# Assessing the Disruptiveness of New Energy Technologies - An Ex-Ante Perspective

Stoiciu, Alexandra; Szabo, Enikö; Totev, Martin; Wittmann, Katharina; Hampl, Nina

*DOI:*
10.57938/8af16bb9-d2e3-44ce-972f-37ed868f98b8

*Published: 01/03/2014*

*Citation for published version (APA):*
Stoiciu, A., Szabo, E., Totev, M., Wittmann, K., & Hampl, N. (2014). *Assessing the Disruptiveness of New Energy Technologies - An Ex-Ante Perspective*. WU Vienna University of Economics and Business. Working Papers / Institute for Strategic Management / Energy and Strategy Think Tank No. 2
https://doi.org/10.57938/8af16bb9-d2e3-44ce-972f-37ed868f98b8

**Institute for Strategic Management**
Energy & Strategy Think Tank

Working Paper No. 2

# Assessing the Disruptiveness of New Energy Technologies – An Ex-Ante Perspective

**Contact**

Institute for Strategic Management

WU Vienna
Vienna University of Economics and Business
Welthandelsplatz 1, 1020 Vienna, Austria
Phone: +43-1-31336-4864
Mobile: +43-676-8213-4864
E-Mail: nina.hampl@wu.ac.at
Homepage: www.wu-wien.ac.at/ism

## Institute for Strategic Management
## Energy & Strategy Think Tank

## Working Paper No. 2

# Assessing the Disruptiveness of New Energy Technologies – An Ex-Ante Perspective

Project Report

March 2014

This research project was sponsored by OMV AG.

**Project Team:**

Alexandra Stoiciu
Enikö Szabo
Martin Totev
Katharina Wittmann
Nina Hampl

**Contact:**

WU Vienna University of Economics and Business
Institute for Strategic Management
Welthandelsplatz 1, 1020 Vienna, Austria
Phone: +43-1-31336-4864
Mobile: +43-676-8213-4864
E-Mail: nina.hampl@wu.ac.at
Homepage: www.wu-wien.ac.at/ism

# Content

# List of Figures

# List of Tables

# 1. Introduction[1]

## 1.1. Problem statement

We live in a world where the way in which we produce and use energy is suffering fundamental alterations. Worldwide, energy demand is rising and cannot be covered exclusively with diminishing resources of fossil fuels. Also at an international level more and more attention is being given to the effort of minimizing greenhouse gas emissions. Consequently, the focus is rapidly turning towards alternative energy sources. It is increasingly becoming more and more important for companies and producers, operators, financial institutions as well as for the large public to take smart decisions for the future by choosing green technologies and thus gradually trying to reduce fossil fuel dependence.

Presently, due to social pressure and market competition, more and more energy companies face the challenging but also very important task of staying relevant, trying to constantly generate new ideas but also dealing with new products and technologies that might threaten their position. As a result this study focuses more on disruptive innovations because in comparison to breakthrough innovations, which are unconventional and break all patterns, disruptive ones can create new markets or reconfigure existing ones and thus they are more likely to happen (Sav, 2013). Therefore the prediction of new disruptive behavior for products or technologies would facilitate decision making in terms of strategy and planning, not only for companies but also for institutions and establishments that need to adapt to the future energy trends.

## 1.2. Objective and scope

Innovation and the development of new technologies has become an increasingly important field of business leaders and an equally interesting topic for the research community. One specific area of innovation management, however, has attracted particular interest, namely the theory of disruption introduced by Clayton Christensen (Christensen, 1997). The phenomenon of disruptive technologies claims to solve the growth needs of many industries, thus it is very crucial to understand what conditions can enable this disruptive change. This study intends to focus on disruptive technologies as a specific field of innovation management.

For those organizations that experience disruption, they usually understand the situation when it is already too late. The real challenge to any theory, especially if it is of high relevance for managers, is how it performs predictively. Can the theory of disruptive technologies be used not only to analyze cases ex post but to predict the potential disruptive technologies ex ante? Established companies are skeptical of the idea of disruptiveness, because of the difficulty of making predictions given the ex post nature of the theory (Danneels, 2004; Govindarajan & Kopalle, 2006 b). In this regard the goal of this report is to provide a general measure of disruptiveness and develop a framework that can assess technologies whether they have the potential to be proven disruptive. The developed assessment framework captures the essential characteristic and holistic success factors for disruptive technologies based on the theory of

---

[1] Please note that most of the text of this project report is drawn from the master theses Stoiciu (2014), Szabo (2014) and Totev (2014) without explicit citation.

Christensen and a number of clarifications as seen in the literature. The framework is applied and validated by assessing the disruptive potential of five renewable energy technologies (wind energy, solar energy, biomass, hydro power, geothermal) in the power generation, heating and transportation sectors of four European countries (Austria, Bulgaria, Germany and Romania). The results show the applicability of the framework and give insights into technology and country specific determinants of energy market sector disruptions.

## 1.3. Report structure

This report is structured as follows: Chapter 2 gives an overview of the main literature in the innovation management field and further defines the theoretical concept of disruptive technologies used in this study. Chapter 3 describes the methodological approach. Chapter 4 deals with renewable energy sources and the according technologies. Chapters 5-8 analyze the energy markets in different European countries (Austria, Romania, Germany and Bulgaria). Chapter 9 provides an overall conclusion of this study.

# 2. Literature review

## 2.1. Definitions and classifications

### 2.1.1. Concept of innovation and technological innovation

This chapter intends to explain the definitions of different types of innovation more precisely and provides a brief overview of the innovation management literature. This summary will help the reader to understand the analytical structure of innovations and how they build upon each other.

Since Schumpeter (1942) coined the concept of 'creative destruction' many scholars proposed a number of different innovation typologies and classified innovations in different ways. The underlying assumption for these distinct typologies was that various categories of innovation have diverse attributes, originate from different sources and they can have a different impact on companies, competition or the economy as a whole. Since all of these innovation categories shed light on the topic from different viewpoints, treating them all the same would cause confusion. By distinguishing among the many definitions of innovation, one can better manage their development and predict their market impact (Markides, 2006; Chandy & Prabhu, 2011; Waldner, 2010).
In the research literature, the definition of innovation incorporates the notion of novelty, commercialization and/or implementation. This means that an idea must be developed into a product, process or service and must be commercialized and applied to be defined an innovation (Popadiuk & Choo, 2006). A new product is implemented when it is introduced on the market. New processes, marketing methods or organizational methods are implemented when they are transferred into the actual use in the firm's operations. Thus an invention that moves from the research lab into utilization and provides economic value to the firm can be considered as innovation (Garcia & Calantone, 2001; OECD/EUROSTAT, 2005).

An OECD study (2005) captures the essence of innovation and outpoints the requirement for implementation in the definition: "An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD/EUROSTAT, 2005, p. 46). Rogers takes a similar view in his definition of innovation: "An innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption. It matters little (...) whether or not an idea is 'objectively' new as measured by the lapse of time since its first use or discovery. The perceived newness of the idea for the individual determines his or her reaction to it" (Rogers, 2003, p. 12).

Rogers' definition explains the requirement of newness from the consumers' point of view, while the OECD innovation statement captures the perspective of the organization implementing the innovation. Nevertheless, the following pattern arises from both definitions: the requirement for implementing the innovation and for the newness of the innovation. This includes products, processes and methods that firms are the first to develop and those that have been adopted from other firms or organizations (OECD/EUROSTAT, 2005). Many researchers agree that innovation can be measured by its newness, however, little continuity exist in the literature about from whose view this degree of newness should be looked at. The distinction between macro and micro perspectives is crucial as it considers to whom and from whose perspective the innovation is new. From a macro perspective, the newness of the innovation is assessed based on factors exogenous to the firm. Macro impact innovations are seen worldwide, industry wide or market wide. The impacts are not dependent on a firm's strategy, competencies, available resources and knowledge structure. On the other hand, the micro perspective evaluates newness from the viewpoint of the firm or the firm's customers. In this case, innovation can take place in different parts of the organization's value chain (Garcia & Calantone, 2001).

This broad definition of an innovation embraces a wide scope of potential innovations. For further study the definition of innovation must be narrowed down to categories:

1. *Product or service innovations* have to be significantly new goods or services aiming at satisfying market needs. This includes improvements in technical details, components and materials, integrated software or other functional features (Afuah, 1998; OECD, 2008).
2. *Process innovation* is concerned with the implementation of a new or significantly improved production or delivery method in a firm's operations such as changes in input materials, techniques or equipment (Popadiuk & Choo, 2006; OECD, 2008).
3. *Technological innovation* is the knowledge of components, processes and techniques that go into a new or improved product launched on the market or into a new or improved operational process applied in industry and commerce (Popadiuk & Choo, 2006; OECD, 2008).
4. An even broader innovation concept is *business model innovation*, which involves systematic changes to the value proposition offered by a product or service and to the cost structure subjected to the firm offering it (Chandy et al., 2010).

A technological innovation is a fundamentally different phenomenon from a business model innovation as well as from a product or process innovation. These innovations arise in different ways, have different impacts on the competition, and require different responses from incumbents (Markides, 2006). Here, the focus will be on **technological innovations**, since this type suits best the requirements of assessing renewable energy technologies. However, it is important to keep in mind the analytical structure of innovations and how they are connected.

### 2.1.2. Models for classifying innovations

A number of models have been developed to give a dynamic tone to the theory and to assess innovation and technological change. The boundaries of these frameworks are, however, often not clear or consistent and redundancies between them can be observed (Gatignon et al., 2002; Waldner, 2010). This chapter introduces some important frameworks dealing with classifying technological innovations.

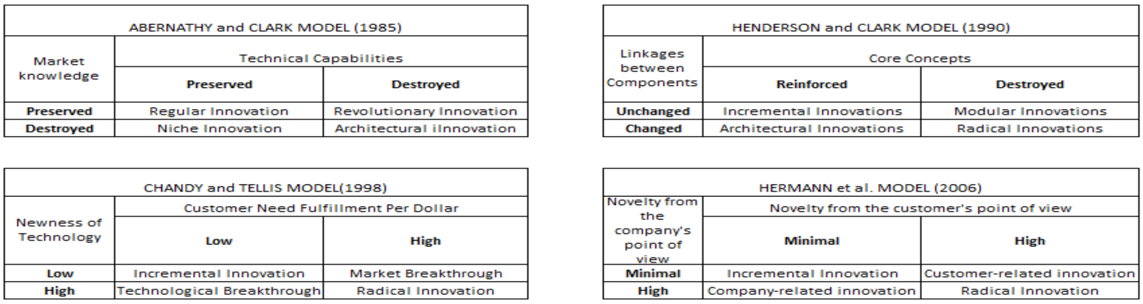
**Abernathy and Clark's** (1985) model classifies innovations according to their impact on the market knowledge and technological capabilities of the firm (see Figure 1). They differentiate between the preservation or destruction of this market knowledge and technological capability. A firm's technological capabilities could become obsolete while its market capabilities remain intact. Therefore, even if the technological capabilities have been destroyed and become obsolete due to a new innovation, a firm can use its market knowledge to take advantage over a new entrant. Combining the dimensions of market knowledge and technological capabilities four kinds of innovation arise. Regular innovation builds on the incumbents' existing technological capabilities and the market knowledge. Niche innovation preserves existing technological capabilities but destroys market knowledge. Revolutionary innovation turns technological capabilities obsolete but preserves market knowledge. Architectural innovation arises if both technological and market capabilities become obsolete (Abernathy & Clark, 1985; Waldner, 2010).

**Henderson and Clark's** (1990) framework classifies innovations along two dimensions. The horizontal dimension captures an innovation's impact on the core design concepts, while the vertical captures its impact on the linkages between components. They call the linkages between components architectural knowledge, that change the way in which the components of an established system are linked together while leaving the core design concepts named component knowledge untouched. In their model component is defined as a physically clear-cut portion of the innovation that involves the core design concept and performs a well-defined function. The combination of component and architectural knowledge produces four kinds of innovation (see Figure 1). Incremental innovation refines and extends an established design. These improvements occur in individual components, but the underlying core design concepts, and the links between them, stays the same. Radical innovations are those, where both types of knowledge are destroyed. Radical innovation establishes a new dominant design and the linkages between components also changes. Architectural innovations maintain existing core design components, but change the linkages between components, thus its architecture. Accordingly, modular innovations destroy core design concepts of the components but leave the linkages between components unchanged. The concept of architectural innovation could explain before the theory of Christensen why established companies fail in the face of innovations that are actually not radical in nature. In their view architectural innovations pose critical challenge for incumbents. The reasons for this are twofold, once they are difficult to be identified since the core design concepts remain the same and second incumbents struggle to see which existing component knowledge is useful and which must be newly learned (Henderson & Clark, 1990; Waldner, 2010).

**Chandy and Tellis's** (1998) model suggest based on the review of literature that two common dimensions underlie most definitions of innovation: technology and markets. The first dimension (technology) determines the extent to which the technology involved in a new product is different from prior technologies. The second dimension (market) determines the extent to which the new product fulfills key customer needs better than existing products. Considering two levels for each factor (low and high) leads to four types of technological innovations (see Figure 1): incremental innovations, market breakthroughs, technological breakthroughs and radical innovations. Incremental innovations show relatively minor changes in technology and give relatively low incremental customer benefits per dollar. Market breakthroughs are based on core technology that is similar to existing ones but provide substantially higher customer fulfillment per dollar. Technological breakthroughs adopt a substantially different technology than existing technologies but provide low customer need fulfillment. In contrast to the previous three, radical innovations are associated with substantially new technology and provide substantially greater customer benefits per dollar in comparison to the existing technology. In their framework the authors point out that although not every technological breakthrough becomes a radical innovation, radical innovations have the potential to render existing technologies obsolete and change the basis of the market competition (Chandy & Tellis, 1998).

**Herrmann et al**. (2006) also introduced their framework based on the concept of novelty. In their view an innovation can be described as a novel technology, which is clearly different from the previous one. The framework specifies the term novelty though operationalizing the concept by two dimensions. The concept takes into consideration the perspective from which the novelty is assessed. Representatives from companies often have a different view on innovations and their changes over time than customers. Based on this assumption, the framework differentiates between novelty as seen by consumers (novelty of utility creation) and suppliers (novelty of technology). Furthermore, the framework also differentiates on the extent and intensity of innovations. Linking the two dimensions and their intensity leads to a four type matrix, as shown on Figure 1. Incremental innovations include minimal changes in the technology being followed by a minimal improvement in benefits achieved for customers. A customer-oriented innovation introduces a new innovation based on existing technology and satisfies customer needs better in comparison to other technologies. In contrast, a company-related innovation is characterized by a new technology; however, the related benefit to the technology is not yet clear to the customer. Radical technological innovations are characterized by a new technological basis and a novel utility experience to the customer (Herrmann et al., 2006).

**Figure 1: Four models of innovations**



| ABERNATHY and CLARK MODEL (1985) | | |
|---|---|---|
| Market knowledge | Technical Capabilities | |
| | **Preserved** | **Destroyed** |
| **Preserved** | Regular Innovation | Revolutionary Innovation |
| **Destroyed** | Niche Innovation | Architectural iInnovation |

| HENDERSON and CLARK MODEL (1990) | | |
|---|---|---|
| Linkages between Components | Core Concepts | |
| | **Reinforced** | **Destroyed** |
| **Unchanged** | Incremental Innovations | Modular Innovations |
| **Changed** | Architectural Innovations | Radical Innovations |

| CHANDY and TELLIS MODEL(1998) | | |
|---|---|---|
| Newness of Technology | Customer Need Fulfillment Per Dollar | |
| | **Low** | **High** |
| **Low** | Incremental Innovation | Market Breakthrough |
| **High** | Technological Breakthrough | Radical Innovation |

| HERMANN et al. MODEL (2006) | | |
|---|---|---|
| Novelty from the company's point of view | Novelty from the customer's point of view | |
| | **Minimal** | **High** |
| **Minimal** | Incremental Innovation | Customer-related innovation |
| **High** | Company-related innovation | Radical Innovation |

Source: Abernathy & Clark (1985); Henderson & Clark (1990); Chandy & Tellis (1998); Herrmann et al. (2006)

## 2.2. Technological innovations from a technology viewpoint

Understanding technological innovation is vital for several reasons. Technological change is perhaps the most powerful engine of growth. It can fuel the growth of new brands (e.g. Gillette Mach 3), create new growth segments (e.g. digital video camera) and transform small firms into market leaders (e.g. Intel) (Sood & Tellis, 2005). The goal of this section is to provide an explanation for classifying innovation based on a technological dimension. As also seen in the above described models (Figure 1), the report will make a distinction between radical and incremental technological innovations.

The definition of technology is closely connected to the technological innovation concept. Technology is a “means of solving a problem based on a platform or a scientific principle” and in the case of technological innovation it is “distinctly different from the current scientific principle used to solve the same problem” (Tellis, 2006, p. 36). Sood and Tellis (2005) classified these innovations as either belonging to platform innovations (unique scientific principle) or component innovations (parts and materials) or design innovation (layout and links). However, as long as the underlying scientific principle stays the same, all these types of technological changes can be described as platform innovations, since modifications within each innovation can lead to improved performance over time (Sood & Tellis, 2005; 2011).

Technological innovation has been explored from different aspects for more than 30 years, however it is found to be a common characteristic in literature to make a distinction between the technology dimension and other characteristics of the technological innovation. Most scholars agree that the "**radical innovation**" is determined by the underlying technology. In this sense, the radicalness refers to the extent an innovation is based on a substantially new technology relative to existing practice. Radicalness is a characteristic, which assesses the degree to which the technological innovation improves the performance faster than the existing technological trajectory (Gatignon et al., 2002; Govindarajan & Kopalle, 2006 a). Hence "**incremental innovation**" means refining, improving and exploiting an existing technological trajectory. Incremental innovations are the ones that "improve price/performance at a rate consistent with the existing technical trajectory" (Gatignon et al., 2002, p. 1107). In comparison, radical innovation disrupts an existing technological trajectory and it advances "the price/performance frontier by much more than the existing rate of progress" (Gatignon et al., 2002, p. 1107).

In reviewing the academic literature, radical innovation has been represented in many ways and in most cases vaguely defined. Abernathy (1978) describes radicalness in terms of the degree of newness of the innovation. The definition from Hill and Rothaermel (2003) goes on to argue that radical technological innovation involves methods and materials that are novel to incumbents, and that these novel methods and materials are derived from either an entirely different knowledge base or from the recombination of the incumbents knowledge with a new stream of knowledge. Damanpour (1991) classifies innovation in terms of degree of change they cause in the existing technology and practices of the organization. In each case, dimensions of radicalness are presented but the content of the dimensions and its operationalization is mostly not clear. Green (1995) identified four basic factors around radical technological innovation. He argues that simply classification of technologies as radical or incremental may be oversimplifying the construct. In his view, technologies can be more or less radical on a number of dimensions that can be differentiated within the general concept of radical innovation (Green, 1995):

1. *Technological uncertainty:* the degree to which the technology employed is not well developed or understood in the general scientific community
2. *Technical inexperience:* the degree to which the firm lacks the required technological experience and knowledge
3. *Business inexperience:* the degree to which the firm lacks required business experience and knowledge
4. *Technology cost:* the cost of developing the technology

Utterback, (1996) goes even further by providing the following definition of radical technological innovation: "By radical innovation, I mean change that sweeps away much of a firm's existing investment in technical skills and knowledge, designs, production technique, plant and equipment" (Utterback, 1996, p. 200). On the other hand incremental innovations give way to standardization and to status quo within the firm or industry.

As seen above, recent literature on new product development shed light on the importance of classifying technological innovation into radical and incremental. However, the definition can be presented in many ways and is always dependent upon from whose perspective radicalness is being evaluated. It is critical to note that radicalness is relative to the firm; therefore the perspective from which the novelty is to be assessed must be determined. What one firm identifies as a radical innovation, can be labeled as an incremental innovation by another firm (Garcia & Calantone, 2001). Furthermore, it is also important to emphasize that while radical technological innovations can be identified by referring to the relative newness of the technology, what cannot be identified ex ante with certainty is whether and when a radical technological innovation will become a commercial success. Many promising technological innovations fail the test of market acceptance even though they represent major technological progress (Hill & Rothaermel, 2003). Therefore in the next chapter the most important innovation feature, the market based dimension will be explored.

## 2.3. Technological innovations from a market viewpoint

The above described models of innovation (Figure 1) signalized the need to discuss the market based dimension in depth. Market based explanations of the competitive outcomes of technological innovations focus on the impact on performance trajectories and industries from a different viewpoint than the technology perspective. Christensen's disruptiveness theory can also be viewed as a market based explanation. Because of its detailed and comprehensive nature, the focus will be on Christensen's theory throughout the report. This section is organized as follows. The first part outlines the notion of disruptive technologies, pioneered by Christensen. Secondly, an expanded view on Christensen's theory will be presented before the different enabling factors for disruptive technological innovation will be described and in the end critiques on Christensen's work will be discussed.

### 2.3.1. Christensen's disruptive technology theory

The theory of disruptive technology has been coined by Clayton Christensen in his seminal and path-breaking works: The Innovator's Dilemma (Christensen, 1997), The Innovator's Solution (Christensen & Raynor, 2003), and Seeing What's next (Christensen, Anthony, & Roth, 2004). The theory has made a significant impact on management practices and awakened plenty of rich debate within the research community (Yu & Hang, 2010).

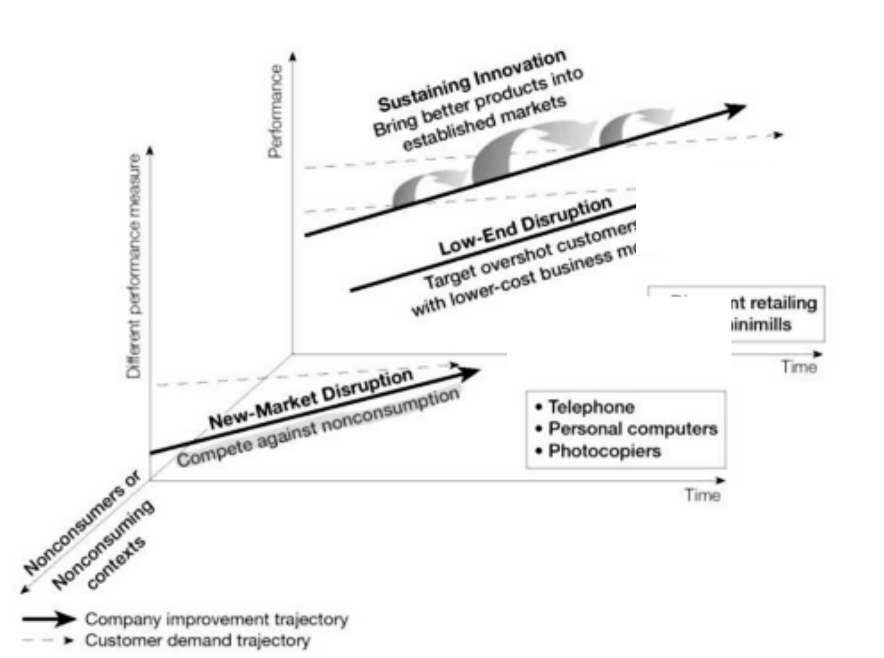
The disruptive innovation theory depicts situations in which new organizations can use relatively simple, convenient, low-cost innovations to create growth and prove superior over established industry players. The theory states that incumbents have a good chance of beating entrant attackers in introducing sustaining innovations. But incumbents almost always lose to attackers when the competition is about disruptive innovations. One important starting point for Christensen's work on disruptive innovations was the phenomenon that market entrants can gain competitive advantage over incumbents in the event of technological change. Christensen created his theory by studying the history of the disk-drive industry and tried to explain the failure of incumbents with existing innovation typologies. However, he was not able to fully define the market failure anomalies with existing theories; therefore he developed his own technological innovation framework (Christensen, Anthony, & Roth, 2004; Waldner, 2010).

Christensen points out that the disruptive innovation concept is very different from the incremental and radical distinction that has previously characterized many innovation studies. "**Sustaining technological innovations"** move companies along established improvement trajectories. They are improvements to existing products along the dimensions of performance that mainstream customers in major markets have historically valued. Most technological innovations are sustaining in a given industry. Christensen argues that sustaining technologies can be radical in nature, while others are incremental; referring to the fact that disruptiveness moves along a different dimension as radicalness. In a competition of sustaining innovations, the established competitors in most cases win over the market entrants. On the other hand "**disruptive technological innovations"** initially offer lower level of performance in traditional performance measurement dimensions. However, they introduce a new value proposition, such as simplicity, convenience and lower price. Thus, disruptive technologies either create new markets or reshape existing industries (Christensen, 1997; Christensen, Anthony, & Roth, 2004).

Disruptive innovation happens in a process, illustrated in Figure 2. A central element of Christensen's framework is the observation that technologies can progress faster than market demand. In any given market customers can only absorb a limited rate of improvement in the performance of the technology and will reward performance improvement till a limited extent (customer demand trajectory). Firms in their quest to provide better products than the competition and earn higher profits, often overshoot their market with sustaining innovations. This means that established companies improve technologies faster than their customers need or are willing to pay for. The idea of "low end disruption" is facilitated by such overshooting by incumbents' technologies: when product performance is higher than what the market demands, customers will no longer make product choices based on established performance attributes but will turn their attention to alternative benefits. In the early development stage such disruptive technology can only serve niche markets that value its non-standard performance attributes. Subsequently, further development can raise the disruptive technology's performance on the mainstream performance attributes to a level sufficient to satisfy mainstream customers. The market disruption occurs when, despite its inferior performance on attributes valued by the mainstream market, the new technology displaces the mainstream product also in the mainstream segment since high end customers start to switch from the old technology to buying the new one. Steel mini-mill is a good example of "low end disruption" where the new market players forced step by step the mainstream integrated steel mills out of the market (Christensen, 1997; Yu & Hang, 2010).

Christensen et al. (2003) refined later his theory and introduced the notion of "new market disruptive innovations" (see Figure 2). While "low end disruptions" attack the least profitable and most overshot customers, "new market disruption" creates a new value proposition, where the challenge is to compete against non-consumption and not the established technologies. “New market disruptive innovations” can occur when characteristics of existing technologies limit the number of potential consumers or force consumption to take place in inconvenient, centralized settings. Examples are the wireless telephone or the Xerox photocopier, which created new growth by making it easier for people to do something that historically required deep expertise or great wealth. All the three innovation offerings are assigned as “company improvement trajectory” on Figure 2 (Christensen, Anthony, & Roth, 2004; Yu & Hang, 2010).

