EEB/?LinkServID=29DFC1E5-5056-B741-DB64C5B6C167A99A>
- Eurostat*. (2015, March 2). Retrieved May 5, 2015, from
<http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=tsdcc210&plugin=1>
- Forsa. (2014). *Forsa survey 2014: "Energy supply and the energy transition"*. WINGAS GmbH.
- Gawel, E., Lehmann, P., Korte, K., Strunz, S., Bovet, J., Koeck, W., . . . Wassermann, S. (2014). The future of the energy transition in Germany. *Energy, Sustainability and Society*.
- Gerbert, P., Rubner, H., Herhold, P., & Steffen, B. (2014). *Germany's Energiewende - The End of Power Market Liberalization?* The Boston Consulting Group.
- Gesellschaft für Anlagen- und Reaktorsicherheit (GRS). (2015). Fukushima Daiichi - 11.März 2011. *Unfallablauf / Radiologische Folgen*. Cologne, Garching, Berlin, Braunschweig, Germany.
- Gross, M. (2011). Energy U-turn in Germany. *Current Biology*, R379-R381.
- Hirth, L. (2012). Integration Costs and the Value of Wind Power. *USAEE Working Paper*, 12(150).
- Horst, D. v. (2007). NIMBY or not? Exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies. *Energy Policy*, 35, 2705-2714.
- I.E.A - International Energy Agency. (2009). *World Energy Outlook 2009*. Paris.

- I.E.A - International Energy Agency. (2011). *Harnessing Variable Renewables - A Guide to the Balancing Challenges*. Paris, France.
- I.E.A - International Energy Agency. (2013). *Energy Policies of IEA Countries - Germany 2013 Review*. Paris, France: I.E.A.
- IAEA - International Atomic Energy Agency. (2013). *Climate Change and Nuclear Power 2013*. Vienna: IAEA - International Atomic Energy Agency.
- IAEA - International Atomic Energy Agency. (2014, October). *The Use of the International Nuclear and Radiological Event Scale (INES) for Event Communication*. Vienna, Austria.
- IAEA - International Atomic Energy Agency. (2015, March 16). *Chernobyl Nuclear Accident*. Retrieved April 22, 2015, from <https://www.iaea.org/newscenter/focus/chernobyl>
- IAEA - International Atomic Energy Agency. (2015, April 10). *INES - The International Nuclear and Radiological Event Scale*. Retrieved April 16, 2015, from *The Use of the International Nuclear and Radiological Event Scale (INES) for Event Communication*: <http://www-ns.iaea.org/tech-areas/emergency/ines.asp>
- IAEA. (2005). *Thorium fuel cycle - Potential benefits and challenges*. Vienna: International Atomic Energy Agency.
- IAEA. (2013). *Country Nuclear Power Profiles 2013 Edition - GERMANY*. Vienna, Austria.
- International Energy Agency. (2013). *Energy Policies of IEA Countries: Germany, 2013 Review*. Paris: OECD/IEA.
- International Energy Agency. (2014 йил June). *Germany - Overview*. Paris: OECD/IEA.
- Joskow, P. L. (2011). Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies. *American Economic Review, Vol 101*(No.3), pp. 238-241.
- Kemfert, C., Petra, O., Traber, T., & Handrich, L. (2015). *Deep Decarbonization in Germany A Macro-Analysis of Economic and Political Challenges of the 'Energiewende' (Energy Transition)*. DIW-Deutsches Institut für Wirtschaftsforschung. DIW-Deutsches Institut für Wirtschaftsforschung.
- Kemfert, C., Opitz, P., Traber, T., & Handrich, L. (2015). *Deep Decarbonization in Germany - A Macro-Analysis of Economic and Political Challenges of the 'Energiewende' (Energy Transition)*. Berlin: Deutsches Institut für Wirtschaftsforschung.
- Kerner, A., Reinhard, S., & Weiß, F.-P. (2011, February). Der Unfall von Tschernobyl 1986. *atw*(56), 80-88.
- 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.
- Langniß, O., Diekmann, J., & Lehr, U. (2009). Advanced mechanisms for the promotion of renewable energy—Models for the future evolution of the German Renewable Energy Act. *Energy Policy, 37*(4), 1289-1297.