**Figure 2: The disruptive innovation theory**



Source: Christensen, Anthony, & Roth (2004, p. xvi)

Disruptive innovations are in most cases introduced by new entrants and tend to be ignored initially by incumbents. The reasons why established companies are not investing aggressively in disruptive technologies are manifold. First, disruptive products generate lower margins and less profit than existing technologies. Second, disruptive technologies typically are first commercialized in emerging or insignificant markets. And third, the incumbent’s most profitable target segment generally does not want or cannot use products based on disruptive technologies. In most cases, a disruptive technology is in the first place only welcome by the least profitable customers in the market. Hence, most companies, listening to their mainstream customers and focusing on generating higher margin products, are rarely able to approve a business case for investing in disruptive technologies until it is too late. On the other hand market entrants are motivated to introduce disruptive technologies since they have less to loose and for them the disruptive technology can be their only chance to gain a foothold in the market (Christensen, 1997; Christensen, Anthony, & Roth, 2004; Danneels, 2004). Christensen calls this factor “asymmetries of motivation” because incumbents in disrupted markets are more motivated to flee to high-end consumers with higher profit margins, instead of defending low-end and from their view less attractive segments. What justifies this view of incumbents is the reality that the resource allocation process of established firms is designed to only support sustaining innovations. This is called the innovator's dilemma: managers of incumbent firms are pressured by shareholders to deliver superior returns on investment and therefore to focus on high-margin sustaining innovation and to neglect lower margin innovations. This process leads to a situation, where incumbents "innovate themselves out of the market" while offering better and better performing products but missing out on disruptive technologies (Christensen & Raynor, 2003; Christensen, 1997; Waldner, 2010).

One of the key findings of Christensen's model is that disruptive technological innovations eventually grow to an extent to dominate the market. In "The Innovator's Solution" the authors argue that disruption is a process and not an event, therefore it can take many years for the forces to get though an industry to materialize into a disruption but they are always at present (Christensen & Raynor, 2003). When the disruptive innovation finally starts to invade the mainstream market, established firms will realize the threat, although by then it is often too late for them not to lose a big chunk of the market in favor of the attacker. Fundamentally, the attacker's advantage stems from the incumbent's inertia and inability to change strategies (Rosenbloom & Christensen, 1994; Bower & Chrisensen, 1995).

Christensen concludes that managers need to abandon some widely accepted rules of good management at the time when it can be predicted that a disruptive technology is likely to break its way into the market. He recommends that established organizations should not adapt a generic technology strategy, rather they should take distinctly different postures whether they are facing a disruptive or sustaining strategy. If management can understand the coming changes, they can in fact succeed when confronted with disruptive technological change. The principles of established organizations need to be overcome to harness disruptive technology (Christensen, 1997, pp. xvii-xxiii; Christensen & Raynor, 2003).

1. *"Principle #1. Companies depend on customers and investors for resources"*: when faced with a disruptive technology, an estabilished company cannot be expected to allocate the critical financial and human resources needed to compete for the low-end, low-margin emerging market. Creating an independent organization for welcoming the disruptive technology is the only viable option for incumbents to succesfully compete against attackers (Christensen, 1997, pp. xvii-xxiii).
2. *"Principle #2. Small markets don't solve the growth needs of large companies":* when faced with a disruptive technology, incumbents should give responsibility to commercialize the disruptive technology to an organization whose size matches the size of the targeted market (Christensen, 1997, pp. xvii-xxiii).
3. *"Principle #3. Markets that don't exist can be analyzed":* companies whose investment process and management board requires quantification of market sizes and financial returns before the technology can enter the market make serious mistakes when it is about disruptive technology. They demand market data when costs and revenue projection does not exist yet. Using planning methods developed to manage sustaining technologies fail when faced with disruptive change (Christensen, 1997, pp. xvii-xxiii).
4. *"Principle #4. Technology supply may not equal market demand":* This principle refers to the rate of technology progress where the performance development exceeds the performance demanded by the mainstream consumers. While

incumbents are developing sustaining technologies they can in the meantime create a niche for disruptive innovations to invade the market. Therefore incumbents should foresee trends in how their mainstream consumers use the technology and what performance measures they value. Only this way they can catch the point which can change the basis of competition (Christensen, 1997, pp. xvii-xxiii).

### 2.3.2. Critique on Christensen's theory

Despite the fact that Christensen's work contributed enormously to the understanding of technological innovations, his findings have left many questions unanswered among the research community. This chapter aims to give an overview of the most important critical arguments and related suggestions by other scholars (Danneels, 2004).

Danneels (2004) provided an extensive research on the critique of the concept of disruptive technologies. The first and most essential critique is that Christensen did not establish a clear **definition** on what exactly a disruptive technology is. The disruptive theory fails to provide clear criteria to determine when a technology can be considered as disruptive. Furthermore, it is also ill-defined in the Innovator's Dilemma (1997) whether a technology is inherently disruptive or disruption is dependent on the perspective of the company subject to it. Christensen himself later argued that a technology can be disruptive to some but sustaining to other firms, therefore a technology can only be disruptive relative to another technology or another competitor (Danneels, 2004; Christensen & Raynor, 2003).

Solving the problem of a precise definition, Danneels suggested his own definition based on Christensen's and other researchers' recommendations: "A disruptive technology is a technology that changes the bases of competition by changing the performance metrics along which firms compete…because they introduce a dimension of performance along which products did not compete previously" (Danneels, 2004, p. 249). Customer needs determine which performance dimensions shape the basis of competition by meaningfully differentiating between competing technologies. The problem with Christensen's theory is that in his presented cases only one or two performance dimensions dominate customer needs. However, in the reality the number of performance dimensions is much higher and customers make trade-offs between these performance attributes. Therefore Christensen's analytical tool that measures only one performance attribute of the mainstream technology against one of the disruptive technology can be challenged (Danneels, 2004; Waldner, 2010).

Another important point, Danneels suggests to be clarified, is the question whether the disruptive technology framework can **make ex ante predictions**. Can the theory also be used to assess disruptiveness not only from the hindsight but also looking into the future? Christensen's work would be most practicable if it allowed managers to recognize which technology will become disruptive. Again, Christensen tries to solve this question by introducing the performance trajectories chart for identifying disruptive technologies. This method is only useful ex post when the relevant performance measures have been already identified. However, ex ante disruptiveness assessment would require to predict what performance the market will demand along various dimensions and what performance levels technologies will be able to supply. According to Danneels this can be very challenging in the case of very new technologies for which only little data exists. Since Christensen presented case studies mainly from the past, he has been accused of highlighting only technologies that eventually turned out to be disruptive (Danneels, 2004; Waldner, 2010).

Christensen found that established organizations fail when the competition is about disruptive technologies. However other empirical studies seem to contradict Christensen's theory and claim that a much smaller number of **incumbents fail** at the times of disruptive change (Danneels, 2004; Waldner, 2010). Some authors even found that incumbents were more likely to survive in the long term and introduce innovative technologies (Tellis, 2006; Chesbrough, 2003). One can thus assume that as opposed to Christensen's suggestions not all incumbents falter in the face of disruptive technologies. Therefore scholars suggested to further analyze what factors determines whether incumbents fail or succeed in the case of disruptive change (Danneels, 2004; Waldner, 2010).

Another criticized issue is that Christensen argued **against customer orientation** by saying that incumbents are captivated by their mainstream customers and therefore miss the emergence of disruptive technologies. In Christensen's view the primary reason why established companies fail when faced with disruptive change is because they pay too much attention to their existing customers (Christensen & Bower, 1996). Danneels draws attention to the fact that customer orientation does not necessarily mean to only focus on current customers but also on potential customers. Danneels goes on by saying that incumbents described in Christensen's studies show a shallow understanding of their customer's need. Therefore a sincerely customer oriented company should understand not just the explicit but also the implicit and unexpressed needs of its current customers. Thus, Christensen's argument for incumbents' failure may be too simplistic and narrow focused (Danneels, 2004; Waldner, 2010).

The last critique is aimed at Christensen's recommendation on setting up a **separate business unit** to explore potentially disruptive technologies. Christensen argues that the traditional resource-allocation process hinders the progress of disruptive technologies since they require a different cost structure in order to be profitable and the size of the opportunity may seem insignificant for shareholders. However, in Danneels' view a separate business may have benefits but they also entail disadvantages and trade-offs and therefore can lead to conflicts within the organization (Danneels, 2004; Waldner, 2010).

### 2.3.3. Disruptive technologies: an expanded view

Christensen's concept is enticing due to the clarity of the case studies presented and its claimed generality across industries. However, by focusing on the supply side interaction of firms and technologies and emphasizing disruption from the low-end Christensen ignores other potential disruptive patterns of change (Utterback & Acee, 2005; Adner, 2002). This chapter is intended to discuss proposed expansions and refinements of Christensen's model by other scholars.

**Adner** (2002) focused on demand-side factors and identified conditions that enable disruptive dynamics. By examining how consumers assess technology and how this assessment changes as technology performance improves, Adner introduced a new theoretical model describing the impact of the demand environment on the competition. With the help of this model he shows how technology improvement can blur the boundaries that divide market segments and change the basis for competition. The structure of demand is described by two factors characterizing market segment preferences: preference overlap and preference symmetry. Preference overlap refers to the degree to which performance improvement is valued in one segment is also valued in another segment (preference similarity), thus serving as an indicator of the ease with which firms can invade other market segments. The other factor, preference symmetry refers to the relative value a segment's customers place on performance improvements in the preferred functional attributes of another segment (Adner, 2002).

Adner's model can be described as a process: as the established technology improves and consumers' performance needs are first met and later even exceeded, consumers' willingness to pay for improvements decreases. This opens up new market segments for potential disruptive technologies. As the new technology improves the performance overlap between technologies is increasing, therefore firms have greater incentive to enter rivals' markets. When this preference overlap is asymmetric, the firm whose technology is relevant to a larger number of consumers has greater incentive to attack the other segment. As consumers' requirements are met, they derive positive but decreasing marginal utility from additional performance improvements. After a certain performance threshold is reached consumers' willingness to pay is decreasing thus unit price increases in importance. Therefore technologies that offer lower relative performance at lower price become more and more attractive (Adner, 2002).

The above-described process makes visible the relationship between consumer preferences and consumer willingness to pay for technology developments as key conditions that bring about disruptive technological innovation. Adner's model offers an alternative to performance oversupply coined by Christensen in explaining the consumer adoption of disruptive technologies. Thus, to identify potential disruption not only the performance metrics should be analyzed but the price trajectories of the competing offer as well (Adner, 2002).

**Govindarajan and Kopalle** (2006 b) support Christensen's framework but provide a more general measure of disruptiveness of innovation. In their frequently quoted paper, the authors suggest to make a distinction between low-end and high-end disruption. In their view a disruptive technological innovation "can be both low-end, i.e., technologically less radical" and introduced at a lower price, "and high-end, i.e., technologically more radical" and introduced at a higher price (Govindarajan & Kopalle, 2006 b, p. 14). Cellular phone relative to wired phones or digital cameras relative to analog cameras exemplify a case of high-end technological disruption. The cellular phone was initially recognized by corporate executives who valued its portability and convenience, despite its relatively high price. When it got commercialized, the mainstream consumers still preferred land-line phones because of their reliability, low cost and high coverage. Nevertheless, further improvements in cellular technology allowed it to offer with acceptable price and higher performance. Disruptive technological innovation with a high price is indeed phenomenon Christensen did not deal with during his theory building. Christensen himself later acknowledged the notion of high-end disruption by saying that despite the fact that these examples have brought better products with higher profit margins to the best customers of the incumbents, they can be still seen as disruptive technologies (Govindarajan & Kopalle, 2006 b).

Hence, disruptive technological innovations that are also radical can be introduced initially at a higher price than existing products but still pose the "innovator's dilemma" since (i) mainstream customers do not value the newer performance feature in the beginning (ii) the technology performs badly on attributes mainstream users value (iii) initially the technological innovation attracts an insignificant niche segment (iv) even though the high end disruptive technology may offer higher margin, the perceived lower market size makes the technology less appealing to incumbents (Govindarajan & Kopalle, 2006 b).

In summary, according to Govindarajan and Kopalle disruptive technological innovations can involve either radical technologies (high-end) or incremental technologies (low-end). However, disruptive technologies must be distinguished from radical but not disruptive technologies. First, disruptive technological innovations perform poorly on the performance measures mainstream customers appreciate, whereas radical but not disruptive innovations perform well on the performance measures mainstream customer value. Second, disruptive technologies also offer new performance features initially valued by the niche segment, while radical but not disruptive technologies compete on the same performance dimensions mainstream customers value. Third, unlike disruptive technologies non-disruptive radical technologies do not pose a dilemma for established companies (Govindarajan & Kopalle, 2006 b).

**Utterback and Acee** (2005) gave a more comprehensive view on technological innovations by adding a third dimension to Christensen's model. They construct an eight rows model by considering the dimensions of cost, traditional performance and ancillary performance. In their alternative scenario, similar to Govindarajan and Kopalle's concept, a higher priced and higher performing technological innovation is introduced into the most demanding established segment and later moves towards the mass market. The case of fuel injection is given as an example for attack from above starting in the luxury car segments and migrating into the mass market. The authors conclude that perhaps the cases of attack from below may have greater potential for explosive growth than do those of attack from above, but both cases are powerful means for enlarging markets and providing new functionalities (Utterback & Acee, 2005).

### 2.3.4. Enabling factors for disruptive technological innovation

The next section deals with the question, namely what are the environmental and contextual conditions that enable or hinder disruptive technological change and when is a market ready for such a disruption.

<u>Context and environment</u>

Some scholars analyzed the reasons under which conditions organizations can be disrupted from the context and environment point of view. Chesbrough's (1999) empirical research found that disruption and the incentive for development of disruptive technologies depends on regulations and culture of the country or region. His case study showed that certain technologies fail in one country but become disruptive in another. The reasons for this phenomenon are mainly the variation in some contextual factors such as regulation, economic conditions and entrepreneurship culture of different countries (Yu & Hang, 2010; Chesbrough, 1999).

According to Christensen a variety of environmental factors such as industry standards, unions, cultural norms, the state of technological development, the country's intellectual property infrastructure and most crucially government regulation affect the motivation or ability to innovate and to bring about disruptive change on a market. Companies that want to introduce disruptive technologies to unfavorable market environment can either search for more favorable market environments or give up their efforts. The government's power to affect technological innovations lies in its policymaking (in form of subsidies and incentives) and in developing a regulatory framework for market participants. Therefore, governments and other industry players can change the industry's context, making it more or less susceptible for change (Christensen, Anthony, & Roth, 2004).

Other researchers pointed at the potential influence of network effects on the introduction of disruptive technologies. Network effects occur, when the value of a good increases with the number of users of that good. For certain industries it was found to be critical to assess the existence of network effects since historically disruption has occurred less frequently in network industries. Keller & Hüsig (2009) presented indicators about the extent network effects work in favor or against the potential disruption. These indicators are the extent to which switching cost and coordination costs arise, customer expectations to the future network size and compatibility of the new technology with the old network. In their model all of these network effects-related factors enhance the assessment for evaluating disruptive potential (Keller & Hüsig, 2009). Tellis et al. (2002) found that due to network effects in some cases dominance of a certain technology occurs fast and may end up with the highest market share. Their argument goes that network effects could be so strong that an inferior technology could dominate its market and even lock out superior quality or lower priced alternatives. In their view the presence of network effects raises a chicken and egg problem (Tellis, Chandy, & Prabhu, 2012).

Market readiness for disruptive technological innovations

Other researchers have examined the market readiness for potential disruptive innovation based on past and current conditions. Klenner et al. (2013) developed a model of disruptive susceptibility to analyze the readiness of the market for commercialization of disruptive technologies. In their model they have identified under which conditions disruptive technological innovations will likely become a threat for established companies. The authors proposed a categorization of factors indicating market readiness for disruption into conditional and accelerating factors. Conditional factors must be fulfilled by a market in order to indicate disruptive susceptibility. A disruptive susceptibility is latent if an industry shows (1) high market entry barriers, (2) low customer loyalty, (3) low number of firms entries and exits, (4) high market share shifts to low-end offers, (5) a decreasing tendency to buy products and services of superior quality, (6) high degree of changes in the value chain. Furthermore, susceptibility for disruption can be increased to the highest level by accelerating factors, such as (i) constant competition with low market growth, (ii) increasing market concentration, (iii) the introduction of sustaining innovations by incumbents, (iv) increasing prices. The analysis of factors influencing the market susceptibility for disruption helps to assess the readiness of markets for disruptive technological innovations even before new technologies enter the market (Klenner et al., 2013).

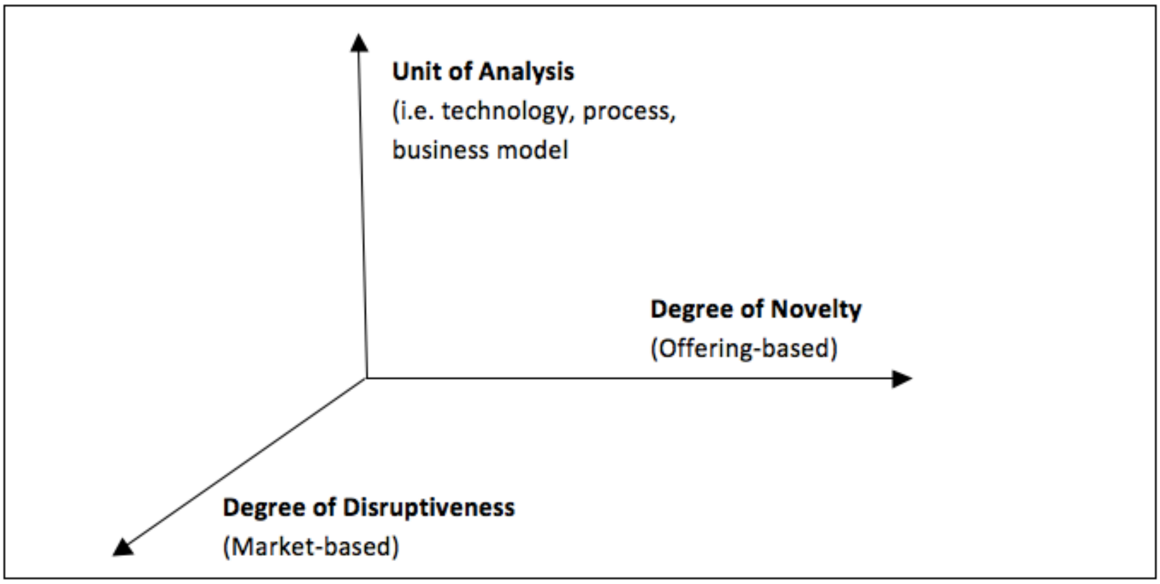
In another model, Adner and Zemsky (2005) also demonstrated when technological disruption is more likely to happen. They found that the threat of disruption becomes larger, the higher the number of companies launching the new technology, the larger the relative size of the mainstream segment, the greater the benefit the mainstream customer gains from the new technology and the greater the marginal costs of the incumbent firms (Adner & Zemsky, 2005; Waldner, 2010).

## 2.4. Three dimensional innovation framework

Besides the degree of market impact and the degree of novelty innovation can also be segemented into units of analysis. Innovations could be product or service innovation, technology innovation, process innovation and business model innovation. Product and service innovations are novel products and services that aim to better satisfy certain market needs. Technology innovation is "the knowledge of components, linkages between components, methods, processes and techniques that go into a product, process or service" (Popadiuk & Choo, 2006). Also, process innovation represents the introduction of new elements into the operational scheme of an organization. Process innovation encompasses novel input materials, task specifications, work and information flow mechanisms and equipment needed to produce a product or deliver a service (Popadiuk & Choo, 2006). Another type of innovation is business model innovation, which deals with the changes in the value proposition delivered by a product or a service and the cost structure of the offering organization. In addition, business model innovation is an introduction of a fundamentally new business model in an existing business (Markides C. , 2006).

The three-dimensional innovation framework includes the *unit of analysis* dimension as well as the degree of disruptiveness and the degree of novelty which were described in the previous chapters. After thorough assessment, each innovation is plotted in the framework according to its type of innovation as per product, service, process, technology or business model. Also, the level of radicalness is assessed in order to determine whether the innovation is radical or incremental and additionally the market impact needs to be analyzed for the disruptiveness classifying the innovation as disruptive or sustaining.

**Figure 3: Three dimensional innovation framework**

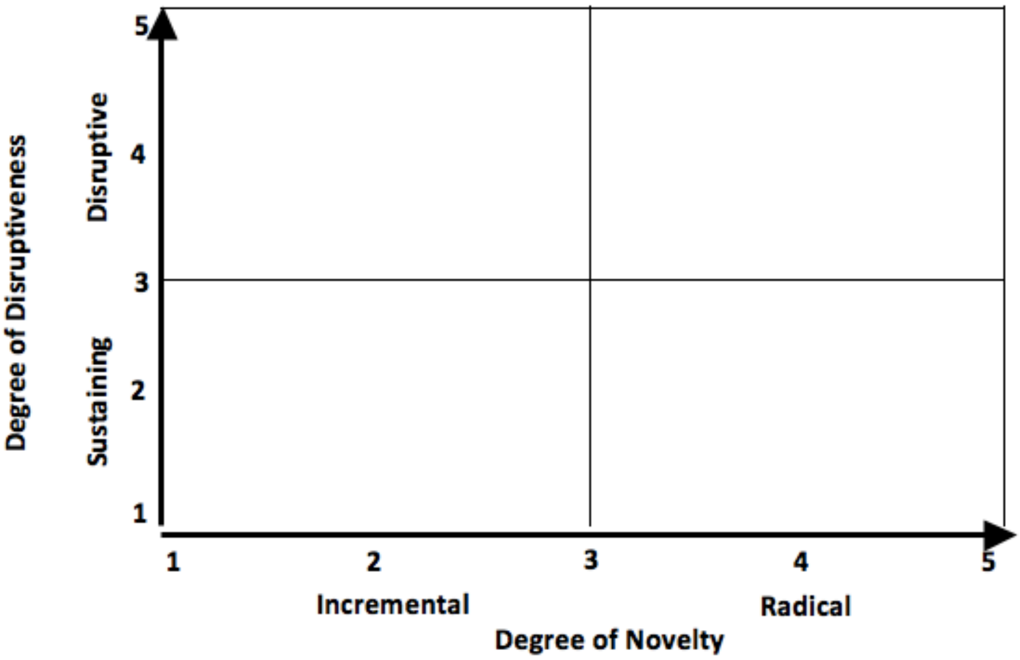


Source: (ISM, 2013)

As the main goal of the report is the evaluation of the disruptive potential of new energy technologies, only the *technology innovation* unit of analysis will be taken into consideration in the assessment process. Therefore, the innovative technologies which are subject to our assessment will be measured against two dimensions: disruptiveness and radicalness (See Figure 4). Nevertheless, it is important to make a distinction among various categories of innovation (units of analysis) as disruptive technological innovation is fundamentally different from disruptive business model innovation and disruptive product and service innovation. All these different types of disruptive innovation differ in the way they occur and evolve as well as in the impact they have on competitors and the way incumbents respond to them (Markides C. , 2006).

**Figure 4: Technological innovation framework**

|



Source: (ISM, 2013)

The purpose of this framework is to differentiate each technology's radicalness or the degree of novelty and its disruptiveness which is related to the impact it has on the market. In fact, radical innovations can have a sustaining market effect, while incremental innovations to a technology might disrupt the whole market or industry (Abernathy & Clark, 1984). It is of high importance to the market players to know where a certain technology innovation stands as per these two dimensions, as the different combinations (radical-sustaining, incremental-disruptive, etc.) require different strategic and operational approaches. A radical-disruptive innovation would be one that introduces a substantially new technology which creates new linkages to markets and users and therefore disrupts the market. On the other side, incremental-sustaining innovations build on the established technology within the existing markets. They are the ones with the smallest individual effect within the industry however they are also the most common ones and their cumulative effect on the production cost and performance of the technologies can be significant. There are also mixed combinations. Radical-sustainging innovations, for instance, are the once that deliver a substantially new technological advancement in the context of the already existing trajectory of performance. And the fourth category, incremental-disruptive innovations, refers to innovations that bring minor technological improvements however manage to achieve significant new market linkages through providing attractive value propositions and thus eventually disrupt the mainstream market (Abernathy & Clark, 1984).

# 3. Methodology

## 3.1. Research design

This report represents a qualitative and quantitative study, which aims to depict and assess the market impact of new energy technologies on the energy sector in Austria, Bulgaria, Germany and Romania. The topic enjoys growing importance due to the rapid technological advancements in the renewable sector, increasing depletion of conventional energy sources and political and social willingness for 'greener' energy markets. Due to the nature of the information available the study is to a high degree descriptive. In addition, the main theory used of *disruptive innovation* (Christensen, 1997), lacks to a large extent a quantitative, clear-cut measurement. Nevertheless, the report also consists of quantitative elements and eventually provides quantitative results of the assessment. Therefore the study is supposed to be of a predominantly qualitative nature with quantitative aspects and suggestions for the final technology assessments.

The main three pillars of the research are: solid theoretical foundation based on thorough analysis of the technology innovation academic literature, twenty five interviews with various experts in the field of renewable energy technologies in Austria, Romania, Bulgaria, Germany and the EU as well as desk research and detailed screening of a wide range of information and data available in regards to new technologies in the energy sectors in the above mentioned countries. As Eisenhardt and Graebner (2006) state it "sound empirical research begins with strong grounding in related literature" thus the first step was to conduct a thorough literature review in the field of technology innovation, and more precisely the academic work related to *disruptive innovation* and *radical innovation*.

Based on the review a clear theoretical framework is built which is the main ground for the technology assessments. In addition, as *disruptive innovation* is the corner stone of the paper a set of assessment criteria is derived from the literature, which served as measurements for the 'disruptiveness' of the energy technologies analyzed. Furthermore, twenty five interviews were conducted with energy experts with various backgrounds. A specifically designed universal questionnaire consisting of open as well as more concrete questions was used. The questionnaire contains enough flexibility in order to be easily adapted to the diverse background of the interview partners (See Appendix 1). Most of the interviewees occupy key positions at leading energy companies and research institutes, national and European energy associations, universities and consultancies. Additionally, highly consistent desk research contributed greatly to the descriptive as well as data input of the study. All in all, the results of the report are based on the relatively subjective but highly expert opinions and estimations of the interview partners as well as highly reliable data from country reports and other papers issued by national ministries, energy agencies and associations as well as well-known energy organizations on European and global level.

## 3.2. Selection of interviewees

Due to the diverse background as well as diverse area of expertise of the interview partners, the selection does not serve as a ground for statistically significant judgments. Their qualitative inputs as well as their partially subjective estimations based on their expertise and experience were the main goals of the conducted interviews. Initially, a list of potentially valuable interview partners had been developed and fortunately after contacting them twenty five experts agreed on having a forty-minute talk via online means of communication, phone or in person. The purpose was to have interview partners whose knowledge covers a greater number of important areas for the study and whose input does not overlap much with the one of the others. Fortunately, experts from all types of renewable energy (bioenergy, solar, wind, hydropower, and geothermal) positively replied to the request for an interview. Table 1 below provides the list of the interview partners together with the organizations they work for and the positions they occupy. As expected, the majority of them work for organizations in Germany, Bulgaria, Austria and Romania however there is also a few who represent Europe-wide organizations. The organizations they work for range from research institutes and universities such as Wuppertal Institute, through national and European energy associations, like EGEC, and energy production companies and ending with prominent energy consulting agencies such as BTG World.

**Table 1: List of interview partners**

| | Name | Position | Company/Institution |
|---|---|---|---|
| **1** | Samuel Hoeller | Research Fellow | Wuppertal Institute |
| **2** | Javier Dominguez | Research Coordinator | CIEMAT |
| **3** | Philippe Dumas | Secretary General | EGEC European Geothermal Energy Council |
| **4** | Ilian Petkov | Chairman of the Board | Long Man Holding AD |
| **5** | Plamen Dilkov | CEO | PVB Power Bulgaria (PVB Group) |
| **6** | Andrey Raykov | Research Associate | Solar World |
| **7** | Tsvetan Kardashliev | Research Associate | RWTH Aachen |
| **8** | Vladimir Alichkov | Deputy Chairman | Bulgarian Photovoltaic Association |
| **9** | Patrick Reumerman | Senior Consultant | BTG World |
| **10** | Wouter van Strien | Business developer | ECN |
| **11** | Lyubomir Damyanov | Busines analyst | BICA Ltd./Bulgarian Association for Biomass |
| **12** | Uwe Schneider | Professor | University of Hamburg |
| **13** | Velizar Kiryakov | Chairman | Association of Producers of Ecological Energy |
| **14** | Andrej Stanev | Project manager | FNR Fachagentur Nachwachsende Rohstoffe |
| **15** | Klaus Wiesen | Project co-ordinator | Wuppertal Institute |
| **16** | Volker Quaschning | Energy researcher | Hochschule fuer Technik und Wirtschafts Berlin |
| **17** | Mircea Vladescu | Owner | Vlamir Solar PV |
| **18** | Mihai Plesa | Wind energy expert | - |
| **19** | Stefan Alexandru Ghita | RES master student | “Prispa” project, sustainable house |
| **20** | Anita Schernhammer | Energy consultant | Wien Energie Haus |

| | | | |
|---|---|---|---|
| **21** | Anonymous | RES expert | Austrian Energy Agency |
| **22** | Badea Gabriela | RES professor | Colegiul National "I.L.Caragiale" |
| **23** | Anonymous | Wind offshore engineer | Hochtief |
| **24** | Costache Gabriel | Engineer | Bucharest Technical Institute |
| **25** | Anonymous | Energy and utilities consultant | Raiffeisen CentroBank AG |

After selecting the interviewees according to their compatibility, availability and expertise in certain fields of interest (e.g. solar photovoltaic, wind energy, biofuels) the interviewing process consisted of sending out a standardized e-mail to the person in question which can be seen in Appendix 14.

## 3.3. Data collection

There were two data sources for the study: interviews with industry experts and consistent desk research. The interviews were held with the support of a preliminarily prepared interview guideline (See Appendix 1). For the purpose of our study, some of the questions such as the ones for 'estimated future market share', 'development stage' and 'future energy technology impact' required more concrete answers. However, other questions like the ones asking for the 'barriers' for the future development of the technologies are open so that they can accommodate fully the knowledge of the interviewee. Nevertheless, the interviews did not have to run strictly according to the guidelines as some of the interviewees were keen on sharing valuable information which was not covered by the prepared questions. Furthermore, most of the interviews were held via online means of communication except for a few where the interviewees preferred to meet in person or to submit a written version of their answers. Regarding ethical considerations, as interviewees were contacted prior to the interviews, the purpose and intentions of this study was fully explained. Everyone who participated was asked before the beginning of the interview if they would like their names to be mentioned or if they prefer to remain anonymous. Moreover permission for recording was also enquired before the interviews and the individuals were given the option of receiving the study upon completion. All recordings together with the filled out questionnaires have been duly submitted to the Institute for Strategic Management at Vienna University of Economics and Business. In addition, some of the interviewees provided supplementary materials during the follow-up correspondence in the form of papers, reports and presentations.

The second source of data was from thorough desk research on the field of renewable energies with emphasis on Austria, Romania, Bulgaria, Germany and the European Union. The literature reviewed comprises country reports provided by the respective national ministries of energy, environment and/or agriculture, various national and European associations related to renewable energies, the International Energy Agency, national electricity system operators and research institutes. Other sources included data sets from Eurostat, news portals, academic papers and other publications by industry experts and consulting agencies.

## 3.4. Data analysis

Once collected the data was thoroughly analyzed and summarized. Based on them and the previously identified 'disruptive' criteria the assessment process was completed. The criteria were chosen on the basis of the available definitions of *disruptive innovation* adapted to the context of renewable energy technologies. The criteria taken into consideration are described in Table 2 below. Each criterion gets a measurement on an adapted scale from 1 to 5, with 1 usually being totally *sustaining*, 5 being totally *disruptive* and 3 being the disruptiveness threshold. The overall degree of disruptiveness is calculated as per the average of all the disruptive measurements. No weights have been assigned to the individual criteria as this would vary significantly for the different technologies and also would have been very subjective. Therefore this represents a limitation to a certain degree because in reality not all the 'disruptiveness' measurements have the exact same effect. Despite that, the deviations should not be of high significance and the end results should be considered reliable. In fact, the degree of disruptiveness should serve more as an orientation of the potential of the technology innovation to change significantly the market. The exact magnitude of the degree of disruptiveness is not of a great importance as, for example, scores of 3.2 and 3.4 lead to identical conclusions. Furthermore, the level of radicalness of the technologies is derived from basic desk research and short questions to the interviewees and it should serve only as an orientation as it is not the aim of the study. For the purpose of the research project, the level of radicalness was also measure on a scale from 1 to 5. Once the degrees of disruptiveness and novelty are determined the technologies are plotted on the two-dimensional technology innovation framework (See Figure 4).

**Table 2: List and description of disruptiveness criteria**

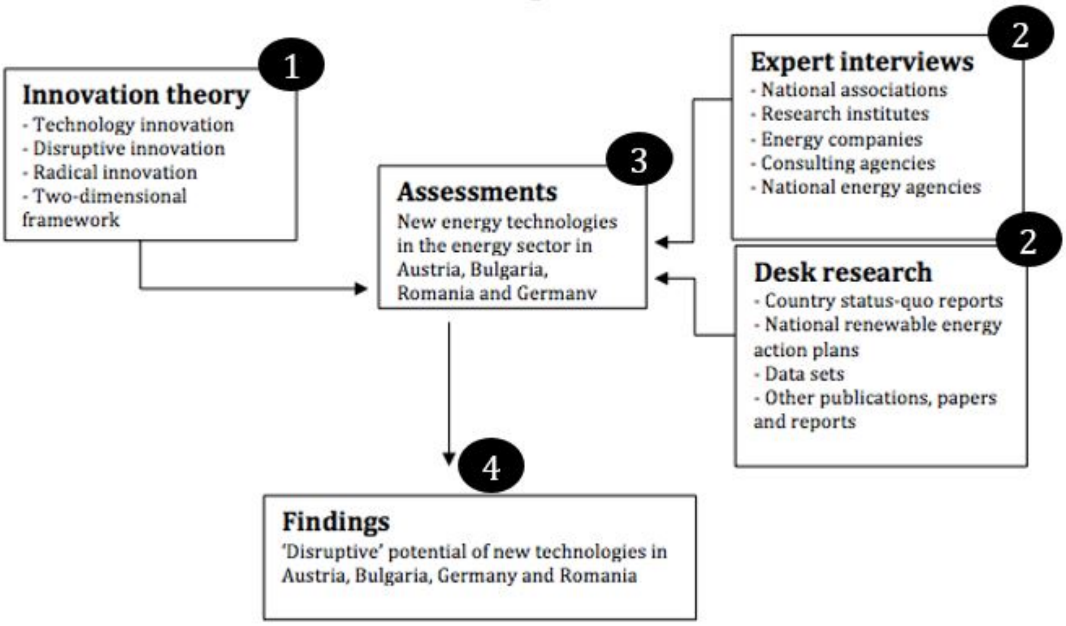
| Category | Criteria/Item | Assessment |
|---|---|---|
| **Market share development** | Current market share | Future development of the assessed technology by comparing the current market share with the estimated market share for the next 20+ years (scalability test). Measured through the annual percentage point increase and the score 1-5 is given as per: annual increase lower than 0.2% points =1, lower than 0.4% points = 2; lower than 0.6% points = 3; lower than 0.8% points = 4; and above 0.8% = 5 (Sainio & Puumalainen, 2006) |
| | Estimated market share | |
| **Value proposition** | Superior value proposition | Disruptive technologies bring different value propositions to the market. The index score reflects the number of value drivers the given technology possesses. The value drivers are: Higher performance (HP); Lower price for end-user (LP); CO2 reduction (CO2); Ease of operation (EO) and Flexibility (FL) (Christensen, 2000; Adner, 2002; Liisa-Maija Sainio, 2007) |
| **Costs** | Initial costs | Measured by comparing initial costs and maintenance costs of the particular technology with the industry key fossil fuel. |
| | Maintenance costs | |
| **Time to market** | Stage of development | The closer an energy technology is to being fully commercial, the higher potential it has of being disruptive. Stage of development of the given |

| | | |
|---|---|---|
| | | technology: Basic and Applied R&D = 1; Demonstration = 2; Pre-commercial = 3; Niche = 4; Fully commercial = 5 (Buerer & Wuestenhagen, 2009). |
| **Barriers** | Technological | The larger obstacles a technology faces, the less likely it is for that technology to become disruptive. Barriers are very qualitative factors therefore are measured with the following scale: Very high=1, High=2, Medium=3, Low=4, Very Low=5. |
| | Economical and Financial | |
| | Political and Legal | |
| | Social | |
| **Learning rate** | Potential learning rate | Measured through the performance (efficiency) and cost development through the years. Due to the wide range of technologies and their individual specific characteristics exact numerical thresholds cannot be given. Very high = 5, High = 4, Medium = 3, Low = 2, Very low = 1. (Christensen & Bower, 1996; Dosi, 1988) |

## 3.5. Summary

The aim of the report is to synthesize the up-to-date technology innovation theory with the knowledge and estimations of industry experts gained through interviews and all the information and data accessible through desk research. The result should be a reliable assessment of the 'disruptive' potential of new technologies in the energy sector in Austria, Romania, Bulgaria and Germany. A schematic illustration of the research methodology is depicted in Figure 5 below.

**Figure 5: Summary of research technology**



# 4. Alternative sources of energy and their specific technologies

This section provides a brief summary of the main sources of renewable energies considered for this study and the most important technologies available as well as offers a glimpse of the general direction in which they are heading.

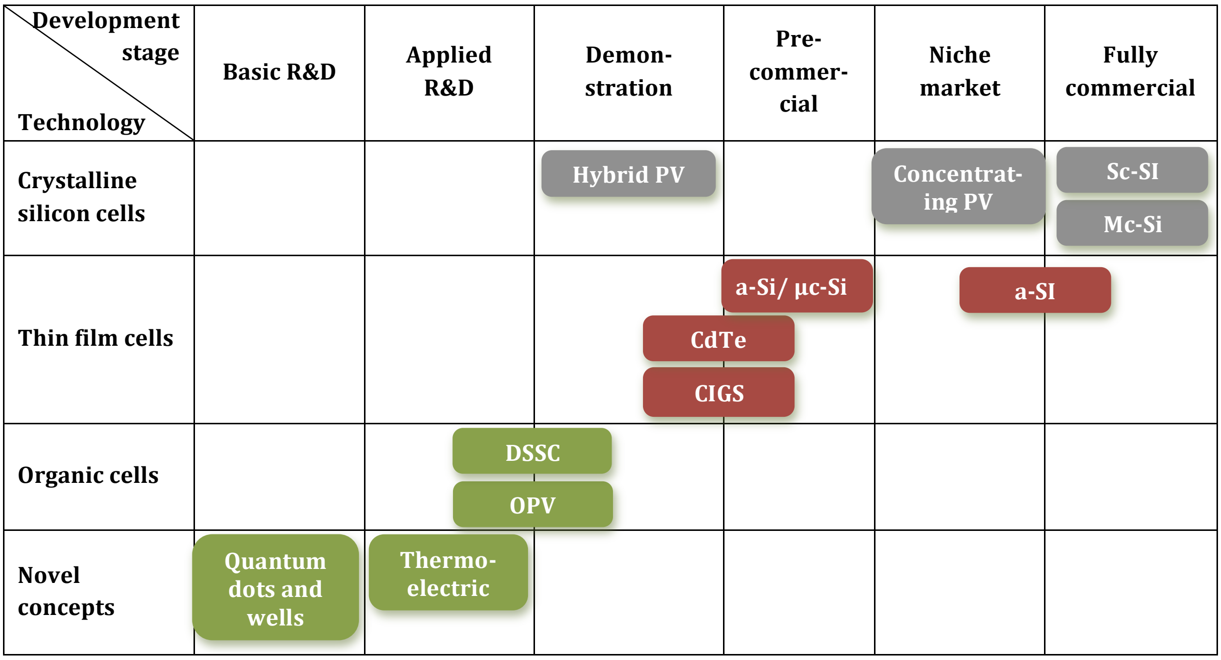
## 4.1. Solar photovoltaic

Solar energy is a clean, environment-friendly, abundant and inexhaustible energy resource which is well-spread over the world (IEA, 2011a). *Photovoltaics* (PV) is a method of producing electricity via conversion of solar radiation into direct current electricity using semiconductors (BPVA, 2012). The IEA (2011a) gives the following definition for Solar PV: "Photovoltaic (PV) cells are semiconductor devices that enable photons to "knock" electrons out of a molecular lattice, leaving a freed electron and "hole" pair which diffuse in an electric field to separate contacts, generating direct current (DC) electricity". PV power generation is achieved through solar panels (modules) composed of numerous solar cells containing photovoltaic material. Some of the materials used include mono*crystalline silicon*, poly*crystalline silicon*, amorphous silicon, cadmium telluride and copper indium silicon selenide or sulfide (BPVA, 2012). The PV modules are combined to form PV systems which usually comprise of photovoltaic cells (solar cells) interconnected and encapsulated in a photovoltaic module, the mounting structure, the inverter, the storage battery and charge controller (IEA-PVPS, 2013). The so called "balance of system" comprises various components including inverters, transformers, electrical protection devices, wiring, monitoring equipment, fixed mounting frames and sun tracking systems (IEA, 2011a). Balance of systems (BOS) costs account for one third of PV systems and their share is expected to grow due to fluctuating prices of typically used elements like copper, steel, stainless steel, etc (IEA, 2011a).

Solar energy has been the fastest-growing source of energy in the past few years. It is the largest energy resource in the world and its potential exceeds by far those of the other RES. The average annual growth of the global PV market has been impressive with 40% until 2009 and 135% in 2010 (IEA, 2011a). Moreover, PV is expected to produce 11% of the global electricity in 2050 (IEA, 2011a). The current PV learning rate is the highest in the history of the energy industry as historical data show that every doubling of installed capacities leads to a 20% cost reduction (IEA, 2011a). Costs for electricity production with solar PVs have been dropping gradually and today solar PVs can be competitive to oil-electricity generation in certain sunny countries. The main drivers for cost reductions have been the manufacturing plant size, module efficiency and the cost of purified silicon. The most recent PV costs are 3.12 USD per watt-peak (Wp) for utility-scale systems and 3.80 USD per Wp for residential ones. Additional reduction of around 40% is expected in the near future due to the technological improvements and massive deployment of new capacities (IEA, 2011a).

Mostly driven by feed-in tariffs the deployment of PV has been remarkable (IEA, 2011a). In 2012, the global cumulative PV capacity surpassed the 100 GW threshold achieving a bit more than 102 GW (EPIA, 2013). Only in 2012, 31.1 GW of new capacity started operating. For the second year in a row PV was the number one RES in Europe in terms of newly installed capacities. Currently, the total European PV capacity is a bit more than 70 GW. PV covers 2.6% of the electricity demand and 5.2% of the peak electricity demand in Europe (EPIA, 2013). The European PV market is quite evenly segmented across ground mounted (28%), residential (21%), industrial (19%) and commercial (32%) PV systems. The growth rate of the European PV market will definitely slow down and stabilize in the years to come as the FiT levels have been drastically decreased (EPIA, 2013).

**Figure 6: Development stage of solar PV technologies**



Source: IEA-PVPS (2013); IEA (2013a); Van Strien (2013); Raykov (2013)

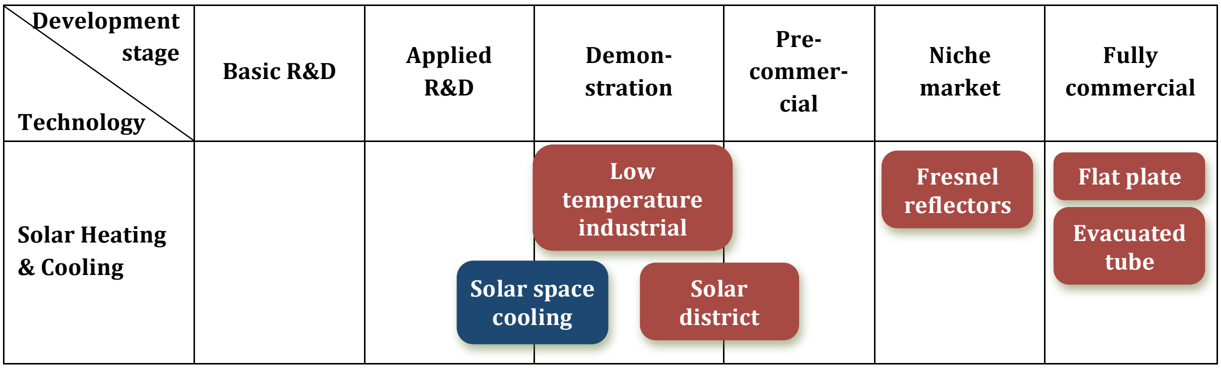
There are several types of photovoltaic technologies that are currently at different stages of development (See Figure 6). At the moment the commercially deployed PV technologies are *crystalline silicon* (c-Si) and *thin films*. *Crystalline silicon* PV technologies could be *single-crystalline* (*sc-Si*) or *multi-crystalline* (*mc-Si*) and they are currently dominating the market with a total share of 85% (IEA, 2011a). The respective efficiencies are 16% - 24% for *sc-Si* and 14% - 19% for *mc-Si* (IEA-PVPS, 2013). They usually have a lifetime of 25 – 30 years (IEA, 2011a). The other commercial PV technology is *thin films*. They are made from semi-conductors deposited in thin layers on a low-cost backing made of glass, stainless steel or plastic (IEA-PVPS, 2013). There are four categories: amorphous (a-Si) with efficiency from 4% to 8%, multi-junction thin silicon films (a-Si/ μc-Si) made with a-Si and *micro-crystalline silicon* (μc-Si) with efficiency up to 10%, *cadmium-telluride (CdTe)* with efficiency of 11% and *copper-indium-(di)selenide (CIS)* and *copper-indium-gallium-(di)selenide (CIGS)*, with efficiencies from 7% to 13% (IEA, 2011a; IEA-PVPS, 2013). Despite their lower efficiency compared to *crystalline silicon*, *thin film* PVs have the advantage of keeping their efficiency rate constant at places with volatile temperature. The *thin film* manufacturing today is highly automated with the usage of roll-to-roll printers and hence costs have been decreasing. Another big advantage of *thin films* (especially CIGS) is their flexibility – they can have various sizes, shapes and colors and hence are constantly expanding their scope of application (Raykov, 2013; IEA, 2011a).

Several other innovative PV technologies are currently at different stages of commercialization. The hybrid PV-thermal panels collect electricity from the PV effect and heat simultaneously and therefore reaching a cogeneration efficiency of 80% and more. *Concentrated photovoltaics* use mirrors and lenses and focus on the solar radiation on small, highly efficient cells deposited in several layers with each capturing a specific range of wavelength of the solar light spectrum. Despite the high costs they incur, *concentrated PVs* have a very high efficiency (up to 38% for cells, 25% for modules) to a large extent due to the sun-tracking systems they employ. Another emerging new technology is organic cells. They can be either full *organic cells (OPV)* or *hybrid dye-sensitised solar cells (DSSC).* They have lower efficiencies and shorter life-time however they offer very low-cost manufacturing and can potentially take up a niche market of consumer devices. Other novel concepts for technologies like quantum dots and nano-particles are being developed with the aim of breaking the theoretical maximum efficiency of *crystalline silicon* PV of around 30% (IEA, 2011a).

## 4.2. Solar thermal

Solar thermal technologies convert sun light into heat which can be used for different applications (RHC, 2012b). Solar thermal systems vary according to the collector type, storage volume, controlling and system configuration based on the temperature and volume of the heat required. The most common technologies are non-concentrating and they are flat plate and *evacuated tube* collectors. Solar thermal brings a lot of benefits including security of supply, stable energy prices, climate protection and long-term jobs (RHC, 2012b; IEA, 2012c). Solar heating and cooling (SHC) systems are characterized by high upfront investment costs and lower O&M costs. Though, the ranges are very large due to the developing stage of most of the SHC technologies and the high dependence of costs on the technology employed and the place of application (See Figure 7) (IEA, 2012c).

**Figure 7: Development stage of solar thermal technologies**



Source: IEA (2012c); ESTELA (2010); Van Strien (2013); Raykov (2013)

The most mature technology for capturing solar heat is solar domestic hot water systems. By the end of 2011 the total worldwide solar thermal collector capacity equaled 245 GW. The majority of them (88.3%) was *flat-plate* collectors (FPC) and *evacuated tube* collectors (ETC) while the *unglazed water* collectors had a market share of 11% (IEA, 2012c). *Flat-plate* collectors are suitable for lower demand hot water systems. They have efficiencies of around 60% and can provide heat temperatures of up to 80°C. The majority of *flat-plate* collectors use water as a heat transfer fluid (HTF)

(IEA, 2011a). *Evacuated tube* collectors can achieve higher temperatures in the HTF and therefore are more appropriate for high demand hot water systems (IEA, 2011a). There are several types of non concentrating solar thermal collectors' designs however they all have a number of common components. The absorber is the device that is collecting the incoming solar radiation and retaining it. The circuit is the part of the solar thermal system through which the heat transfer fluid flows. Also, most non concentrating collectors have a housing which protests the other components from degradation and reduces the energy losses (ESTIF, 2013a).

Even though at a smaller scale, solar cooling systems have also been increasing their deployment and amounted to 750 systems installed at the end of 2011 (IEA, 2012c). They are based on two main processes: closed cycles that produce chilled water that can be supplied to any air-conditioning and open cycles that produce directly conditioned air (ESTIF, 2013a). A very important feature of solar cooling is that since maximum solar radiation usually coincides with peak demand for cooling, solar cooling can reduce the electricity peak demands for conventional cooling. Also solar cooling can provide cooling during the evening if there is a thermal storage system at place. Moreover solar cooling systems can also be used for heating purposes (ESTIF, 2013a).

Heat storage technologies are of paramount importance for the development of SHC. Some of the technologies that are currently being developed comprise sensible heat storage, latent heat storage, sorption heat storage and thermochemical heat storage. Solar thermal systems can be applied in buildings in two ways: thermosiphon and pumped systems. Thermosiphon systems rely on the natural circulation of water when heated liquids are lighter than cold ones and pumped systems use forced circulation based on pumps (ESTIF, 2013a).

Solar thermal will potentially play a key role in the future heating energy sector. The heating and cooling demand accounts for 49% of the total energy demand in the EU hence if well-developed solar thermal might have a significant footprint of the future energy market. According to IEA if the necessary steps are taken by the governments solar energy can cover 16-17% of the total global need for low temperature heating and cooling. Solar collectors for hot water and space heating can potentially reach 3,500 GW by 2050 and cover 14% of the space and water heating energy. In addition solar collectors for industrial applications can reach installed capacities of 3,400 GW in 2050 and therefore accounting for 20% of the needs by that time. Also solar cooling is estimated to have 1,000 GW of installed capacities which will be enough to satisfy 17% of the energy needs for cooling by 2050. Nevertheless the technologies required are not economically viable as of today. Experts estimate that compact storage for heat will be commercially available between 2020 and 2030 while solar cooling systems could enter the market already in 2015-2020 (IEA, 2012c).

## 4.3. Wind power

Wind energy is the kinetic energy of wind exploited for electricity generation in wind turbines (IEA, 2013c). Wind energy is a massive, indigenous source of energy that will never run out, it is abundant and inexhaustible. It is considered by scientists as a form of solar energy as winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and the rotation of the earth (WindEIS, 2013). Wind energy experienced a significant growth since the beginning of the 21st century as the global installed capacities increased from 18 GW at the end of 2000 up to 282 GW at the end of 2012 (IEA, 2013b). Today, wind power provides 2.5% of the global electricity demand (IEA, 2013b).

Wind energy is a renewable source of energy which is widely available throughout the world and brings a lot of benefits to the society. It can reduce dependence on energy import, improve energy diversity and hedge against fossil fuels price volatility, hence stabilize the cost of electricity production in the long term. Wind energy is also very environment-friendly as it does not emit directly any GHG emissions and other pollutants as well as it does not consume any water (IEA, 2013b). Last but not least, wind turbines do not harm the surrounding land therefore do not represent any obstacle for the agricultural industry (EREC, 2012b).

The efficiency of wind turbines has been increased substantially during the years however the basic model of the turbine has not change much. Today, most wind turbines have three aerodynamically designed blades, a rotor, a nacelle with a drive train, a generator and a tower with foundation (WWINDEA, 2013). At the presence of wind these blades spin a shaft which connects to a generator that produces electricity (EWEA, 2013c). Wind turbines are usually clustered in wind farms which might consist of several hundreds of turbines and be spread over a vast area. Moreover, wind turbines are increasingly being installed off shore due to the more powerful wind available in the open seas and the minor aesthetic impact they have (EWEA, 2013c).

The rate of technology development for wind turbines is quite high and as a result of it wind energy is developing towards a reliable and competitive mainstream electricity technology. Cost reduction is the main driver for technology development, other include grid compatibility, acoustic emissions, visual appearance and suitability for site conditions. The general trend for technological improvements is towards increase of the rotor diameter, the hub height and the power capacity (IEA, 2013b). The average capacity of new grid-connected turbines in 2012 was around 1.8MW compared to 1.6MW in 2008. The largest market segment is comprised from turbines in the power capacity range 1.5MW to 2.5MW. For offshore turbines the average capacity grew from 3MW in 2008 to 4MW in 2012. In addition new rotors designed for lower wind speeds have been invented which allows the installation of wind turbines in lower-wind-speed areas that are usually closer to the points of consumption (IEA, 2013b). In addition, repowering has been on a rise as many old wind turbines have been replaced with modern, much more efficient ones. Wind turbines can produce electricity from wind speeds in the range from 3 – 4 meters per second (m/s) up to 25 m/s or even 34 m/s if storm control systems are available (IEA, 2013b).

An evidence for the achieved cost reductions are the investment costs which have decreased on a global level by 33% since 2008 (IEA, 2013b). Investment costs for offshore projects are usually two to three times higher than the ones for onshore projects. Another important factor is that while the wind turbines constitute around three quarters of the costs for land-based projects they account for less than half for offshore projects (IEA, 2013b). Moreover, operation and maintenance (O&M) costs usually stand for 15% – 25% of the wind power costs. O&M activities comprise scheduled and unscheduled maintenance, spare parts, insurance, administration, rent, consumables and power from the grid. Optimization factors during the past years have led to a decrease in the O&M costs with 44% from 2009 to 2013 (IEA, 2013b).