- Lieb-Dóczy, E., Börner, A.-R., & MacKerron, G. (2003). Who Secures the Security of Supply? European Perspectives on Security, Competition, and Liability. *The Electricity Journal*, 10-19.
- Linehan, J. R. (2013). Fukushima to Fessenheim: France and Germany's Policy Responses to the Fukushima Nuclear Disaster, 11 March to 18 June 2011. Ottawa.
- Mills, J. P. (n.d.). Retrieved from A History of Massive Solar Storms: What Does History Tell Us About The Coming Solar Storms:
http://space.about.com/od/sunsol/a/History_Of_Solar_Flares.htm
- Morgan, J. (2014, August). The catch-22 of energy storage. *Chemistry in Australia*, p. 22.
- N.E.A - Nuclear Energy Agency/OECD. (2010). *Comparing Nuclear Accident Risks with Those from Other Energy Sources*. Organisation for Economic Co-Operation and Development. OECD.
- Narbel, P., Hansen, J. P., & Lien, J. R. (2013, April). Global energy resources, technologies, and economy. Bergen, Norway.
- NEA - Nuclear Energy Agency / OECD. (2002). *CHERNOBYL Assessment of Radiological and Health Impacts*. Paris, France.
- Nienaber, M. (2015, June 3). *Reuters*. Retrieved from Power line standoff holds back Germany's green energy drive: <http://www.reuters.com/article/2015/06/03/germany-energy-protests-idUSL6N0WH0WH20150603>
- Oeko-Institut e.V. (2014). *Proposal for a Revision of the Industry Exemption rules under the German EEG*. Berlin: Agora Energiewende.
- Pesch, T., Martinsen, D., Heinrichs, H., & Hake, J.-F. (2012). *The German "Energiewende" - A Scenario Analyses*. Juelich, Germany: Forschungszentrum Juelich, Institute of Energy and Climate Research - Szstem Analysis and Technology valuation (IEK-STE).
- Praktiknjo, A. J. (2013). Acceptance of Supply Security and Blackouts in the Context of Climate Protection and Nuclear Energies in Germany. *36th IAEE International Conference*. Daegu: International Association for Energy Economics.
- RAP. (2015). *Report on the German power system (Version 1.0)*. Berlin: Agora Energiewende.
- Richter, F., Steenbeck, M., & Wilhelm, M. (2013). *Nuclear Accidents and Policy: Notes on Public Perception*. Berlin: German Socio-Economic Panel Study (SOEP), DIW Berlin.
- Rolle, D. C. (n.d.). Retrieved from http://www.energiewende-richtig.de/sites/default/files/portrait/vortrag-carsten_rolle-nho-2013.pdf
- Royer, E. (2014, November 19). Commissariat à l'énergie atomique et aux énergies alternatives. (T. Bennett, Interviewer)
- RSK - Reactor Safety Commission. (2011). *Translation of Chapter 1 of the document entitled "STATEMENT - Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ) deutscher Kernkraftwerke unter Berücksichtigung der Ereignisse in Fukushima-I (Japan)*. NEA-OECD.
- RWE AG. (2012). *Akzeptanz Fuer Grossprojekte*. Bocholt: RWE AG.

- Salvatore, J. (2014, January 2). H1 2014 LEVELISED COST OF ELECTRICITY GENERATION. *Bloomberg NEW ENERGY FINANCE - LEVELISED COST OF ELECTRICITY UPDATE*. 2014: Bloomberg NEW ENERGY FINANCE.
- Schill, W.-P., Diekmann, J., & Zerrahn, A. (2015, October). Power Storage: An Important Option for the German Energy Transition. *DIW Economic Bulletin*, pp. 137-147.
- Schweizer, P.-J., Renn, O., Koeck, W., Bovet, J., Benighaus, C., Scheel, O., & Schroeter, R. (2014). Public participation for infrastructure planning in the context of the German 'Energiewende'. *Utilities Policy*, 1-4.
- Sopher, P. (2015). Lessons Learned from Germany's Energiewende: The Political, Governance, Economic, Grid Reliability, and Grid Optimization Bedrock for a Transition to Renewables. *Renewable Energy Law and Policy Review*, 99-112.
- Stegen, K. S., & Seel, M. (2013). The winds of change: How wind firms assess Germany's energy transition. *Energy Policy*, 1481-1489.
- Strunz, S. (2013). The German energy transition as a regime shift. Leipzig: UFZ.
- U.S Energy Information Administration. (2014, April). Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2014. Washington D.C, USA.
- Ueckerdt, F., Hirth, L., Luderer, G., & Edenhofer, O. (2012). System LCOE: What are the costs of variable renewables? *System LCOE: What are the costs of variable renewables?* . Potsdam, Germany: Potsdam-Institute for Climate Impact Research. .
- Uekoetter, F. (2012). Fukushima and the Lessons of History: Remarks on the Past and Future of Nuclear Power. *RCC Perspectives*, 1(1), 9-32.
- Umfrage: Wähler strafen Union für Atomkurs ab. (2011, 03 23). *Spiegel Online*.
- Volkmer, M. (2013). *Kernenergie Basiswissen*. Berlin, Germany: DAfF - Deutsches Atomforum e.V.
- Volkmer, M. (2013). *Kernenergie Basiswissen*. Berlin, Germany: DAfF - Deutsches Atomforum e.V.
- Weißbach, D., Ruprecht, G., Huke, A., Czernski, K., Gottlieb, S., & Hussein, A. (2013). Energy intensities, EROIs (energy returned on invested), and energy payback times of electricity generating power plants. *Energy*, 210-221.
- Witneben, B. B. (2012). The impact of the Fukushima nuclear accident on European energy policy. *Environmental Science and Policy*, 15, 1-3.
- Wolsink, M. (2000). Wind power and the NIMBY-myth: institutional capacity and the limited significance of public support. *Renewable Energy*, 21, 49-64.
- Wolsink, M. (2007). Wind power implementation: The nature of public attitudes: Equity and fairness instead of 'backyard motives'. *Renewable and Sustainable Energy Reviews*, 11, 1188-1207.
- World Nuclear Association. (2015, June 11). Retrieved from Nuclear Power in Germany: <http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Germany/>

Zeit Online. (2011, June 30). *Bundestag besiegelt den Atomausstieg*. Retrieved June 18, 2013, from <http://www.zeit.de>: <http://www.zeit.de/politik/deutschland/2011-06/beschluss-atomausstieg-bundestag>

Zoellner, J., Schweizer-Ries, P., & Wemheuer, C. (2008). Public acceptance of renewable energies: Results from case studies in Germany. *Energy Policy*, 36(11), 4136-4141.