Technologies for short-term wind forecasting have also been improved. Through precise assessment of the wind characteristics investors and developers of wind farms can choose the right turbines for the given site and select the specific locations for turbines within the wind farm (micro-siting) (IEA, 2013b). Moreover, precise measurement of external conditions like climate can increase substantially the efficiency of the turbines. The role of short-term wind forecasting has been growing recently as they proved to be very useful for producers to meet delivery commitments and produce electricity most efficiently (IEA, 2013b).

Governments and other policy makers have a key role in the development of wind energy. Some of the instruments they have been using are deployment of targets such as the EU 20-20-20 target, establishing incentives and support mechanisms (feed-in-tariffs), internalizing external costs for electricity production like cost of GHG emissions as well as public financing (IEA, 2013b). Nevertheless, additional efforts are needed for the tackling of main barriers for the development of wind energy which are costs, grid integration issues and permitting difficulties (IEA, 2013b).

## 4.4. Hydropower

Hydroelectric power is the energy derived from flowing water from rivers or from man-made installations where water flows down from a high-level reservoir. Turbines located within the flow of water extract its kinetic energy and convert it into mechanical energy. Consequently, this causes the turbines to rotate at high speed and drive a generator that transforms the mechanical energy into electricity (IEA, 2010a). Hydropower is currently the most popular form of renewable energy and plays an increasingly important role in the global power generation. Hydropower contributes to more than 16% of the world's electricity generation and around 85% of the global renewable electricity (IEA, 2012b). In 2010 its global capacity reached 1000 GW (IEA, 2012b).

Hydropower has several advantages over other sources of electricity including a high level of reliability, proven technology, high efficiency, low operating and maintenance costs, flexibility and large storage capacity (IRENA, 2013; IEA, 2012b). Its flexibility will be of increasing importance due to the growing share of not very flexible renewable sources like wind and solar PV (IRENA, 2013). It is considered an enabling technology for the whole RES sector. Other benefits that hydropower brings are the long and productive local generation capability, safe operation and energy security environmental and social sustainability (IEA, 2012b). In addition, costs for electricity generation from hydropower can vary a lot but usually fall into the rage of 50 – 100 USD/MWh. Construction costs are around 2 million USD per MW for large-scale hydro (>300MW) and from 2 to 4 million USD per MW for medium and small scale hydro projects (<300MW) (IEA, 2010a).

**Figure 8: Development stage of hydropower technologies**

| Development stage<br>Technology | Basic R&D | Applied R&D | Demon-stration | Pre-commer-cial | Niche market | Fully commercial |
|---|---|---|---|---|---|---|
| **Hydropower** | | | | | | Reservoir<br>Run-of-river<br>Pumped storage |

Source: IEA (2012b); IRENA (2013); IEA (2010a); BMU (2013a)

Hydropower plants (HPP) are well-established, commercialized technologies which are very site specific and tailor made to local conditions (See Figure 8). They differ in terms of size and type of plant and generating unit, height of water fall ("head") and function. The main three categories are *run-of-river* (*RoR*), *reservoir* (or storage) and *pumped storage* plants (PSP) (IEA, 2012b). *Run-of-river* hydropower plants harness the energy from the flow of a river. Such plants might have a short-term storage capacity but usually the generation of electricity is driven by the natural flow of the river or releases from upstream reservoirs. *Reservoir* HPP are usually artificially created by building a dam which controls the natural river flow. Storing water in reservoirs provides flexibility to produce power when it is needed and reduces the dependence on variability of inflows. At *pumped storage* hydropower plants, water is pumped from lower reservoir to higher reservoir during period of low demand and it is released to flow back from the upper reservoir through turbines to generate electricity when demand is high. Important feature of *RoR* and reservoir HPPs is that they can be started and shut down within a few minutes and also they can provide spinning reserve and additional power supply within seconds in case of unexpected load changes (IEA, 2012b).

Estimations show that Europe has used the highest portion of its hydropower potential compared to the other continents. Nevertheless there is still a considerable untapped potential which analysis show to be 47% (IEA, 2012b). As of the end of 2012 there are 338 GW of hydropower capacities installed in Europe. Strict environmental legislation and administrative hurdles hinder the development of the hydropower sector in Europe.  Furthermore, social acceptance is also challenging in certain cases especially for larger projects. Also, the high upfront investment costs are another barrier. The LCOE of HPP highly depends on the type, size, location and function of the production plant and can range from 20 USD/MWh for highly competitive large HPP to 230 USD/MWh for smaller projects (IEA, 2012b). Due to the maturity of the hydropower technologies there are no major technological obstacles. Modern hydropower turbines reach efficiencies up to 90 -95% (IEA, 2012b). Currently, technological advancements are being made in order for the scope of application of hydropower installations to be increased and include small-scale facilities appropriate for smaller rivers and shallower reservoirs (IEA, 2010a).

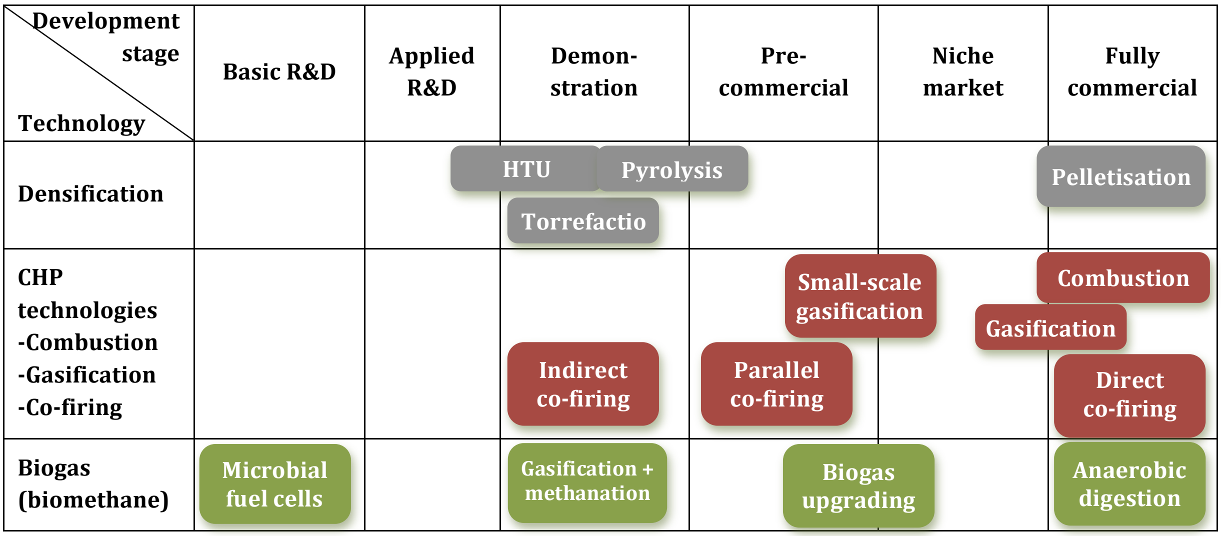
## 4.5. Bioenergy

Bioenergy refers to the technological process through which biomass is produced or collected, converted and used as an energy source (European Oil and Gas, 2012). The European Parliament and the Council of the European Union (2009) defines biomass through its Renewable Energy Directive as: “the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste”. Biomass is presently the largest global contributor of renewable energy and has potential to further extend its production of electricity, heat and transportation fuel. Biomass is derived from different types of organic matter which include energy plants such as oilseeds, plants containing sugar, energy grass as well as forestry, agricultural and urban wastes including wood, food and drink manufacturing effluents, sludges, manures, industrial organic by-products and household waste (European Commission, 2010; IEA Bioenergy, 2009; EREC, 2012). It can be found in different forms, including solid (plants, wood, straw), gaseous (from organic waste, landfill waste) and liquid (derived from wheat, rapeseed, soy or lignocellulosic material) (European Commission, 2010; Rettenmaier et al., 2008). Biomass feedstocks’ properties and characteristics vary a lot. Significant differences can be observed in the moisture content, energy content, shape, size, particle consistency of the raw material, weight, volume, density, ash content, etc. The high diversity of the biomass resources requires a wide range of tailored conversion technologies in order for energy to be produced most efficiently (See Appendix 2 for a schematic illustration of the bioenergy conversion routes). In addition, the co-production of chemicals along with the biomass energy conversion can potentially play an important economical and environmental role and hence gradually attracts increasing attention (See description of biorefineries in Appendix 3) (Bauen et al., 2009).

Biomass is a unique source of renewable energy in many respects. First, it can be stored and transported relatively easily in contrast to solar and wind. The economics of bioenergy are fundamentally different from those of the other renewable energy options as the cost of biomass represents a significant share of the bioenergy production cost (50%-90%) while the other renewables mostly rely on free resources such as sunlight, geothermal heat, wind and waves (EUBIA, 2012; IEA Bioenergy, 2009). Biomass is the only source of renewable energy that can substitute fossil fuels in all sectors – electricity, heating and transportation (IEA Bioenergy, 2009a).

Despite the advantage of being a renewable source of energy, biomass has a major disadvantage compared to the traditional fossil fuels. It has much lower energy density (up to five times) and it is more variable in physical and chemical nature which makes transportation, storage and handling more complex and costly. Hence, pretreatment or upgrading techniques are used in order to convert raw biomass into denser, homogenous and easy-to-handle fuel (IEA Bioenergy, 2009a). The four main upgrading technologies for biomass material are *pelletisation*, *pyrolysis*, *torrefaction* and *hydrothermal upgrading*. Pellets are small, wood-based cylinders with a diameter of 6-12mm and length of 10-30mm (AEBIOM, 2013; FNR, 2009). They are made through compression of grained small particles of solid biomass such as wood, peat, herbaceous and fruit biomass. *Pelletising* is an efficient way of energy densification as pellets normally have a bulk density of 650 kg/m3 which is more than three times higher than industrial softwood chips (IEA Bioenergy, 2009a). Furthermore, *pyrolysis* is the controlled thermal decomposition of biomass occurring at around 500°C in an oxygen-free environment. The final product is liquid bio oil which is a mixture of gas (syngas) and charcoal (IEA Bioenergy, 2009; AboutBioenergy, 2013; EUBIA, 2012; Uslu, Faaij, & Bergman, 2008). *Hydrothermal upgrading* is a liquefaction process especially developed for the conversion of high moisture content biomass to a product with high energy density (Biomass Energy Centre, 2011c). The main product is bio oil and it is produced through *hydrothermal upgrading* with water and other solvents at high pressure (120-200 atmospheres) and comparatively mild temperatures (300-400 ºC) (IEA Bioenergy, 2009a). Lastly, *torrefaction* is a high-efficiency thermal process that occurs at 200-300°C by which biomass (mostly wood) undergoes chemical upgrading and is transformed into dry product with a similar appearance to coal. Torrefied biomass has a very high energy density of around 92% of original feedstock energy and it is hydrophobic which gives it a great advantage to other biomass energy products as it can be transported over long distances without absorbing much water and therefore not losing its calorific value (Uslu et al., 2008; IEA Bioenergy, 2009).

**Figure 9: Development stage of biomass heat and power technologies**



| Development stage / Technology | Basic R&D | Applied R&D | Demon-stration | Pre-commercial | Niche market | Fully commercial |
|---|---|---|---|---|---|---|
| **Densification** | | | HTU<br>Pyrolysis<br>Torrefactio | | | Pelletisation |
| **CHP technologies -Combustion -Gasification -Co-firing** | | | Indirect co-firing | Small-scale gasification<br>Parallel co-firing | | Combustion<br>Gasification<br>Direct co-firing |
| **Biogas (biomethane)** | Microbial fuel cells | | Gasification + methanation | Biogas upgrading | | Anaerobic digestion |

Source: Kardashliev (2013); Damyanov (2013); Reumerman (2013); IEA Bioenergy (2009a); IEA (2012a)

There are several technologies that can be employed for the production of energy from biomass (See Appendix 4 for detailed description of each of them). The current trend is towards the use of *combined heat and power (CHP)* plants as they have higher overall (thermal and electric) efficiency which can reach up to 80% - 90% provided that the heat production and demand are matching (IEA, 2008; EUBIA, 2012). Several sub-technologies can be employed for biomass heat and power production, which are currently at different stages of development (See Figure 9). *Combustion* is a process by which flammable materials are allowed to burn in the presence of oxygen with the release of heat (Biomass Energy Centre, 2011b). It is an old and well-established technology and at the moment is the biomass conversion technology that makes the biggest contribution to the global energy supply (IEA Bioenergy, 2009; AboutBioenergy, 2013). In addition, *gasification* is a thermo-chemical process by which biomass is transformed into a mixture of several combustive gasses called fuel gas or producer gas (IEA Bioenergy, 2009a). *Gasification* has the advantage that any type of biomass feedstock can be converted into fuel gas with a conversion rate of 70%-80% (EUBIA, 2012g). Also, *co-firing* is the co-*combustion* of biomass materials with fossil fuels in thermal processes for heat and electricity production (IEA Bioenergy, 2009a). The most popular approach is *direct co-firing* of coal and solid biomass feedstocks in existing coal plants where electric efficiencies for the biomass portion of can reach 35% to 45% which is higher than the efficiency of biomass-dedicated plants (IEA, 2007; EUBIA, 2012d). Lastly, anaerobic digestion is the biological degradation of biomass in oxygen-free conditions (EUBIA, 2012b). Its main product is *biogas* which can be either burnt in power generation devices for electricity generation or cogeneration, or upgraded to natural gas standards and injected into the natural gas network or used as a gaseous biofuel (AEBIOM, 2013).

## 4.6. Geothermal energy

Geothermal energy is the energy stored in the form of heat below the earth's surface. The energy can be found in different temperatures depending on the local geology and depth (RHC, 2012a). Its potential is practically inexhaustible and it can deliver energy 25 hours a day throughout the whole year. Today geothermal energy is used for electricity generation, district heating as well as heating and cooling of individual buildings. The main benefits from geothermal power plants are the provision of base-load and flexible renewable energy, diversification, independence from weather and climate effects, no seasonal variations, global-wide availability, low GHG emissions, protection against volatile prices of electricity and fossil fuels as well as economic development at site (EGEC, 2013a). Even though geothermal energy has a huge potential in the heat and power industry currently it is still at very early development stage. The total production of geothermal electricity in 2013 in the EU was 6 TWh. According to the NREAPs of the member states the total production will increase up to 11 TWh in 2020. Furthermore the total potential until 2030 is estimated at 174 TWh and in 2050 at more than 4000 TWh (EGEC, 2013a).

**Figure 10: Development stage of geothermal energy technologies**

| **Development stage** / **Technology** | **Basic R&D** | **Applied R&D** | **Demon-stration** | **Pre-commercial** | **Niche market** | **Fully commercial** |
|---|---|---|---|---|---|---|
| **Geothermal Heat & Power** | | | | **EGS** | **Binary**<br>**District heating** | **Flash**<br>**Dry steam**<br>**GSHP** |

Source: Dumas (2013); EGE (2009b); GEOELEC (2013a); EGEC (2009a)

There are three main types of technologies for electricity production from geothermal heat (See Figure 10). The first one is conventional geothermal. It is usually associated with geothermal sources with higher temperature (180°C-390°C) and it is utilized with power capacities from 10 to 100 MW. Conventional geothermal technologies can be split into *flash* and *dry steam*. During the *flash* process high temperature, high pressure water is brought to the surface where it goes into a low pressure chamber and '*flash*es' into steam. Subsequently, the pressure created by the steam drives a turbine which starts spinning and generating electricity. On the other hand, *dry steam* plants utilize steam directly as it is channeled from production wells to the plant where it drives an electricity generating turbine. Both *flash* and *dry steam* technologies can be applied at cogeneration plants that create electricity and district heating (GEOELEC, 2013a; EGEC, 2009a).

The second type of power generation from geothermal heat is binary geothermal and includes the technologies Kalina and Organic Rankine Cycle (ORC). It is appropriate for lower temperatures, for example between 80°C and 180°C, and it is associated with power capacities from 0.1 to 10 MW. Moreover, an important characteristic is that binary geothermal plants employ a so called 'working fluid' which can boil at lower temperatures. After the hot geothermal water is brought to the surface it is run through a heat exchanger where heat is transferred to the working fluid. Then the working fluid vaporizes and rotates the turbine for electricity generation. After the process the geothermal water is injected back to the ground and the working fluid is cooled back to its liquid state. No emissions are associated with this type of technology. Binary geothermal systems are increasing their popularity around the world as they can operate with lower temperatures and hence can be applied more widely (GEOELEC, 2013a; EGEC, 2009a).

Furthermore, *Enhanced Geothermal Systems* (*EGS*) (also known as "Hot Dry Rock" or HDR) is an advanced geothermal energy technology which utilizes the high temperature of rocks with artificial water injection. *EGS* aims to use the heat of the Earth where insufficient steam or hot water exist or where permeability is low (IEA, 2011b). It enables energy geothermal energy production from a much larger fraction of the accessible thermal energy in the Earth's crust (GEOELEC, 2013a; EGEC, 2009a).

Apart from electricity generation, geothermal energy can also be applied for heating purposes. *Ground source heat pumps* (*GSHP*) or shallow heat pump systems are a heating technology that makes use of geothermal energy and uses it for space heating, space cooling or domestic hot water (EGEC, 2009b). *GSHP* systems consist of three main components: the ground side which gets heat out of and into the ground, the heat pump that converts the heat to a suitable temperature level and the building side equipment that transfers the heat or cold to the rooms. There are a few types of *GSHP* systems according to the geology of the underground, area and utilization on the surface, existence of potential heat sources and the heating and cooling characteristics of the particular building. Open systems employ as a main heat carrier ground water which flows freely in the underground and serve as both a heat source and a medium to exchange heat with the solid earth. Open systems use groundwater wells to extract and inject water from and to the underground. On the other hand, closed systems can be horizontal and vertical. Horizontal are easier to install but they require a bigger land area for the installation of the pipes. However if the surface area is limited vertical closed systems or borehole heat exchangers (BHE) can be installed through placing the pipes vertically under the ground. U-pipes consisting of a pair of straight pipes with a "u-turn" on the bottom or coaxial, consisting of pipes with different diameters can be employed (EGEC, 2009b). *GSHP* find vast applications in the residential sector, from small buildings to large complexes. Typically heating capacities from 5 to 20 KW are used (EGEC, 2009b; RHC, 2013; RHC, 2012a).

Geothermal energy can also be used for heating purposes of whole districts. *Geothermal District Heating (GDH)* is a developing technology that is still not wide spread in Europe. Wells for district heating can reach 2,000 – 3,500 meters depth and are highly dependable on the geological characteristics of the site. Also in order for *GDH* systems to be developed a large potential customer base is required. Another developing technology is foundation type heat exchangers which are heat exchangers installed in the foundation of buildings or roads, parking lots, airport runways, etc. So far they find limited application and significant further technological development is needed for them to be more effectively installed in buildings, etc. (RHC, 2012a).

Geothermal technologies face significant barriers for their development. As Philippe Dumas (2013), Secretary General of the European Geothermal Energy Council, pointed financial and political barriers are the most challenging ones in the general case. The initial capital investments for geothermal are very high due to the drilling technologies employed and the insurances needed to cover the geological risks (EGEC, 2013a). The usual capital costs for geothermal plants in Europe range from 4 million EUR/MW for *dry steam* and 5 million EUR/MW for *flash steam* to a bit more than 6 million EUR/MW for binary plants and 8 million EUR for *EGS* plants. (GEOELEC, 2013b). Drilling solely can take up to 50% – 75% of the total costs. In the case of geothermal heating prices for heat pumps are around 1.5 – 2.5 million EUR/MW and for district heating 1 million EUR/MW. Moreover, the low awareness and knowledge of policy makers is a big obstacle for them to realize the potential of geothermal energy (Dumas, 2013). Only a few countries in the EU have established geothermal energy associations and other types of representative authorities. In addition, in the case of *EGS* the technological barrier is the largest. Considerable technological advancements are required in the field for the technology to become economically viable. Even though no significant social barriers exist, some reluctance to drilling is present at the society however so far seismic events caused by the operation of geothermal plants have not been large enough to cause any human injury or property damage (GEOELEC, 2013a). Hence, geothermal energy producers need to be very careful and thoroughly communicate their projects with the society. Social acceptance is of paramount importance as without it a geothermal project will not be realized no matter how economically advantageous it is (EGEC, 2013a; GEOELEC, 2013a).

Although geothermal energy is still at its early stage facing basic technological and political barriers there will be a positive development in the years to come. Very important role will play geothermal *CHP* plants with higher efficiencies as well as *EGS* installations which do not depend on the presence of specific geological characteristics (GEOELEC, 2013a). Estimations show that installed capacities for geothermal power in the EU will double reaching up to 1,620 MW in 2020. In addition shallow *GSHP* heating production in the EU will increase from 12.9 GWh in 2010 to 35 GWh in 2020 and deep geothermal will increase from 2.9 GWh in 2010 to 15 GWh in 2020 (RHC, 2012a). All in all, the IEA (2011b) estimates that geothermal energy will reach 3.5% of the global electricity supply and 3.9% of the final energy for heat by 2050 therefore playing a significant role in the world energy industry.

# 5. Austria – country overview

The following section provides a picture of the Austrian renewable energy market including the political situation for renewables, the main energy goals the country wants to achieve as well as the potential of energy sources. The chapter concludes with a potential disruptiveness assessment of the main renewable energy technologies. Furthermore, these technologies have been analyzed according to the relevant market sectors in which they are most predominantly used: electricity, heating and transportation.

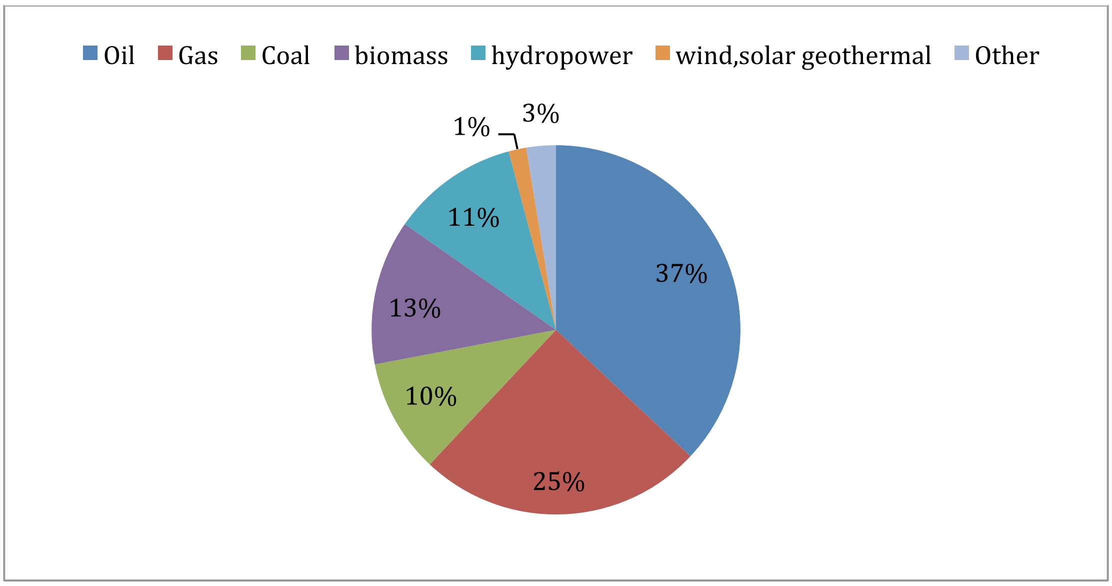
## 5.1. Introduction

For decades, Austria's energy policy has mostly focused on ensuring a sustainable and socially balanced supply of energy, constantly promoting the use of renewable energy sources (RES) and enhancing the rational utilization of energy. The long-term commitment to this energy policy has helped generate a large part of the Austrian energy from RES. Having a regional geography that allows forest exploitation, it comes as no surprise that fact that the one of the most significant sources of renewable energy is biomass along with hydropower. Austria is also one of the European leaders in solar thermal per capita (together with Cyprus and Greece) as well as European leader on RES contribution to gross electricity consumption. Through a referendum held on November the 5th, 1978, a little over half of the voters agreed to ban the use of nuclear power for electricity production purposes in Austria. Therefore, the use of nuclear power has been prohibited by law (European Renewable Energy Council, 2009). Austria is also involved in oil and gas exploration however due to specific geology and topography of the Alpine area, this process is rather costly and difficult (Hamilton, Wagner, & Wessely, 2000).

Austria's commitment to use renewable resources will not only increase the degree of national energy self-sufficiency, reducing the dependence on fossil fuels imports but will also affect in a positive way the Austrian GDP and employment, restructuring its economy towards an economic and energy system fit for the future (Biermayr, 2011).

## 5.2. Primary energy mix

**Figure 11: Primary energy mix Austria 2011**



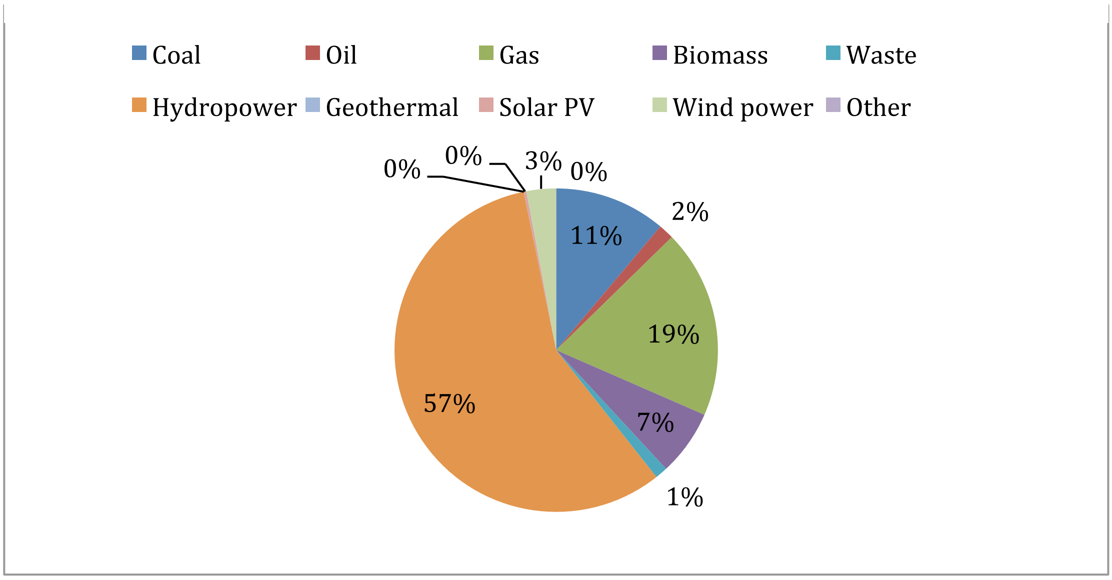
Source: (Austrian Energy Agency, 2012)

Austria's primary energy mix is mainly dominated by fossil fuels energy source (see Figure 11): having a share of 37% out of the whole primary energy mix, oil is the number one source used in energy production. Gas and coal follow closely with a percentage of 25% and 10% respectively. Due to the constraints imposed by the European Union as well as an ever-growing concern for increasing the use of sustainable energy sources, the past years have resulted in a record high use of renewable energy sources in Austria. Therefore, 31% of the gross energy consumption in 2010 was secured using renewables, with biomass occupying a top position (41% out of the whole renewable energy sources, resulting in 13% out of the whole primary energy mix). Hydropower also plays a very important role in the production of Austrian energy (36% out of the whole renewable energy sources, resulting in 11% out of the whole primary energy mix). Newer forms of unconventional energy production such as solar, wind and geothermal energy accounted for approximately 1% out of the total share of the primary energy mix in 2010 (Austrian Energy Agency, 2012). Even though their share was very small, technologies such as solar photovoltaic are expected to have a significant impact in the future due to extensive investments and support in this area.
In 2010 Austria imported 29.7 Mtoe of energy out of which 3% were represented by renewable imports (defined by the European Commission as being hydro, wind solar, tide wave and ocean, biomass and renewable waste and geothermal) and approximately 6% out of 29.7 Mtoe of energy imported was electricity. In terms of export, Austria exported in 2010 8.3 Mtoe of energy out of which 5% (0.4 Mtoe) were from renewable sources (European Commission, 2012).

All the energy produced in Austria has been divided into three main areas of interest: electricity, heating and cooling and transportation (other areas apart from these include agriculture/foresting, residential, commercial and public services as well as other non-energy uses) for the purpose of this paper. They have been elaborated in the following sub-sections.

### 5.2.1. Electricity mix

**Figure 12: Electricity mix in Austria 2011**

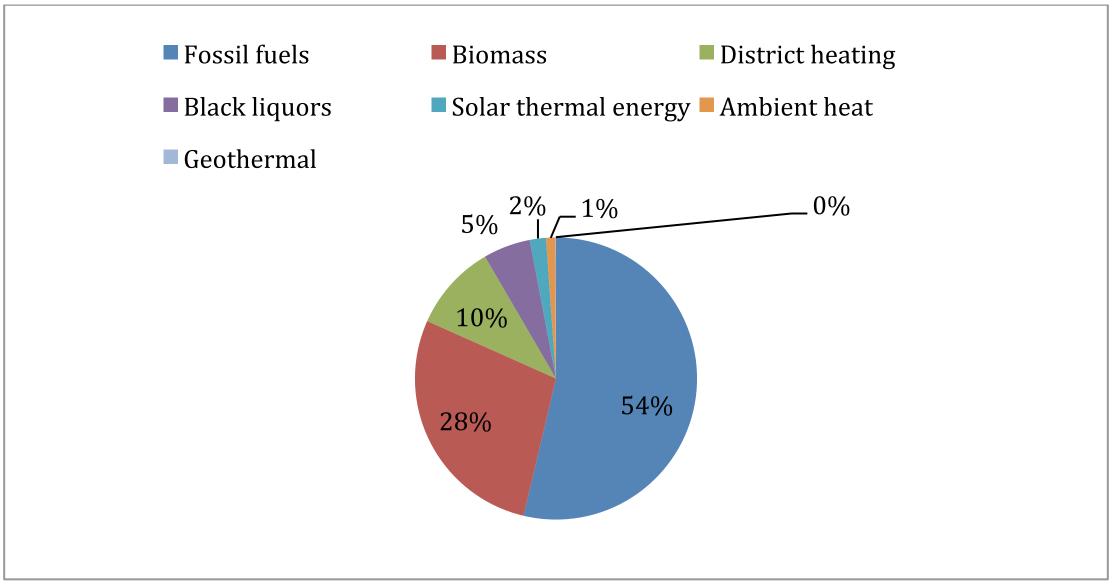


Source: (International Energy Agency, 2011)

The electricity mix in Austria is largely dominated by “CO2 free” power generation (approximately three quarters of power production). While fossil fuels are still present in the mix, their contribution to the electricity-generation-pie amounts to a total of approximately 30% as shown in Figure 13. Their shares have been approximately halved between 1990 and 2009, coal having today a share of 11% (compared to 14% in 1990) and oil 2% (4% in 1990) (ABB, 2011). Gas- fired generation accounts for 19%.
Meanwhile Austria has started to rely more and more on the power of water, generating 57% of total electricity in 2011 using hydropower. The advantage of using this technology lies in the fact that it is reliable and not as volatile as wind (3%) or solar photovoltaic (0.1%), which in 2011 have generated 174 GWh and 2089 GWh respectively, compared to approximately 40 000 GWh generated through hydropower (International Energy Agency, 2011; Biermayr, 2011).

### 5.2.2. Heating and cooling mix

**Figure 13: Heating Mix in Austria 2011**

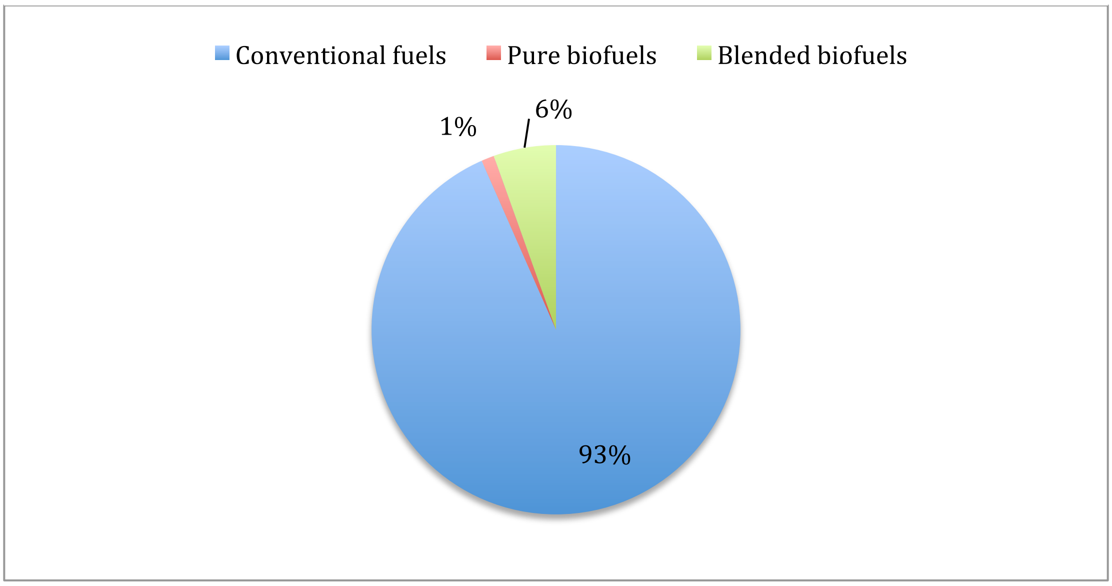


Source: (Biermayr, 2011)

In Austria, approximately 50% of the total final energy consumption is used in the heating generation sector. Compared to other European countries, the share of renewable energy sources in the heating sector in Austria is relatively high. This comes as a result of the high share of bioenergy in residential heating and the high importance of industrial wood residues which are partly used to cover the wood-processing industries' heat – and to some extent also power – demand (Kalt & Kranzl, 2009).
According to the statistics from the European Commission, the share of gross heat generation from renewable energy sources in the gross final energy has had a sinusoidal path throughout the years from 37.98% in 2008, decreasing to 36.97% in 2009 and having a comeback in 2010 (38.19%) (European Commission, 2012). The most recent data available from 2011 (see Figure 14) suggest a continuation of the RES-H growth path amounting to 46.3% out of the total heating generation (Biermayr, 2011).

### 5.2.3. Transportation mix

**Figure 14: Transportation mix Austria 2011**



Source: (Biermayr, 2011)

In 2009 a new directive was issued by the European Commission (Directive 2009/28/EC) setting a target for each Member State of achieving a share of energy from renewable sources in the transport sector amounting to at least 10 % of final energy consumption by 2020 including hydrogen and electricity produced from renewable sources.

The Directive also elaborates on the expansion of biofuels-use in the EU. The Directive targets the use of sustainable biofuels that will ultimately lead to a positive impact on biodiversity and land.

According to the European Commission, the share of biofuels and renewable energy sources used in the transportation sector in Austria has increased throughout the years from 5.20% in 2008 to 6.20% in 2010 (European Commission, 2012). In 2011 a share of 6.6% of renewable energy sources was registered in the transportation sector, which correspond to 1031 GWh pure biofuels (1.11%), and 5055 GWh blended biofuels (5.48%) produced (Biermayr, 2011).

## 5.3. Political situation for renewable energy

Austria represents one of the leading nations in Europe in terms of renewable energy supply. Austria's energy policy focuses mainly on three areas of interest: heating and cooling, electricity generation and transportation fuels putting an emphasis, and especially trying to facilitate the development of biomass in the heating sector. The steps in which Austria tries to support the growth and increase in usage of renewable energy sources is either through tax exemptions or different types of financial supports (direct/consumer support). All these measures were taken in accordance with the Climate Change Strategy[2] (Austrian Energy Agency, 2012).

---

[2] The Austrian Climate Strategy, first released in 2002, was adopted by the Council of Ministers following its evaluation and revision in 2007. Its aim is to ensure that the greenhouse gas reduction targets set out

The main document supporting the use of renewable energy sources, since 2002, in the electricity sector is called the Austrian Green Electricity Act (Oekostromgesetz). Its adoption fueled a strong increase in wind energy, biogas and biomass particularly because of the attractive feed-in-tariffs. However this rapid deployment soon came to a stop throughout the course of the years and prompted in 2009 the federal parliament to pass an amendment that brought several improvements to the Green Electricity Act. Slightly increased feed-in-tariffs, longer support periods and a technology independent budget along with decreases on the cost side of RES technologies stimulated new capacity additions and in a very short amount of time the technology caps were reached, resulting in long waiting lists (Winkel et al., 2011).

The new 2012 Green Electricity Act was introduced to address all the above issues. The new act raised the annual increase in the total subsidies amount for new electricity generation facilities that use green and renewable sources (amount increased from EUR 21 million to EUR 50 million) as well as introduced fixed quota applicable to some renewable electricity technologies (Austrian Energy Agency, 2012).

In the heating and cooling sector, the main national policy supporting renewable sources development is called the Environmental Support Act (Umweltfoerderungsgesetz). The support it offers mainly comes in the form of investment grants. Since October 1st 1999 an extended support structure came into effect taking into consideration mostly commercial entities, public institutions and utilities and non-profit organizations. Private households installing a renewable energy source heating and cooling system receive support in the form of investment grants at the provincial level. The financial effectiveness of these programs set them apart as being momentarily the main promotion scheme for renewable energy sources in the Austria heating and cooling sector (Winkel et al., 2011).

The presence of renewable energy sources in the transportation sector is mainly in the forms of biofuels. The promotion strategy is twofold: first, biogenic products have guaranteed market access due to minimum blending obligations and second, biofuel production is supported financially through tax incentives (Winkel, et al., 2011). Several pilot projects are being developed to not only promote e-mobility and support the sustainable substitution of fossil fuels but also have as objective the strengthening of the Austrian automotive and electronic industry. Some of the current developments involve the retail chains REWE and SPAR installing an infrastructure of e-charging stations and even the telecommunication operator TELEKOM has started to extend public phone boxes with e-charging facilities (Bruckner, 2010).

The biofuel directive, previously mentioned, (November 4th 2004) requires obligated parties to increase the share of biofuels or other renewable fuels in their total fuel sales from year to year in order to reach the 10% target established by the European Commission by 2020 (Winkel et al., 2011). Since Austria is a member state of the European Union it must also comply with the abovementioned directive.

---

in the Kyoto Protocol (-13% of greenhouse gas emissions for the first commitment period 2008-2012, compared to 1990) are met (Austrian Energy Agency, 2012).

## 5.4. National energy strategy

The Austrian government had very high ambitions in setting the national renewable energy targets for 2020. In 2007, the share of renewable energy in the total primary energy was around 21.3%. By 2020, the Austrian government planned to double this figure setting a 45% target. However a new government program was instated after elections in December 2008, which did not define any specific goals regarding renewables. This left Austria with having to comply only with the European directive 2009/28/EC, which entered into force in June 2009, stipulating that the share of renewable energy sources in the gross final energy consumption are to increase to 34% in 2020. This also includes a 10% share of biofuels produced from renewable sources (Austrian Energy Agency, 2012).

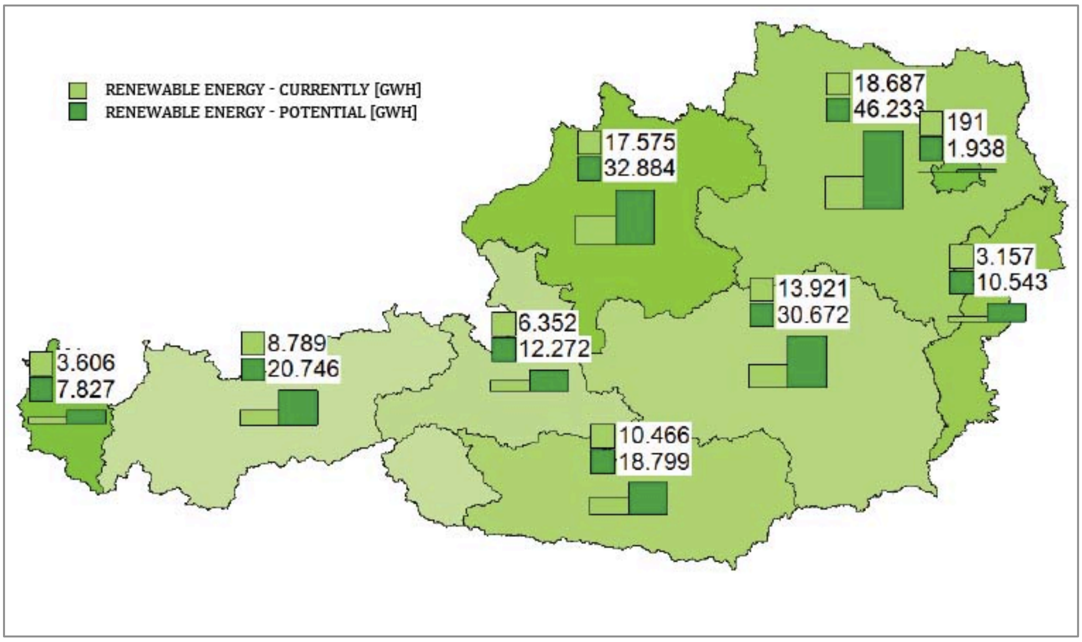
In order for the 34% target to be reached, Austria has specified in its Energy Strategy 2010, the plan to stabilize the final energy consumption level by the year 2020, at the 2005 level. In order for this to happen, the final energy consumption must be reduced around 13% taking into consideration current demand growth trends. The NREAP (National Renewable Energy Action Plan) as well as the Austrian Energy Strategy have both created future efficiency scenarios. In order for Austria to achieve the trajectory created by the two documents, reduction of energy consumption in three main areas of interest are to be expected: 22% in the transport sector, 12 % in the heating and cooling sector and 5% in the electricity sector. Therefore, the 2020 goal of achieving a 34% share of renewable energy in the gross final energy consumption will heavily rely on synergies between renewable energy policies and measure and energy efficiency (Austrian Energy Agency, 2012).

## 5.5. Theoretical potential for renewable energy sources

Austria has a reputation of being a leader in promoting renewable energy sources, especially in the electricity area. In 2011, around 64% of Austria's electricity was generated by renewables (Biermayr, 2011), among the highest of all European nations, and the Austrian government still plans to increase this number by 2020. The primary reason for this success is the large potential represented by hydropower but also recent developments in using wind and biomass.

From a spatial distribution point of view the greatest potential for renewables in Austria is located in Lower and Upper Austria as well as in Styria as also illustrated in the figure below.

**Figure 15: Renewable energies in Austria: location and potential**



Source: (Mueller-Syring & Huettenrauch, 2012)

An interesting aspect is represented by the Austrian's energy market potential for bio methane, solar photovoltaic and wind energy. The greatest potential for bio methane are in Upper and Lower Austria, Styria and Vienna where much organic waste is produced which is later used as a base for biogas production.
Wind energy potential is best exploited in regions such as Burgenland and Lower Austria while photovoltaic would be used mostly in Upper and Lower Austria, Styria and Tirol (Mueller-Syring & Huettenrauch, 2012).

Renewable energies such as biomass, hydropower, solar energy, and wind power are crucial to ensure sustainable supply that does not harm the environment. For the future it is estimated that bioenergy will play a huge role by 2020 in the overall energy generation, in Austria, with a potential capacity of 208-272 PJ, followed by hydropower with 144-154 PJ. Other forms of renewable energy such as photovoltaic, solar thermal and wind energy are also expected to contribute to future energy generation capacity with 10.8 PJ, 28 PJ, and 26.6 PJ respectively (BMLFUW, 2009). Presently, over a quarter of Austria's total power consumption comes from renewable energy sources, making Austria one of the best on the global stage (Advantage Austria, 2013).

## 5.6. Disruptiveness assessment

The proposed assessment tool discussed in the methodology section has been used to analyze and predict which renewable energy technology could have the greatest impact in the three application sectors of interest: electricity, transportation and heating. In order to have a more comprehensive overview of the Austrian renewable energy market, two scenarios have been assessed: an optimistic scenario with estimated figures provided by the industry major players and a pessimistic scenario based on figures provided by the Austrian National Renewable Action Plan. Due to the conservatism of the NREAP, the results of the pessimistic scenario were inconclusive. However the industry assessments provided a more promising result, making it possible to discern between the technologies that could have a potential disruptive future and the not so promising technologies. Therefore the findings discussed below pertain to the optimistic scenario. However both pessimistic and optimistic assessment scenarios can be found in Appendix 17 and Appendix 18 respectively.

### 5.6.1. Electricity sector

#### Solar photovoltaic

Having a production of 174 GWh in 2011 (Biermayr, 2011) and experiencing an incredible growth in 2012 reaching 337.5 GWh (Fechner & Leonhartsberger, 2012), solar PV is predicted to reach in 2020 a contribution to the electricity production of 6819 GWh (meaning a growth rate of 0.74 percentage points per year) as reported by the National RES Industry Roadmap Austria (European Renewable Energy Council, 2011).

One of the characteristics that set it apart from other energy technologies is its non-polluting character (no CO2 emissions), its ease of operating and the low electricity price it offers to customers.

In Austria, solar PV is still considered to be in a niche development phase, only being used for a small percentage of electricity generation (0.95% in 2013 as estimated by Bundesverband Photovoltaik Austria, (2013)). Perhaps a reason for this is the technological barrier that it must overcome, mainly develop a better efficiency and improve storage capabilities. Even though the initial investment of acquiring solar PV panels is quite high, this particular energy technology is supported by the government through the Green Electricity Act. The main support consists of offering customers fixed feed in tariffs, between 19 and 27 cents per KWh depending on the location and the capacity of the solar panels (KPMG International, 2012), as well as investment grants rapidly gaining popularity amongst Austrians.

Ever since it's commercialization, solar PV has managed to take advantage over the years of scale economies. Efficiency grew and prices sank making it more accessible to a larger audience.

Given the above, **the disruptiveness potential of solar PV** has been assessed as being: **3.71[3].**

#### Wind energy

Harnessing the power of the wind, Austria produced in 2011 approximately 2089 GWh (Biermayr, 2011) and was estimated to potentially reach a production of 7300 GWh by 2020 (a growth of 0.48 percentage points per year) (European Renewable Energy Council, 2011). There has also been a rapid increase of wind power during the last years. As of October 2012, 656 wind power plants in Austria with a total capacity of 1084 MW supply power to the national grid. These systems generate approximately 2.1 billion kWh of clean electricity and thus meet the needs of 600 000 households (Austrian Energy Agency, 2012). In terms of value proposition, wind turbines differentiate themselves from fossil fuel technologies by being environmentally friendly

---

[3] Scale of disruptiveness: 1 = no potential disruptiveness; 2 = low potential disruptiveness; 3 = medium potential disruptiveness; 4 = high potential disruptiveness and 5 = very high potential disruptiveness. Scale applicable to ALL other energy technology assessments.

(no CO2 production), after installation the turbines are fairly easy to operate and they offer end consumers a low electricity price.
Interview partners considered wind turbines in Austria as being already a fully commercial technology (Schernhammer, 2013) and contributing to approximately 3% of electricity generation in 2011.

One of the greatest technological barriers that this form of renewable energy faces is the lack of storage capability. Wind energy under good conditions is highly efficient and its power is not something to be neglected but the storage disadvantage makes it unreliable and unavailable whenever power is needed. Financially the cost of setting up a wind turbine is quite high but through the Oekostromgesetz producers receive a feed in tariff of 9.6 ct/kWh (KPMG International, 2012) and investment grants are available.
The interview partners rated the potential learning rate for this technology as being low (Plesa, 2013; Costache A. , 2013). Even though the cost of wind turbines has decreased throughout the years, it has not been dramatic, in most cases still requiring initial financial support (European Wind Energy Association, 2003).

Given the above, the **disruptiveness potential of wind energy** was rated **3.50.**

### Geothermal energy

1.5 GWh was produced in 2011, in Austria, using geothermal electricity and is estimated to reach by 2020 a production of 200 GWh according to the European Renewable Energy Council, (2011) having an annual percentage point increase of 0.02 (see Appendix 5).
The advantages of using this technology are the low electricity price it offers and the absence of CO2 emissions. However, geothermal provided the smallest share of electricity production in 2011 and it is generally not optimal for this task due to its low efficiency, being considered as pertaining to a niche market.
The technology still has some major hurdles to overcome, the largest being the high losses during the transformation processes resulting in a low overall efficiency and the social stigma (geothermal drilling can cause earthquakes and/or release of toxic gases). However financially and politically it is supported through the Oekostromgesetz and producers receive as feed-in tariff 7.5 ct/kWh.
The potential learning rate was evaluated as being very low due to low investments in R&D in this area making it difficult to find new ways of cutting costs while improving the product (Sanyal & Morrow, 2012; Trabish, 2013).

As a result, the overall potential disruptiveness of **geothermal energy** was rated **2.36.**

### Hydropower

Perhaps the most intense used renewable energy source, hydropower has produced in 2011 almost 40 000 GWh in Austria (International Energy Agency, 2011). Despite this, the predictions for 2020 are rather conservative and estimate a production of almost 48 000 GWh using hydropower (annual percentage point increase of -0.89 as shown in Appendix 5 in comparison to the entire electricity mix growth) (European Renewable Energy Council, 2011).

The use of hydropower does not generate CO2, it is easy to operate, provides the end customer with a low electricity price and most importantly it is flexible in the sense that it can be stored using the pumped-storage technique.

Due to its widespread use, hydropower is fully commercial in Austria. The barriers that this technology is currently facing are in terms of initial costs, which can be extremely high especially for large hydro power plants, and social acceptance, which is quite low due to the extensive digging and terrain clearing that more often than not result in environmental damage.

The potential learning rate for this technology has been classified by interview partners as being medium (Ghita, 2013), resulting in an overall potential disruptiveness grade for **hydropower** of **3.00.**

### Biomass energy

With the help of biomass, in 2011, 3240 GWh of electricity were produced (Biermayr, 2011). The players in the renewable energy sector estimate that approximately 4900 GWh of electricity will be produced in 2020 using biomass (European Renewable Energy Council, 2011). This results in a 0.03 annual percentage point increase as seen in Appendix 18.

Even though biomass is a renewable energy source, it does have a disadvantage in the fact that it produces CO2 emissions through the burning process. However it does make up by providing the user a low electricity price, ease of use and flexibility in terms of storage solutions.

In terms of time to market, biomass technology in the electricity sector is still in a niche phase due to a low adoption rate among Austrians. Biomass is confronted with barriers such as an inadequate harvesting technology for forest residues or the profitability issue of land conversion into biomass production for energy as opposed to the current land utilization, which also raises social acceptance problems (Fagernäs et al., 2006).

Biomass in the electricity sector has been rated as having a low potential learning rate due to a slow development throughout the years between the price/efficiency ration (International Energy Agency, 2000).

The overall potential disruptiveness of **biomass in the electricity** sector has been rated **2.86.**

## 5.6.2. Heating and cooling sector

### Solar thermal

In 2011 solar thermal energy helped produce 1913 GWh energy in the heating sector (Biermayr, 2011) and it is estimated to reach a production of 10607 GWh in 2020 (0.78 annual percentage point increase) (European Renewable Energy Council, 2011). This particular technology could have a great potential in the heating sector if it were to be combined with fossil fuel technologies such as gas. Solar thermal technology does not produce CO2 emissions, it is easy to use and offers a lower price to the end consumer.

In Austria, solar thermal technology is starting to gain more popularity but for the time being it is still considered to be in a niche market.

In terms of barriers, it must overcome the lack of storage solution, and some of the options for this problem may include the combination between solar thermal and other fossil fuel-based technologies. Even though the cost of a solar thermal system is quite

high, the long-term effect may consist in up to 75% reduction in heating energy (Philibert, 2006).
The interview partners rated the potential learning rate for this technology as being medium (Quaschning, 2013; Vladescu, 2013).

The overall disruptiveness score for **solar thermal in the heating** sector is **3.29.**

**Geothermal energy**
In 2011, the heating sector was supplied with 77 GWh (Biermayr, 2011) produced using geothermal energy. It is estimated that in 2020 this renewable energy source will supply 10 607 GWh (European Renewable Energy Council, 2011), resulting in a 0.03 annual percentage point increase of geothermal energy in the heating sector.
This energy producing technology provides the consumer with a lower energy price and it protects the environment having no CO2 emissions. However the efficiency of geothermal makes it highly inflexible (approximately 15% efficiency). It is also a complicated technology requiring complex drilling procedures and could end up causing earthquakes and toxic residue leaks. In terms of stage of development, the technology is in a fully commercial state and not much R&D funds are being invested in this area for further developments.

The overall disruptiveness rate given to **geothermal energy in the heating sector** is **2.64.**

**Biomass energy**
Biomass is a renewable energy source intensively used in the heating sector in Austria. In fact it represents the biggest share amongst renewables in this sector, producing in 2011, 28 875 GWh (Biermayr, 2011). It is estimated by the European Renewable Energy Council (2011) to produce 53 882 GWh in 2020 (1.88 annual percentage point increase as shown in Appendix 18). The superior value proposition, as opposed to fossil fuel technology, consists of ease of use, lower price for the customer and flexibility in storage solution. Even though through combustion biomass is CO2 neutral, it does, however, release in the atmosphere harmful emissions for the human health. Biomass incinerators produce nitrogen oxides (NOx) and volatile organic compounds (VOC) which are dangerous to the respiratory system. Fine particulate matter (PM) is also produced and can induce asthma, heart diseases and even cancer (Massachusetts Environmental Energy Alliance, 2013).

The **biomass technology in the heating sector** is in a fully commercial state of development and has received a score of **3.86** disruptiveness potential.

### 5.6.3. Transportation sector

**Biofuels**
In 2011, the transportation sector in Austria was provided with 1031 GWh of energy produced from pure biofuels (Biermayr, 2011). The European Renewable Energy Council (2011) estimates that in 2020 the production of biofuels will reach 6630 GWh (Appendix 18 shows an annual percentage point increase of 0.22).

Ease of use, lower price for customers and flexibility in storage are all biofuel characteristics. The technology is currently in a fully commercial state, excluding 2nd generation biofuels, with Austria being named one of the top performing countries in this sector (Sims, Taylor, Sadler, & Mabee, 2008).

Biofuels have governmental support, one of the reasons being the pressure to increase biofuels presence in the transportation sector to 10%, complying with the Kyoto protocol. In 2011 6.6% biofuels were present in the transportation sector (European Commission, 2012).

The potential learning rate for this technology is high as many investments are being made in this sector to come up with cheaper more efficient products (International Energy Agency, 2000).

Therefore the overall disruptiveness grade for **biofuels in the transportation sector** was **3.64.**

# 6. Romania – country overview

The following section provides a picture of the Romanian renewable energy market including the political situation for renewables, the main energy goals the country wants to achieve as well as the potential of energy sources. The chapter concludes with a potential disruptiveness assessment of the main renewable energy technologies. Furthermore, these technologies have been analyzed according to the relevant market sectors in which they are most predominantly used: electricity, heating and transportation.

## 6.1. Introduction

Even though the past 20 years have brought considerable changes in the energy sector in Romania, a great deal of the resources this country possesses still remain largely unutilized. Significant improvements in this area have started together with Romania's accession to the European Union, which requires the former communist country to increase its renewable resources utilization and promotion (Colesca & Ciocoiu, 2013).

Romania ranked the second place in the European Union concerning the share of energy from renewable sources in gross final consumption between 2006–2010 (Colesca & Ciocoiu, 2013) and in 2013, the production of renewable energy reached a record level, when the total capacity of existent projects surpassed 3,757 MW, with 60% more than in 2012 (Transelectrica, 2014). Therefore in the first 11 months of 2013, 1,400 MW of power capacity were added to the already existing 2,335 MW. 2013 will be remembered as the year in which the Romanian energy sector recorded the highest rate of installation of renewable resources projects.

Energy generation from renewable resources has become more than just an environmentalist problem. It represents an inevitable future for the Romanian national energy system, which must improve production and make more efficient the current capacities to satisfy the ever-growing consumption demands. Even though renewable energy sources like wind, solar or geothermal are not able to replace 100% of current power plants, they do have the potential of becoming a central element in the Romanian energy system (TPA Horvath, 2013).

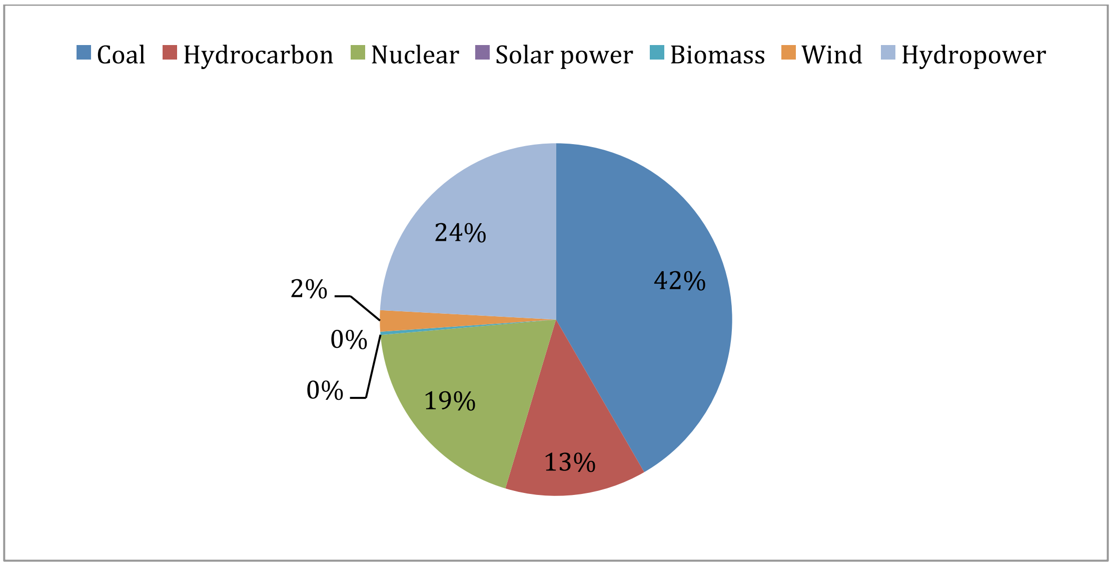
## 6.2. Primary energy mix

Romania possesses a diversified, but quantitatively reduced, portfolio of primary energy fossil and mineral resources such as: coal, petroleum, natural gas, uranium as well as an important capitalized potential for renewable resources. Most of Romania's energy requirements are satisfied by national sources and those sourced from global energy markets. Presently, domestic production supplies around 70% of the primary energy demand. Fossil fuels and hydropower are the country's primary sources of energy (Colesca & Ciocoiu, 2013).

The total installed capacity in the National Energy System in 2011 was 21,717 MW out of which 7,091 MW were coal-fired power plants, 5,519 MW in hydrocarbon-fired power plants, 6,528 MW from hydroelectric power plants, 1,413 MW from nuclear power plants, 1,140 MW from wind turbines, 26 MW from biomass and lastly 1 MW from solar power plants (Hidroelectrica, 2011). In 2011, the Romanian domestic energy consumption was 60,027 GWh, with 3.75% more than in 2010.

Figure 18 below illustrates the energy structure in accordance with the primary energy types:

**Figure 16: Primary Energy Mix in Romania 2011**

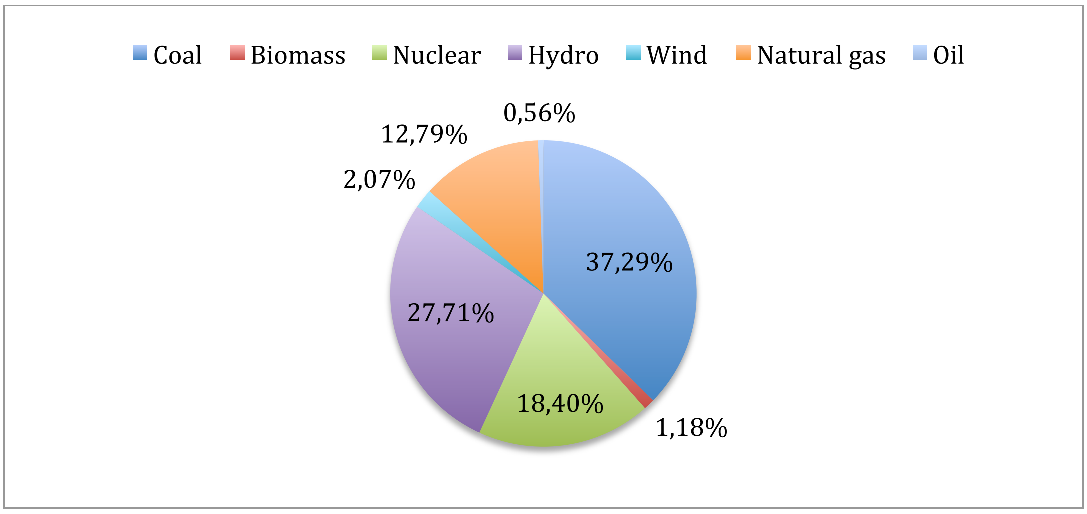


Source: (Hidroelectrica, 2011)

### 6.2.1. Electricity mix

At a national level, a large selection of primary sources for production of electric energy exist such as hydro, nuclear, coal, oil, natural gas, wind, biomass and solar. This has a significant contribution to increasing the security degree in supplying electrical energy. The most significant resources are coal (37%) and hydro (water) (28%) while natural gas (13%) only has a small weight in the energy mix.

**Figure 17: Electricity Mix in Romania 2011**



Source: (ANRE, 2011)

ANRE is the Romanian Energy Regulatory Authority whose main mission is overseeing the entire electricity, heat and gas markets and ensures their proper functioning as well as develops and implements appropriate regulatory system in terms of efficiency, transparency and consumer protection. In 2011, ANRE reports that the main contributor to electricity generation, with a share of 38% was coal closely followed by hydropower with a share of 28%. At the opposite side lies the share of natural gas in the electricity sector, which is relatively low with 12.8%. The share of gas in electricity is mainly low due to the import dependence. Even though Romania is considered as being the largest gas producer in the CEE region, it only covered 77% of consumption with domestic production (Transgaz, 2013).

Renewables such as wind, solar and biomass are slowly beginning to be adopted. In 2011 together they generated around 1,500 GWh (International Energy Agency, 2011). Recent news have registered a spectacular leap in the photovoltaic sector, where in November 2013 a total of 740 MW were installed, 15 times more than at the end of 2012 when only 49 MW existed. Wind energy projects have also increased to 2,459 MW in 2013, compared to 1,822 MW at the end of 2012. Small hydro plants have added 100 MW of capacity reaching 505 MW and biomass power plants have now a total capacity of 53 MW (National Press Agency, 2014). This growth however, is expected to stagnate in the future due to subsidy reduction, slow process of grants and funds approval and the overall high bureaucracy level.

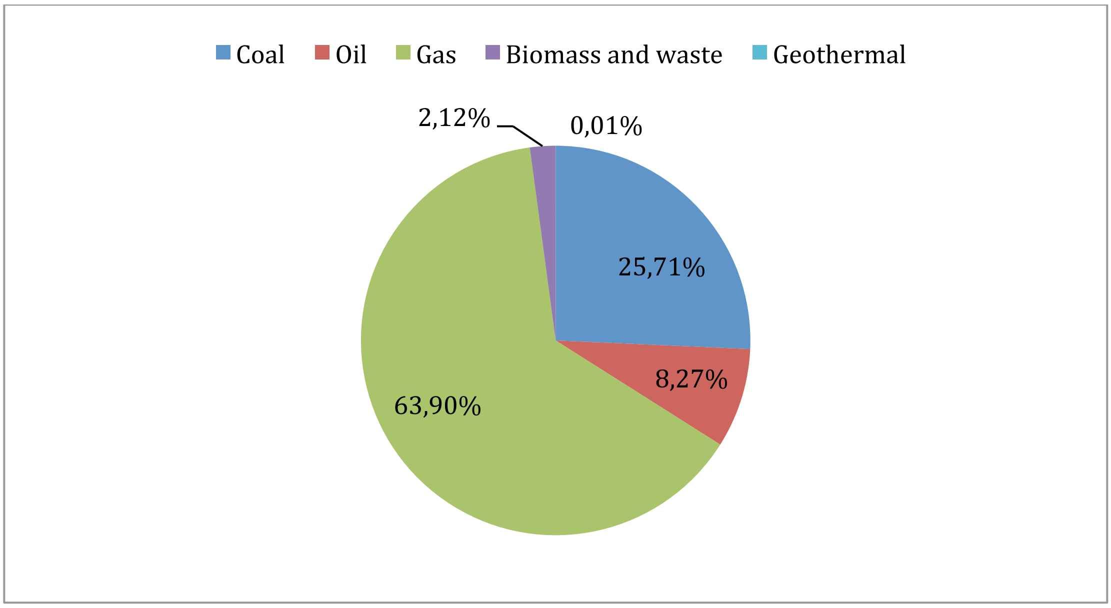
### 6.2.2. Heating and cooling mix

The most common utilized renewable energy sources for the heating and cooling sector in Romania are biomass, geothermal and solar resources. Biomass is the top contributor in heat generation among all renewable sources. This is the result of a high use of forestry products for heating. The share of solar energy in the heating sector is almost negligible having produced in 2010 only 5 ktoe (Colesca & Ciocoiu, 2013). The underdevelopment of the heating sector is due to the poor legislative framework in this area and the lack of investments.

Romania does, however, possess significant geothermal resources, which are mainly used for district heating, greenhouse heating, aqua culture and health and recreational bathing. The lack of funds and the high initial costs that this technology requires impede it to be fully exploited (Colesca & Ciocoiu, 2013). According to Cohut and Bendea (2000) Romania has over 200 wells drilled to depths between 800 and 3,500 m in which geothermal resources of temperatures up to 120 degrees can be encountered.

Figure 20 provides an overview of the gross heat generation in Romania in 2011 as provided by the International Energy Agency:

**Figure 18: Heating Mix in Romania 2011**



Source: (International Energy Agency, 2011)

### 6.2.3. Transportation mix

Romania, along with all other EU member states must comply with the Kyoto Protocol requiring an increase in the use of biofuels in the transportation sector. Biofuels in Romania are obtained through processing different crops such as rape, corn, sunflower and soybean. Even though in terms of biofuels, Romania would have a tremendous potential, their production was very low (Colesca & Ciocoiu, 2013).

According to the European Commission (2012), the final production of biofuels in Romania in 2010 was of 46.2 ktoe out of which 35.4 ktoe was attributed to bio gasoline (obtained from plant sugars) and 10.8 ktoe to biodiesel. This represents a share 2.5% of renewable energy sources in the total transport fuels.

## 6.3. Political situation for renewable energy

The promotion of renewable resources in Romania is mainly regulated through Law 220/2008, which supports the production of energy from renewable energy sources published by ANRE. Romania has implemented since 2005 a system of promoting RES through a combination between an obligatory quota and green certificates ("GC"). These green certificates are awarded monthly to energy producers based on the types of facilities used, the sources of energies used and the production from that particular month (Meyer & Trandafir, 2013; TPA Horvath, 2013).

This system applies to energy produced from wind, solar, geothermal, biomass, bio liquid or waste energy sources. It also applies for hydro power plants with a capacity of maximum 10MW. All the technologies must be accredited first by ANRE and either commissioned or retrofitted by the end of 2016 (TPA Horvath, 2013).
However the green certificate system will slow down starting with 2014 according to Government Decision 994/2013. After the boom from 2013, the continuation of the market development would have meant a spectacular increase in energy bills paid by

end customers. The support scheme entails the grant of GC to producers, which they sell on a specialized market and obtain an extra income besides the energy price. The suppliers for end customers are obligated to buy a certain number of green certificates and subsequently transfer the GC acquisition cost to the end-customer-energy bills. As a result, the end customer (population and industry) is actually the ones who pay for these subsidies (National Press Agency, 2014).

The most recent Emergency Ordinance 57/2013 ("EGO 57"), nominally in force since July 1st 2013, deals with the previously mentioned issue. It is expected to bring a major advantage for energy produced from biomass, bio liquids, biogas and waste fermentation from which Romania has great resources. The downside of this legislative amendment is the impact it will have on wind, solar and hydropower (Meyer & Trandafir, 2013) by reducing the number of GC. This new amendment will also have repercussions in terms of diminishing investment in the renewable energy sector.

## 6.4. National energy strategy

Romania's renewable energy support system was developed to help reach by 2020 the 24% target of the gross domestic consumption covered by RES, compared to 17% share of RES in 2005 when the national renewable energy action plan was established. However the ANRE announced in November 2013 that Romania has already achieved its 2020 target and therefore needs to cut back on the RES subsidies (National Press Agency, 2014).

The support scheme promoted in Romania until 2013 was the most generous in all the European Union. According to it, the producers of wind energy received 2 GC for every MWh delivered into the grid, the producers from the photovoltaic sector gained 6 GC and the small hydropower producers received 3 GC. These subsidies have attracted thousands of projects during 2011-2013 and as a consequence the green energy market has experienced a high growth throughout these years. According to the Association of Wind Energy Producers (RWEA), the investments in this sector surpassed 4.5 billion euros (RWEA, 2012).

Therefore, the main goals for energy will not be to increase capacity and build new power plants, but instead focus on maximizing efficiency for the existing ones, refurbishing and modernizing the ones that have been in existence for more than a decade such as the large hydro power plants. Another great endeavor in the energy sector will be represented by the government initiative to rehabilitate the thermal system. The goal of this program is to first of all comply with EU regulations, and secondly reduce heat and energy losses, reduce CO2 emissions generated by energy production and transport and improve the end customers comfort as a whole (Ministry of Regional Development and Public Administration, 2012).

## 6.5. Theoretical potential for renewable energy

A correct evaluation of the potential for covering the entire energy resources for the future must start from the present situation of the national reserves and must be correlated with a realistic estimation of the potential resources taking into account consumption estimations. Therefore, it has been estimated that Romania's own coal reserves will be available for approximately 40 more years at an exploitation level of 30

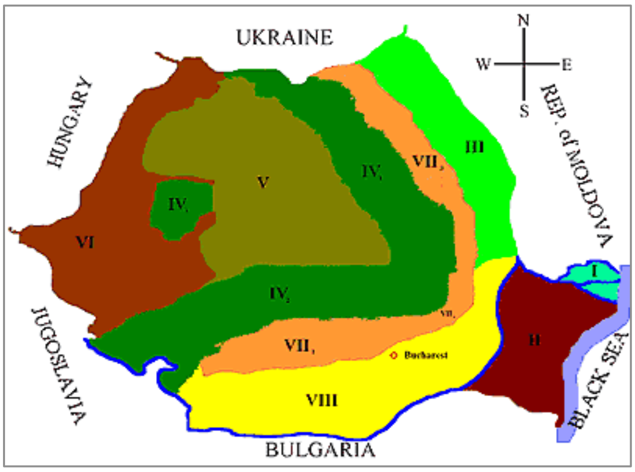
million tons/year, making it the only suitable energy source (apart from renewables) to significantly contribute to the Romanian energy production for the next 2-4 decades. Oil and gas reserves have been estimated at 28 million tons and 77 billion square meters respectively (Ministry of Industry, 2011).
Romania presents a high potential for renewable sources amongst which: hydroelectric power, biomass, solar energy, wind energy and geothermal. By utilizing more renewable sources in providing energy, the security of energy supply is increased and the imports of energy resources can be limited.

It is estimated that Romania has a potential for biomass of 7,594,000 toe/year out of which 15.5% is represented by waste from forestry and wood fire, 6.4% from other wood waste, 63.2% agricultural waste, 7.2% household waste and 7.7% biogas. The potential for solar thermal systems is estimated at around

1,434,000 toe/year and the photovoltaic systems are estimated having a potential of 1,200 GWh/year. The potential for wind energy (taking into consideration only the already established wind farms) is around 8 TWh/year. Romania also has a potential of around 167,000 toe/year of geothermal resources out of which around 30,000 toe/year have been fructified (Pambuccian & Iusein, 2007).

From a geographic perspective the southeastern part of the country holds the largest potential for solar and wind power in the Dobrogea and Danube Delta (I and II) region. Biomass and micro hydropower can best exploited in the Carpathians and Sub Carpathian regions (IV and VII) while the geothermal potential is mainly present in the West and South Meadow region (VI and VIII) (Sandulescu, 2010).

**Figure 19: Renewable energy potential in Romania**



Source: (Sandulescu, 2010)

## 6.6. Disruptiveness assessment

The Romanian energy sector has seen some developments in recent years, especially in the renewable energy sector, mostly due to the requirements of the European Union. As all other member states, Romania must also adhere to the Kyoto protocol energy thresholds and increase its renewable energy share in the overall energy production. With the help of the assessment framework, a short glimpse in the Romanian energy future is provided, thus making it possible to distinguish between the green energies that might have the biggest impact in the next years, on the energy sector. Due to lack of data, it was not possible to envision two scenarios as in the case of Austria. The only available predictions for renewable energy systems are provided in the NREAP and only cover the electricity and transportation sector, omitting completely the heating sector, thus a few assumptions and estimations had to be made. All of them are further explained below.

### 6.6.1. Electricity sector

#### Solar photovoltaic

Romania has an excellent potential for solar energy with an annual solar energy radiation of 1,450-1,600kWh/m2/year, in regions such as Dobrogea and the Black Sea coastline, as well as in other southern regions. In all other regions of the country the solar energy radiation does not go over 1,200-1,350 kWh/m2/year (Universitatea Tehnica Cluj, 2008).

Up until 2013 this particular energy sector has had a full support from the government. In 2011, the electricity sector was supplied with a modest 2GWh of solar generated electricity (EUROBSERV'ER, 2012) and is estimated to have an impressive growth trend in the future, reaching 320 GWh in 2020 (with an average annual percentage point increase of 0.04 as seen in Appendix 19) (European Renewable Energy Council, 2011). The end of 2013 brought very good news for the solar sector where in November 2013 a total of 740 MW were installed, 15 times more than at the end of 2012 when only 49 MW existed (National Press Agency, 2014). Even though the future of photovoltaic might seem promising, recent legislative developments could hinder its development. The main law supporting renewable energy system was sent for revision by the Government at the end of 2013. As a result, the number of green certificates, the main support form for renewables, has been drastically diminished. Before solar PV energy producers received 6 GC (with a maximum price of 57 euros/certificate) for every MWh delivered to the grid and now the number has been reduced to 4 GC (Transelectrica, 2014). This will also have further ramifications in terms of financing because investors will divert the money in more profitable endeavors.

In terms of technological barriers, due to recent developments in the RES sector, the national energy grid infrastructure is not capable of receiving all the energy that is sent towards it. Also due to lack of storage solutions, all the electricity produced and not inserted in the grid is wasted (Ministry of Industry, 2010).

Given the above, the disruptiveness potential of **solar PV in the electricity sector** was **3.21**[4].

#### Wind energy

Romania's wind energy potential was recognized by Ernst&Young in 2013, when they ranked the country on the 10th place worldwide regarding wind energy potential (TPA Horvath, 2013). Presently, Romania has an installed wind capacity of 2,394 MW according to Transelectrica. In 2011, the share of wind power in the electricity

---

[4] Scale of disruptiveness: 1 = no potential disruptiveness; 2 = low potential disruptiveness; 3 = medium potential disruptiveness; 4 = high potential disruptiveness and 5 = very high potential disruptiveness. Scale applicable to ALL other energy technology assessments.

production was 2.42%, which corresponds to a production of 1,254 GWh (ANRE, 2011). The NREAP estimates that in 2020 wind energy will reach a share of 11.4% corresponding to 8,400 GWh generated electricity (European Renewable Energy Council, 2011) having an average annual percentage point increase of 1.00. Even though this source of energy does not have any CO2 emissions and is easy to use, wind power along with all other renewable energy sources do not provide a lower price for the end consumer. In fact when receiving the electricity bill every month, the population has to pay a certain amount for the RES used to generate electricity. Therefore renewable energy sources are practically subsidized by citizens whether they want it or not.

The amendments to the Law 220 raise new barriers for wind technology: beside the fact that producers have to demonstrate that the wind parks are not placed on agricultural land they also received less green certificates (1 instead of 2) (Official Monitor, 2013), thus reducing investment attractiveness.

More than 25 big capacity projects are in construction and most of them in Dobrogea. The investment volume thus far was around 380 million euros but recently companies such as Verbund (which had planned an investment of 100 million euros for 2014) announced that they will postpone activities due to GC reduction (Abrihan, 2013).

Therefore, the disruptiveness potential for **wind power in the electricity sector** was **3.57.**

### Hydropower

Hydropower represents the top renewable energy source used in the production of electricity in Romania. In 2011, it has produced 16,377 GWh meaning a 32% share out of the total energy production (ANRE, 2011). For 2020 it is estimated that close to 20,000 GWh will be supplied to the electricity sector using hydropower. The average annual percentage point increase estimated in Appendix 19 is -0.52.

At the European Hydroenergy Summit, Romania's potential in this sector was declared as being approximately 5,900 MW only for rivers and could reach 8,000 MW if investments were made for the Danube section also (Borbely, 2012). The largest hydroelectric producer is Hidroelectrica, administering 591 hydro power plants and pumping stations with a total installed capacity of 6,528 MW (Hidroelectrica, 2011).

The barriers that exist in front of hydroelectricity in Romania are mainly monetary. All the existing hydro power plants are fairly old and they need refurbishing. A program has already been initiated but it needs a lot of investments in order for it to continue. Another problem in this sector is the energy efficiency. More energy is produced than what is actually consumed, leading Hidroelectrica to release 1 TWh worth of water from lakes (Vasiescu, 2013). A solution to this problem would be to export the surplus to other countries but at the moment the price is not competitive enough for export.

Given the above, the disruptiveness potential for **hydropower in the electricity sector** was **3.00.**

**Biomass energy**

Romania traditionally uses biomass for heating purposes and focuses less on producing electricity from it. Therefore it comes as no surprise that the share biomass has in the electricity sector amounts to approximately 1%, equivalent to 285 GWh produced in 2011 (ANRE, 2011). The NREAP estimates that biomass growth in the electricity sector will be rather slow, reaching an approximate 3% share by 2020 (European Renewable Energy Council, 2011) and thus experiencing an annual percentage point increase of 0.23 (see Appendix 19). Even though biomass has certain advantages such as ease of use and the possibility to store it, in Romania it is still in a niche development phase in the electricity sector. The amount of available literature in this area suggests that biomass for electricity production will not have a major increase in the future most likely reaching a share of maximum 5% in 2035 (as seen in the assessment framework in Appendix 19) due to the country's preference and much greater experience with hydroelectricity.

Given the above, the score for potential disruptiveness for **biomass in the electricity sector** was **2.86.**

### 6.6.2. Heating and cooling sector

**Solar thermal energy**

It was estimated that solar thermal collectors would have a contribution to the supply of hot water and heat of approximately 1,434 ktoe (60PJ/year), which would have meant replacing 50% of hot water or 15% of thermic energy presently used for heating (Terra Mileniul III, 2013). However in 2011 it was reported that 0 GWh were produced using solar thermal technology (International Energy Agency, 2011). Even if no thermal power was reported as being produced using this technology, the Solar Thermal Barometer reported in 2011 that Romania had 86.1 MW installed solar thermal capacity. It also informs that in 2011 alone total of 18,300 m2 were using for building 10,000 flat plate collectors and 8,300 vacuum collectors (EUROBSERV'ER, 2012) suggesting that the country is starting to give more and more importance to this renewable energy source.

Due to lack of estimates for the heating sector in the NREAP (European Renewable Energy Council, 2011), estimations were made for the final disruptiveness assessment based on the 2020 RES target in the heating sector of 22%. Therefore it was estimated that in 2020 approximately 500GWh would be generated using this technology.

The main barriers that might hinder the development of solar thermal are very similar to the ones solar PV is confronted with. The reduction in GC is alienating investors, the lack of power storage make it unreliable for 24/7 energy generation and the most recent development of demonstrating that solar panels or collectors are not built on agricultural land.

Therefore, the disruptiveness assessment graded the **solar thermal technology in the heating sector** with **3.14.**

**Geothermal energy**

Theoretically Romania occupies the 3rd place having the highest geothermal potential in Europe after Italy and Greece. The annual theoretical potential has been assessed as being 5,290 TJ/year (Terra Mileniul III, 2013). However this renewable energy source has not been fully exploited mainly because the costs of using geothermal energy for heating are much higher than using fossil fuels (Befu, 2011). In 2011 according to the International Energy Agency, 1.9 GWh (7TJ) were produced using geothermal technology resulting in a negligible share of approximately 0.01% in the heating mix. The NREAP does not provide a numeric estimation for the future of geothermal and therefore, given the available literature on the subject, it was estimated that in 2020 approximately 10 GWh will be produced. The NREAP does however specify that geothermal usage in the heating sector is supported financially by the government (with GC) and is expected to slightly increase in the future (Ministry of Industry, 2010).

In 2011, 58 out of the 87 drilled geothermal wells were exploited. Up until 1990 all the wells were privately owned by oil or mining companies but now they are publicly owned. The state does not have money or specialized personnel to further invest in their development and usage, and thus the unattended wells leak highly mineralized water that infiltrates into the ground water changing the chemical composition (Diac, 2011). Other problems with geothermal technology include the risk of earthquakes and high maintenance for pipes transporting the water (Befu, 2011). ANRE declared that the chances for geothermal energy in Romania are modest at best (Diac, 2011).

Therefore, **geothermal energy in the heating sector** obtained a score of **2.43.**

### Biomass energy

Bioenergy will play an important part in the increase of renewable energy use in Romania. It can have a decisive contribution because of its unexploited potential that comes from the available agricultural surface (Ministerul Economiei, NL Agency, ENERO Romania, 2010). Statistical data from the International Energy Agency show that in 2011, 582 GWh were produced in the heating sector using biomass (International Energy Agency, 2011). This means a total share of approximately 2% in the heating mix. Approximately 50% of the Romanian population lives in the rural area (Institutul National de Statistica, 2013) and the majority of them have been using biomass as a source of heating. It is estimated that between 2010-2020, approximately 28% of the current traditional stoves will be replaced with new centralized biomass systems having approximately 15% higher efficiency (Ministerul Economiei, NL Agency, ENERO Romania, 2010). The NREAP does not include details over the projections of renewable energies in the heating sector for 2020 (European Renewable Energy Council, 2011) and therefore estimations were made when conducting the assessment. Therefore 10 000 GWh would need to be produced in 2020 by biomass to cover the 22% RES target. This means that in 2020 the share of biomass in the heating sector will reach 21% (the other 1% is covered by geothermal energy and solar thermal with 1.05% and 0.01% respectively as shown in Appendix 19).

Even though, through combustion, biomass releases CO2 emissions, it has the great advantage of being socially accepted amongst citizens for heating purposes, the population using it lives mostly in rural areas where biomass is easily accessible and they have the necessary experience in collecting, depositing and using biomass. From a technological point of view the main barrier is the efficiency. The old technologies are highly inefficient and experience great heat losses. The plan to replace them will most probably result in a reduction of final biomass consumption but will ultimately streamline the available resources (Ministerul Economiei, NL Agency, ENERO Romania, 2010). Financially biomass has an advantage because the GC in this sector have remained (2-3 GC) the same mainly to stimulate investments which have not been very high (Capital, 2013).

Given the above, **biomass in the heating sector** has scored **3.79.**

### 6.6.3. Transportation sector

**Biofuels**

According to the National Institute for Statistics, in 2011, the production of biofuels accounted for 3.55% out of the total fuels production. This translates into a total of 2,162 GWh worth of energy and 196,188 ktoe. The prediction of the NREAP suggests that in 2020, 5687 GWh of energy will be produced from biofuels in the transportation sector (European Renewable Energy Council, 2011). However according to the assessment, if we take into consideration an increase of 10% in fuel production, it will result an 8.37% share of biofuels in transportation. This would mean that Romania will not be able to reach the 10% target set by the European Union by 2020. This hypothesis seems to be feasible since currently a lot of issues regarding biofuels have been raised. In 2013, EU has adopted a legislative proposal, which requires the limitation of traditional biofuels from agriculture to 6% in total production (1st generation) and urges the transition to new biofuels such as algae and waste. This will have major repercussions because investments have already been made and capacities increased both for biofuels producers and for farmers who have already planted the seeds (Tinteanu, 2013). One of the disadvantages of biofuel production is the decision of using the land for bioenergy purposes instead of cultivating it for food.

Therefore, the potential disruptiveness assessment for **biofuels in the transportation sector** was **3.43.**

# 7. Germany – country overview

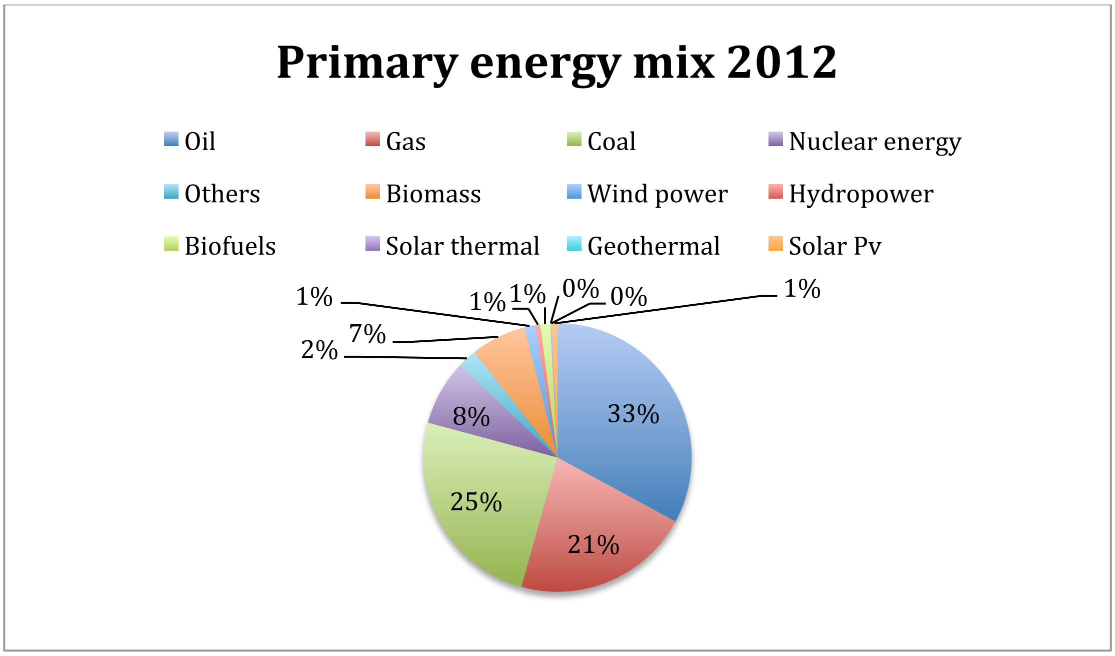
## 7.1. Introduction

Germany's renewable energy sector is considered to be among the most innovative and successful worldwide. On the other side governmental regulation is unclear especially after the Fukushima disaster which was followed by the "Energiewende". This heavy focus is clashing with the needs and claims of industrial companies which fear a location disadvantage. This special setting makes the German energy market interesting for research in the field of (disruptive) energy technologies.

## 7.2. Primary energy mix

The following figure illustrates the primary energy mix in Germany.

**Figure 20: Primary energy mix in Germany 2012**



Source: (Bundesministerium fuer Wirtschaft und Technologie, 2012)

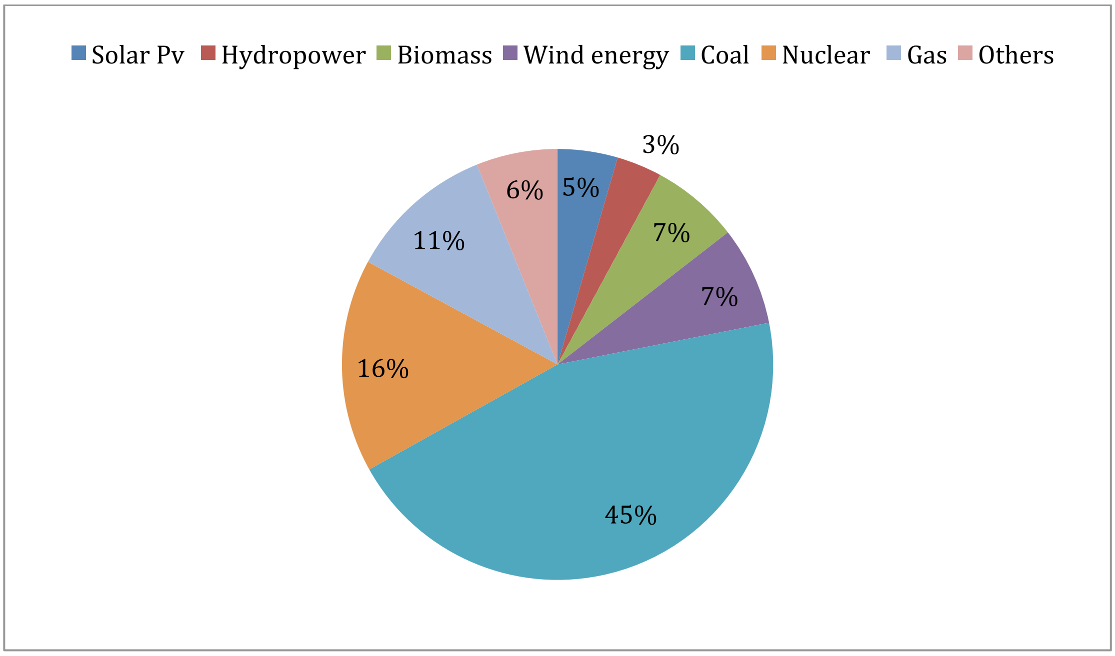
Germany's primary energy mix is mainly dominated by fossil fuels: having a share of 33% out of the total mix, oil is the number one source used in energy production. Gas and coal follow closely with a percentage of 21% and 25% respectively. The past years have seen Germany taking important steps towards the use of renewable energy. Therefore, it comes as no surprise that the primary energy mix was supplied in proportion of 11.6% by renewable energy technologies. The top renewable energy source used was biomass (6.7%) followed by wind power (1.3%) and biofuels (1.2%). Other renewable energy sources such as solar PV, solar thermal, geothermal energy and hydropower combined, supplied Germany's primary energy mix with a total of approximately 1.5% (Bundesministerium fuer Wirtschaft und Technologie, 2012).

In 2010, Germany imported 241.9 Mtoe of energy out of which 0.5 Mtoe were represented by renewable energy. In terms of exports, in 2010 Germany exported a total of 39.3 Mtoe out of which renewables represented 0.6 Mtoe (European Commission, 2012).

All the energy produced in Germany has been divided into three main areas of interest: electricity, heating and cooling and transportation (other areas apart from these include agriculture/foresting, residential, commercial and public services as well as other non-energy uses) for the purpose of this paper. They have been elaborated in the following sub-sections.

### 7.2.1. Electricity mix

**Figure 21: Electricity mix in Germany 2012**



Source: (AG Energiebilanzen BMU, 2013)

The electricity mix in Germany is mainly dominated by fossil fuels (more than half of the power production). Coal plays an important role in the generation of electricity and supplies approximately 45%, followed by natural gas supplying 11% as seen in Figure 23.

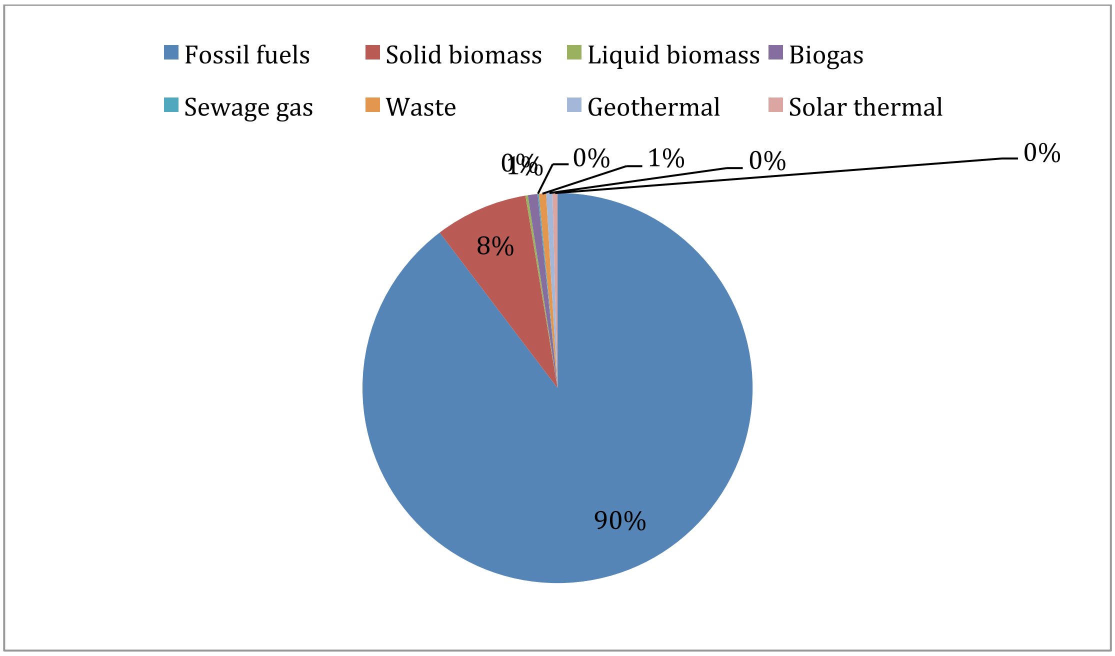
An important role in the electricity generation is played by nuclear energy, which Germany is planning to reduce in the following years. However in 2012, 16% of the electricity was generated using this type of alternative energy.

Renewable energy technologies also play an important part in the national electricity generation and they amount to a total of approximately 22%. It must be noted that equally popular renewable energies used to generate electricity in Germany are wind power (7%) and biomass (7%). However more and more focus has started to be shifted towards hydropower (3%) and especially in recent years, solar photovoltaic (5%) (AG Energiebilanzen BMU, 2013).

### 7.2.2. Heating and cooling mix

In 2012, the total percentage of renewable energy sources present in the heating and cooling mix in Germany was 10.4%, remaining unchanged from 2011.

**Figure 22: Heating and cooling mix Germany 2012**



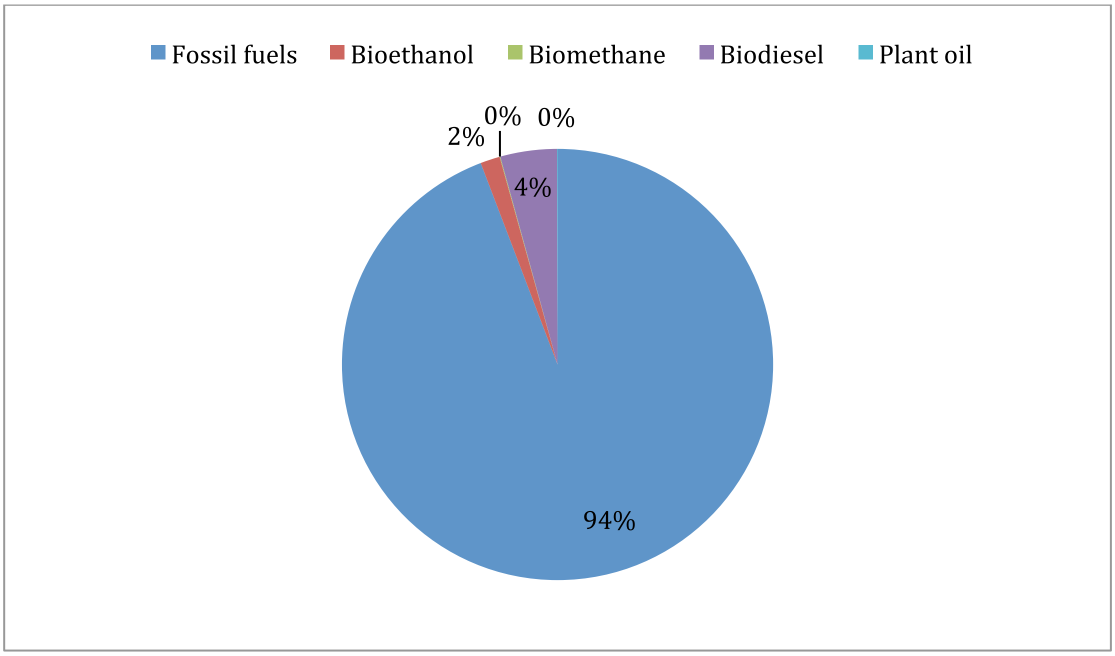
Source: (Bundesministerium fuer Umwelt, Naturschutz, Bau und Reaktorsicherheit, 2013)

According to the Bundesverband der Energie- und Wasserwirtschaft the most important renewable energy source in the heating sector is biomass. Out of the total 10.4%, biomass represents almost three quarters with 74%, followed by biogas (8%). Geothermal energy represents 5% out of the 10.4% while solar thermal energy amounts to 4% (BDEW, 2013).

It is no surprise that biomass represents the most used renewable energy source in this category. Germany is considered EU's largest wood producer, and wood represents the most common biomass source. Roughly 40% of timber production is used as a source of energy (Energy Transition, 2012).

### 7.2.3. Transportation mix

**Figure 23: Transportation mix Germany 2012**



Source: (Bundesministerium fuer Umwelt, Naturschutz, Bau und Reaktorsicherheit, 2013)

In 2012, renewable energy in the transportation sector has experience a slight increase compared to 2011, from 5.5% to 5.8% in the total mix.

Germany, being part of the European Union, must comply along with the other member states to the Kyoto protocols stating that a 10% share of renewables in the transportation mix must be reached by 2020. Thus far, Germany seems to be on the right track.

In 2012, the biggest renewable contribution was represented by biodiesel with approximately 4.5%. Other important contributors were bioethanol with approximately 2% and biomethane with a modest contribution of 0.05%.

## 7.3. Political situation for renewable energy

Crossing from nuclear energy and fossil fuels to green, renewable energy sources is probably one of the most difficult tasks that Germany has faced in recent years. However the agressivity with which Germany has pursued this endeavor has resulted in numerous complaints from the general public due to energy price increases. The industry also had to suffer and players fear the competitivity risk.

The main law supporting the expansion and usage of renewable energy technologies is called "Energiewende". However this law is based on the payment of a supplementary tax, which is added to the electricity bill in Germany (Poenaru, 2013).

The Energiewende is mainly a set of dates for different energy-related goals. The last nuclear power plant in Germany has been set to be switched off in 2022.

After the decision of Germany's chancellor in 2011 to gradually reduce and finally renounce to nuclear energy, Germany has as objective to utilize in proportion of 35% renewable sources till 2020 and 80% in 2050.

German consumers are very enthusiastic about these targets but dread, however their side-effects. The cost of electricity has risen as a consequence of a law passed in 2000 which guarantees not only 20 years of fixed high prices for solar and wind producers but also preferred access to the electricity grid. As a result, Bavarian roofs now gleam with solar panels and windmills dominate entire landscapes. Last year, the share of renewables in electricity production hit a record 23.4% (The Economist, 2014).

Due to the rapid implementation of the Energiewende, the costs associated with renewable energy are expected to rise from 14.1 billion euro to 20.4 billion euros according to BDEW (2013). Another consequence of this law is that by encouraging solar and wind energy, coal and gas power plants experience loss of activity during sunny or windy days and continue to be more and more unprofitable (Poenaru, 2013).

In the electricity sector the Renewable Energy Sources Act (EEG) represents the main supporter of RES growth. Recently the EEG was subjected to a revision and three amendments. The most recent amendments announced by the Ministry of Environment and Economy are considered ill-fitting, not thoroughly thought through and could have repercussions endangering the Energiewende (Bolintineanu, 2013).

In the heating and cooling sector the current support policy is considered to not have delivered any major results. It was however revised, but nevertheless the Renewable Energy Heat Act (EEWaermeG) has not brought any worthy changes.

In the transportation sector the E10 fuel policy was introduced in 2011 but resulted in a complete failure. Regarding the pure biofuels, the preferential tax treatment ceased at the beginning of 2013. Regarding electro-mobility there are still no relevant incentives (Bolintineanu, 2013).

## 7.4. National energy strategy

The National Renewable Energy Action (NREAP) plan written by Germany describes how the country plans to achieve its legally binding target of 18% renewable energy in the gross final consumption of energy by 2020.

Germany's Energy Strategy represents the central pillar for the development of climate and energy policy in Germany. The climate and energy goals of Germany are a 40% reduction in the GHG level by 2020 compared to the level in 1990. It also targets an 18% share of renewables in the final energy consumption and at least a share of 30% of renewables in the electricity sector by 2020. It also pays attention to efficiency, estimating a doubling by 2020 compared to the 1990 levels. Among other goals are that cogeneration will generate 25% of electricity by 2020, and the fact that RES will supply approximately 14% of the heat production by 2020.

In order to reach the above-mentioned targets, Germany has taken measures mostly in two areas of energy generation: namely electricity and heat. In the electricity sector the main incentives are priority for renewable energy in the grid feeding, a price guarantee that will exist for a period of 20 years but which is regularly adapted to market situations, technological development and energy source and lastly the EEG costs are passed on to the consumer.

In the heating sector current measures include a mandatory use of renewable energies when building new constructions, Germany spent 500 million EUR on the retrofitting of existing buildings with heating from renewable energy and thus triggered additional investments and lastly feeding electricity from CHP plants into the grid is repaid (BDEW, 2013).

## 7.5. Theoretical potential of renewable energy sources

The theoretical potential of renewable energy sources in Germany is explained in detail in the Disruptiveness assessment chapter.

## 7.6. Disruptiveness assessment

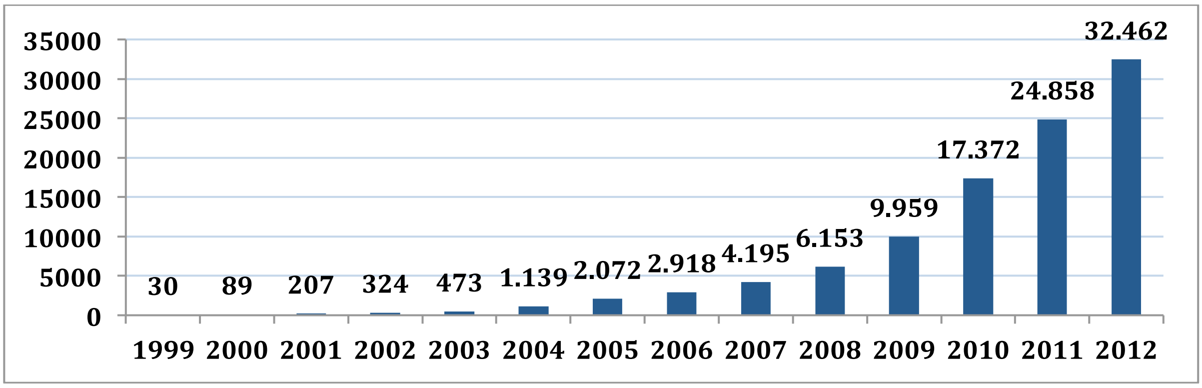
With the help of the assessment framework, a short glimpse in the German energy future is provided, thus making it possible to distinguish between the green energies that might have the biggest impact in the next years, on the energy sector. The three main areas assessed, as previously mentioned in Chapter 6.6 and Chapter 5.6. are: electricity, heating and cooling and transportation.

### 7.6.1. Electricity sector

**Solar photovoltaic**

Germany is a global leader and a trendsetter in the solar PV industry. Around 28,060 GWh were produced with solar PV in 2012 in Germany, which was a bit more than 20% of the total electricity generated via RES (See Appendix 7) and 4.7% of the total electricity consumption in Germany in 2012 (AGEE, 2013). Only in 2012, 7,600 MW of new PV capacities were installed in Germany which is equal to 44% of the total new capacities in Europe for 2012 (EPIA, 2013). At the end of 2012 the total PV capacity was 32,400 MW which is enough to cover the electricity needs of more than 7 million 3-person households (See Figure 25). The total number of installed PV systems at the end of 2012 was 1,280,000 (AEE, 2013b).

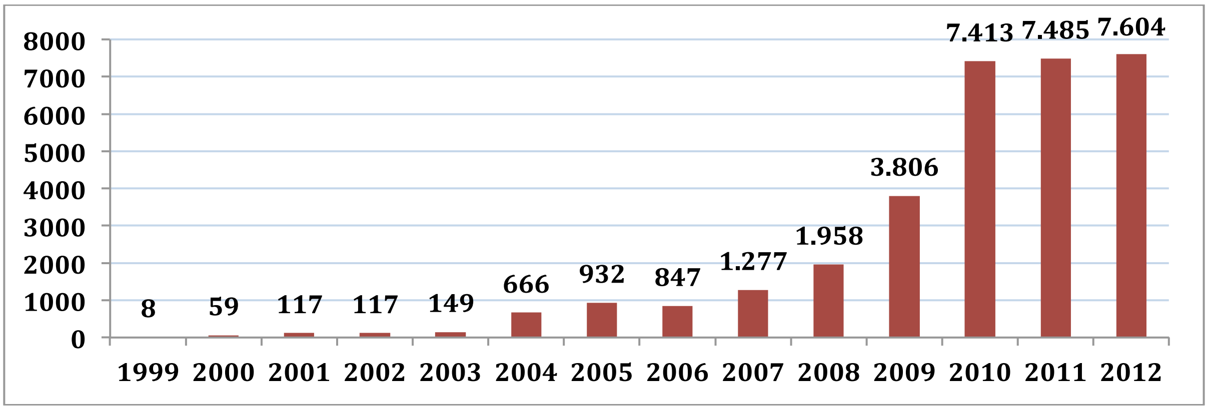
**Figure 24: Cumulative installed PV power capacity (MW) in Germany for the period 1999-2012**



Source: (IEA-PVPS, 2013)

The rate of development of the solar PV industry in Germany is tremendous after installing more than 7 GW of PV systems in three years in a row (See Figure 26). In June 2013, Germany set up a new solar record when for 2 days solar energy plants produced 22GW of electricity per hour which is equivalent to the electricity supplied by 20 nuclear stations operating at full capacity (EREF, 2013). Estimations show that solar PV will reach a capacity of 51 GW and 7% of the electricity mix in Germany in 2020, or even 8-10% (EREC, 2011; Hinrichs-Rahlwes, 2012; AEE, 2013). According to Raykov (2013), Research Associate at Solar World, solar PV will reach 15% market share in the electricity consumption in Germany in 2035. The main factors driving towards this positive trend have been the long-term stability of support systems, the confidence of investors, the desire of residential, commercial and industrial building owners for PV installations and the very positive social attitude towards PV technologies (IEA-PVPS, 2013; Raykov, 2013; Van Strien, 2013). In addition, PV prices have been dropping rapidly reaching average price for end-customer for installed roof mounted PV systems of 1.698 EUR/kWp without tax (BSW, 2013b; AEE, 2013b). Due to the rapid price decrease Germany introduced the "Corridor" concept in 2011 a method according to which the level of feed-in tariffs is to be adjusted according to market evolution (IEA-PVPS, 2013). Furthermore, in September 2012 Germany abandoned feed-in tariffs for installations above 10MW (IEA-PVPS, 2013). Also, the German government tries to promote the self-consumption of electricity from PV with self-consumption premium which is higher than the retail electricity price. In addition to that, "market premiums" aim to incentivize PV producers to sell their output on the market rather than getting a fixed feed-in tariff. At the end of 2012, a bit less than 3 GW of PV installations were selling on the market under this model (IEA-PVPS, 2013).

**Figure 25: Annual installed PV capacity (MW) in Germany**



Source: (IEA-PVPS, 2013)

Together with hydropower, solar PV is the fastest growing RES in Germany (See Appendix 7). The total investments in construction of PV installation in 2012 amounted to 11.2 billion EUR which was by far the largest investment in renewable energy installations (AGEE, 2013; AEE, 2013). Also, in 2012 the total revenues in the solar PV sector were around 1.22 billion EUR. In 2012, 100,500 people were employed in the solar energy sector which was a decline from 125,000 in 2011 (AGEE, 2013). Moreover, funding for R&D in the PV sector in Germany has grown through the years and in 2012 amounted to 66 million USD. An important role played the implementation of the *Photovoltaics* Innovation Alliance, a joint program of BMU and BMBF, which started in 2010 and promotes reduction of PV production costs. The priorities for the BMU funding are silicon wafer and *thin film* technologies, systems engineering, alternative solar cell concepts, etc. At the same time BMBF's funding is mainly directed towards organic solar cells, thin-film solar cells and the cluster 'Solarvalley MItteldeutschland'

(IEA-PVPS, 2013). Commercial and ground mounted PV segments are the biggest ones, however the trend is towards increase of the ground mounted PVs (EPIA, 2013).

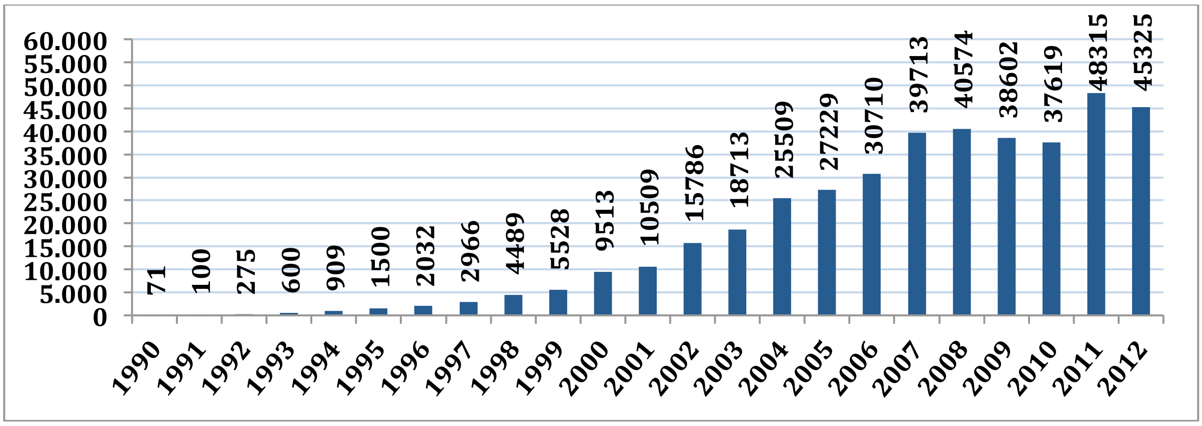
There are no major barriers for the development of PV in Germany. The main technological challenges are the increase of efficiency of photovoltaic cells, adaptation of the grid for RES and the reduction of costs for storage facilities. However they are expected to be overcome in the near future. The government's policies increasingly aim to direct the PV industry towards a more market-based industry with less dependence on feed-in tariffs (Raykov, 2013). This will most probably slightly decrease the growth rate of PV installations as grid parity is not yet fully met. Nevertheless the strong pro-renewables political and social attitude and the economic stability of Germany will be important factors for the excellent condition of the investment climate in the country. All in all, solar PV is expected to play an increasingly important role on the German electricity market.

**Solar PV in the electricity sector** was rated as having a disruptiveness score of **3.6.**

### Wind energy

Wind energy is the most important source of renewable energy for electricity generation in Germany. In 2012, almost 46 billion KWh of electricity were produced via wind energy which accounted for 33.8% of the total electricity produced from RES and 7.7% of the total electricity consumption in Germany (See Appendix 7 and Figure 27) (AGEE, 2013). Onshore wind turbines contributed with 45.3 billion KWh, while offshore with 0.7 billion KWh. As per 31.12.2012 a total of 22,962 wind turbines with a capacity of 31,315 MW have been installed in Germany (31,035MW onshore and 280MW offshore) (DEWI, 2012; Ender, 2013; IEA WIND, 2013; AEE, 2013).

**Figure 26: Development of electricity generation from wind energy plants in Germany (GWh)**

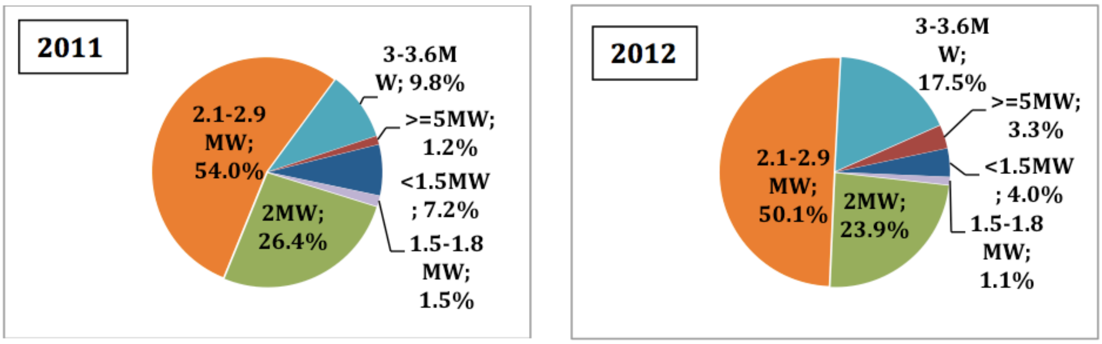


Source: (DEWI, 2012; AGEE, 2013)

The total investments in construction of wind energy installations in 2012 in Germany amounted to 3.75 billion EUR (AGEE, 2013). At the same time the revenues from the operation of wind energy installations in Germany in 2012 were 1.43 billion EUR. Also, the German wind energy sector employed around 117,900 people in 2012 (AGEE, 2013; AEE, 2013; IEA WIND, 2013). Moreover there was a strong upward trend in the construction of wind energy facilities in 2012. Additional 2,440 MW capacities were built in 2012 which is significantly higher than 2,007MW in 2011 (BMU, 2013b). One of the main reasons was the growing share of wind turbines in the range above 3MW that rose up from 11% to 21% and hence increased the average installed power from 2,224KW to 2,377KW (See Figure 28) (Ender, 2013; IEA WIND, 2013). According to Hinrichs-Rahlwes (2012) from BEE, wind energy will contribute to the electricity mix in Germany in 2020 with 25%, whereby offshore will contribute with 6% and onshore with 19%. Consequently, the installed capacities in 2020 will rise to 45,000MW for onshore and 10,000MW for offshore (EREC, 2011). The upward trend is already visible as in 2013 the total installed new capacities will be from 2,700 to 2,900MW (BWE, 2013). In addition Wiesen (2013) gave a prognosis of 42% market share of wind energy in the total electricity consumption in Germany in 2035.

Offshore wind energy will be of paramount significance for the development of wind energy in Germany. While onshore turbines have been on the market since 1990, the first offshore wind turbines were installed in 2009 (AGEE, 2013). The total offshore wind turbines installed capacity was 280 MW in 2012 and additional 2,700 MW are under construction (GWEC, 2012; EWEA, 2013b). Moreover, 29 additional offshore wind energy projects have been licensed which will increase the capacity to 9,000 – 10,500 MW depending on turbine characteristics (GWEC, 2012). The offshore wind energy industry solely employs around 10,000 people (EWEA, 2013b). Even though the share of offshore wind energy remained very low in 2012 with 675 million KWh there was an increase of 19 percent on a year-basis (BMU, 2013b). As for the location of the facilities, the North Sea has been the preferred option so far. By the end of 2012 there we 32 wind turbines already generating electricity and 8 more were completed but not operating (Ender, 2013). Furthermore, in 2012 the construction of additional offshore wind farms in the North Sea began. Some of the ongoing projects include “Riffgat” (108 MW), “Borkum West 2” (200Mw later 400 MW), “Global Tech I” (400 MW), “Nordsee Ost” (295 MW) and “Meerwind” (288 MW) (Ender, 2013). The situation in the Baltic Sea is far less active. The construction of the wind farm “EnBW Baltic 2” (288 MW) has been delayed and is expected to start in 2013 (Ender, 2013). Most of the offshore wind farms in Germany are located 20-60 kilometers off the coastline in 20-40 meters depth (EWEA, 2013b). Germany’s goal is to have 10GW capacity of installed offshore wind turbines by 2025 (IEA WIND, 2013).

**Figure 27: Share of the wind turbine classes in the newly installed capacities in 2011 and 2012**



Source: (Ender, 2013)

Throughout the years certain technological advancements have been observed. There has been a tendency towards wind turbines with rotor diameters of more than 90 meters (See Table 3). Their share in 2012 was 47% of all wind turbines installed in Germany. The biggest increase can be seen in wind turbines with rotor diameter of 100 meters as their share increased from around 14% to 25%. Meanwhile the share of wind turbines with rotor diameter of less than 80 meters has been decreasing (Ender, 2013). Another important characteristic of the wind turbines is the hub height. In 2012, more than 65% of the installed wind turbines had a hub height of more than 100 meters (Ender, 2013). This is an important matter also because in some states in Germany there are certain restrictions for the total height of the wind turbines which is the sum of the hub height and the rotor radius. The trend towards, higher hubs, longer rotor diameters and power capacity can also be observed in the figures for 2012 and the first half of 2013.

**Table 3: Average turbine configuration in Germany in 2012 and the 1st half of 2013**

| | **2012** | **1st half 2013** | | |
|---|---|---|---|---|
| | **Overall** | **Onshore** | **Offshore** | **Overall** |
| **Average capacity of wind turbines** | 2,420KW | 2,557KW | 5,000KW | **2,677KW** |
| **Average rotor diameter** | 88.4 m | 93.1 m | 122 m | **94.5 m** |
| **Average hub height** | 109.8 m | 115.2 m | 90 m | **114 m** |

Source: (Deutsche WindGard, 2013; Deutsche WindGuard, 2012)

Repowering of wind turbines has become an important driver for the wind energy industry in Germany. It has the potential two double the amount of capacity and triple the yield with significantly fewer turbines deployed (GWEC, 2012). On one-hand old wind turbines installed at the coastal areas are replaced with modern turbines which utilize the wind more effectively. On the other hand the technological advancements in repowering made it possible for wind turbines to be installed in inland areas where previously it would not have been economically efficient (Neddermann, 2013). Repowering of wind energy installations increased twice in 2012 compared to the previous year. In total f 325 wind turbines with 196 MW were pulled down and directly replaced by 210 turbines with 541 MW (Ender, 2013).

Despite all the positive trends in the wind energy industry in Germany there are certain barriers that hinder the deployment of wind turbines. One of the main obstacles is the height restrictions in some regions which hinder the installation of modern turbines with hub heights above 120 meters. At very good sites these modern turbines can reach capacity factors of 35% (3,000 full load hours) in mainland Germany and 45% at the coastal and mountain areas (GWEC, 2012). Nevertheless federal and state governments have initiated discussions on the framework conditions that hinder the wind energy development. An additional challenge for the expansion of RES is the slow optimization of the grid capacity as well as the delayed offshore grid connection which influences negatively the whole maritime economy in Germany (EWEA, 2013b).

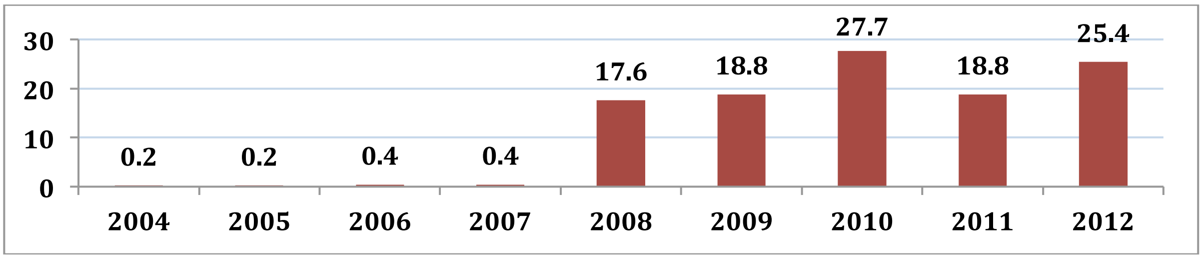
The situation worsened off when the Transmission System Operator (TSO) declared serious problems in realizing planned grid connections in the North Sea in due time (IEA WIND, 2013). Additionally, despite the positive upward trend the investment climate in Germany has deteriorated due to directionless political debates for the amendment of German Renewable Energy Sources Act (EEG), the decreasing subsidization and the recent elections (BWE, 2013; Wiesen, 2013). A big challenge for the wind energy industry is the maintenance of the gearbox due to its robustness. A solution for this problem could be the medium speed permanent magnet generator with single stage gearbox (Wiesen, 2013). Also increasing prices of core materials for the construction of wind turbines such as steel and copper is a further challenge for the cost competitiveness of wind energy. The social acceptance can potentially become a major obstacle due to the increasing sizes of the onshore wind farms and the high population density in the country (Wiesen, 2013). Despite all the challenges wind energy will greatly expand its presence on the energy market in Germany and to a certain extent disrupt the market dominance of fossil fuels.

**Wind power in the electricity sector** was rated as having a disruptiveness score of **3.7.**

### Geothermal energy

Although Germany is not the richest country in geothermal resources, it is one of the most efficient one in using the available geothermal energy. Total electricity produced with geothermal energy in 2012 amounted to 25.4 GWh and contributed to 0.02% of the renewable-based electricity consumption in Germany. The first installations started operating in 2004 however reasonable output was not generated until 2008 (See Figure 29). As of today the total installed capacities for geothermal electricity generation are 12.1 MW (AEE, 2013b).

**Figure 28: Development of geothermal electricity generation (in GWh) in Germany 2004-2012**



Source: (AGEE, 2013)

The barriers that exist in front of the geothermal energy industry in Germany are identical to the ones the rest of the EU faces. Geothermal electricity generation faces significant technological challenges which hinder its market penetration. As of today the binary systems that are in place depend very much on the hydrothermal resources and therefore are only deployed in Bavaria and Baden Wuerttemberg. Significant market break through is expected when *EGS* become more competitive. Cogeneration is a plausible option for increasing the efficiency of geothermal technologies and it is increasingly employed in the country (Dumas, 2013).

Even though the level of awareness and knowledge from geothermal technologies in the policy makers is not at a desirable level, compared to other countries considerably better support schemes are in place in Germany. Germany's NREAP foresees a growth in the geothermal electricity generating capacities from 10 MW (27 GWh) in 2010 to 298 MW (1,654 GWh) by 2020 (EGEC, 2011). Another very important support scheme is the availability of insurance schemes against geological risks which exploration companies can make use of and get partially reimbursed if their exploration attempts happen to be unsuccessful (Dumas, 2013). The relatively high feed-in tariffs are an additional advantage for the geothermal industry in Germany. However investment costs are still a major obstacle and even though some reductions of the investment costs are expected (5-10%) prices will still stay high (RHC, 2012a).

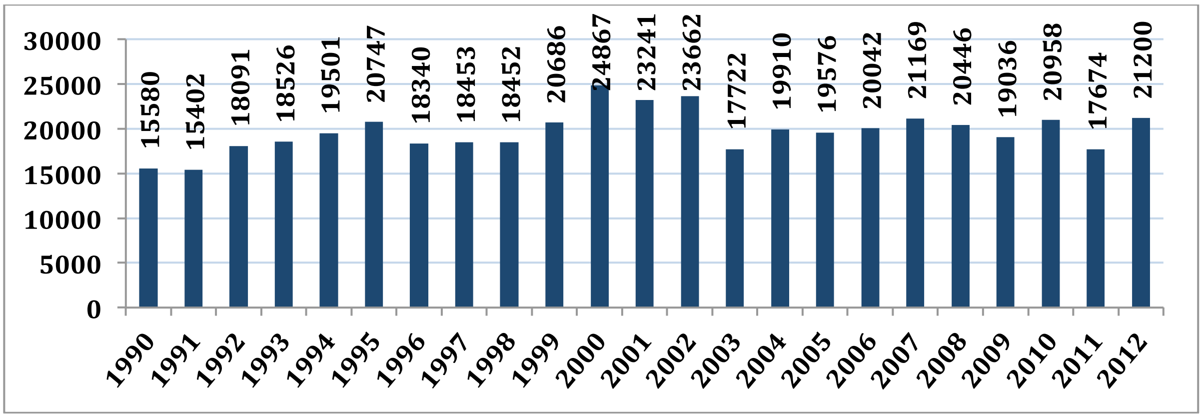
To sum up, Germany is on the right way of commercializing the geothermal industry. According to Hinrichs-Rahlwes (2012) geothermal energy will produce 4TWh of electricity in 2020 and therefore contribute to 0.7% to the total electricity consumption (EREC, 2011). Nevertheless significant advances in the technologies are required for a more disruptive impact on the energy market.

**Geothermal energy in the electricity sector** was rated as having a disruptiveness score of **2.2.**

### Hydropower

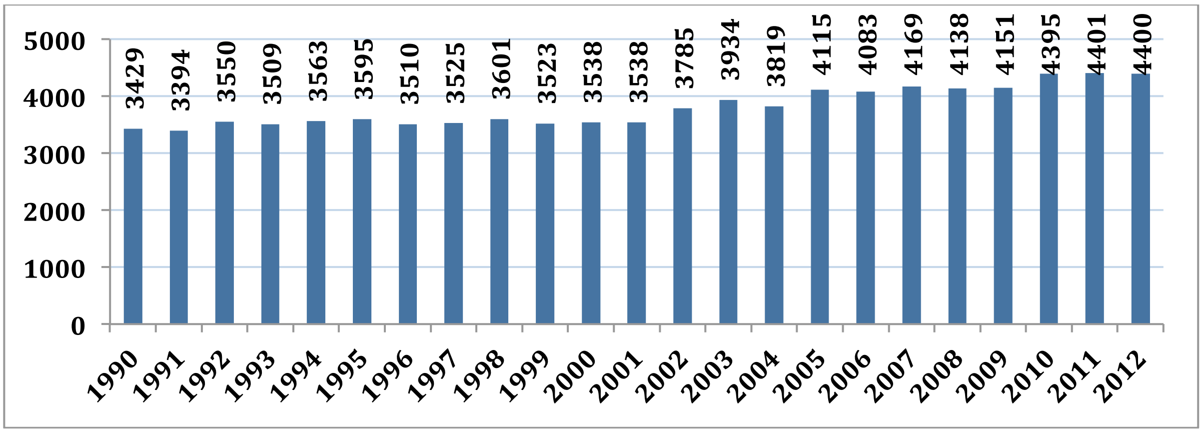
Hydropower has been an important source of renewable energy in Germany for decades. Hydropower plants generated 21,200 GWh and contributed to 3.6% of the total electricity consumption of Germany in 2012 which was an increase from 2.9% in 2011. Also, 15.6% of the electricity supplied with RES was from hydropower installations. Hydropower is a mature technology for electricity production in Germany and the output has been very volatile throughout the years due to fluctuations in the natural water supply (See Figure 30). Also, due the naturally limited resources the installation of new capacities has been quite marginal with 4,400 MW in 2012 compared to 3,429 MW in 1990 (See Figure 31) (AGEE, 2013; AEE, 2013b). The annual growth rate of hydropower capacities from 1990 to 2000 was 2% and from 2000 to 2012 1.2% (BMU, 2013a; BDW, 2011).

**Figure 29: Annual production of electricity from hydropower in GWh in Germany 1990-2012**



Source: (AGEE, 2013)

**Figure 30: Total installed capacities in MW for hydropower production in Germany 1990-2012**



Source: (AGEE, 2013)

Investments in new HPP capacities have also been quite negligible compared to other RES. In 2012, 70 million EUR were invested in new hydropower installations which 0.3% of the total investments in RES sector. Moreover, the revenues accumulated from the operation of the hydropower installations in Germany in 2012 were 380 million EUR or 2.6% of the total revenues from RES. Opposite to the other RES, at the hydropower sector there is a downward trend of the number of employed people which decreased from 9,500 in 2004 to 7,200 in 2012 (AGEE, 2013; AEE, 2013b; BMU, 2013a).

Small hydropower plants (SHP) have an important role in the development of the German hydropower industry. The total installed capacities in 2010 were 1,732 MW generating almost 8,000 GWh and are expected to increase up to 1,830 MW in 2020 with total generation of around 8,600 GWh. Also the number of hydropower plants is expected to increase from 7,400 in 2010 to 7,800 in 2020 (ESHA, 2012).

The support schemes for hydropower installations have not evolved much during the years. The duration of the feed-in tariffs is 20 years and they depend on the production capacity of the HPP (See Appendix 11). Apart from the slight increase of the FIT in 2012, there have not been any further changes of the support scheme including no simplification of administration and permitting procedures. Hence no significant increase in the capacities is expected (ESHA, 2012).

The barriers that hydropower faces are also quite different from the ones the other RES have to cope with. Basically, no major technological challenges exist due to the maturity of the technology and the limited additional potential. Moreover, investments in R&D are very limited. Also, there is no evidence for any strong political will for a push in the sector. Despite, the fact that social acceptance is high, the extremely powerful environmental organizations in Germany hinder the development of the hydropower sector and therefore limit the construction of new capacities (ESHA, 2012).

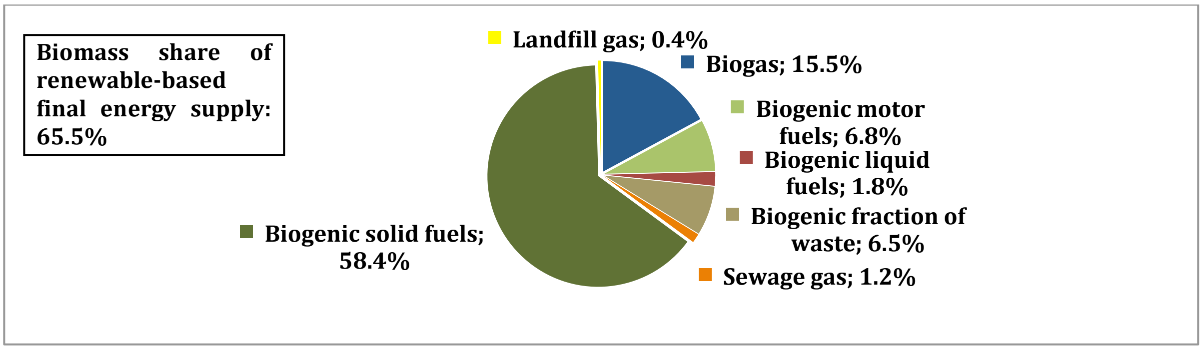
According to (Hinrichs-Rahlwes, 2012) and the German Renewable Energy Association, the total consumption of electricity from hydropower will increase up to about 32,000 GW in 2020 and will contribute to 5% of the electricity mix in Germany (EREC, 2011; AEE, 2013b; BEE, 2012). Nevertheless, this is an ambitious prognosis as it plans 6,500 MW of installed capacities by 2020 and given the past growth rates it will be rather difficult to achieve. In fact, the supply of electricity from hydropower is expected to reach a ‘plateau’ at around 5% of the total electricity consumption in Germany mainly due to the naturally limited resources.

**Hydropower in the electricity sector** was rated as having a disruptiveness score of **2.6.**

### Biomass

Germany has a huge potential for bioenergy production. The forest in Germany covers an area of 107,000m2, which represents more than 3.5 billion m3 of wood with an annual growth of 120 million m3 of new biomass (CrossBorder Bioenergy, 2012c). About a quarter of the wood production in Germany is used for energy production (BMU, 2012b). In addition to that, various types of waste and used wood as well as wood products like paper are also used to produce energy. Other important suppliers of biomass are agriculture and biogenic residues and waste. About 65.5% of Germany’s total final energy from renewable sources (319.9 billion KWh) was supplied by biomass in 2012 (AGEE, 2013) (See Appendix 7). The biogenic solid fuels and biogas had the biggest shares in the final energy produced from biomass with 58.4% and 15.5% respectively (See Figure 32) (AGEE, 2013).

**Figure 31: Structure of final energy produced from biomass in Germany in 2012**



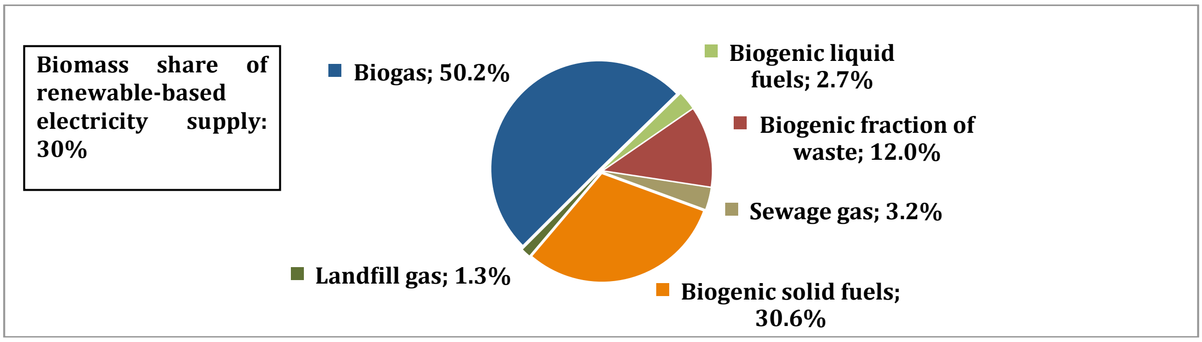
Source: (AGEE, 2013)

The German bioenergy industry is excellently organized as there is an existing association for each market sector which represents the diverse interests of the stakeholders. They are all organized under the umbrella of the German Bioenergy Association (BEE). Big part of the biomass energy production in Germany is concentrated in Bavaria and Lower Saxony (BDEW, 2013). Around 128,900 people were employed in the biomass energy sector in 2012 (AGEE, 2013). According to AGEE (2013), the total investments in construction of bioenergy installations in 2012 were 1.5 billion EUR for electricity production and 1.05 billion EUR for heat production (Statista, 2013). Also considerable attention has been directed towards biorefineries and the production of valuable biomass by-products (See Appendix 8). Nevertheless, there is a significant drop in the investments since 2010. Bioenergy installations yield the highest revenues, for instance in 2012 they amounted to 6.77 billion EUR for heat and power production and 3.53 billion EUR for biofuels production. Together they represented 71.5% of the total revenues in the renewable energy sector (AGEE, 2013).

Germany offers a very favorable ground for investments in the bioenergy sector. In addition to the generally attractive for investments energy sector in Germany (See Appendix 9) the country also demonstrates convincing support mechanisms for the development of biomass-fired *CHP* plants with the Renewable-Energy-Act (EEG) being the most important support scheme offering grants, tax liability reductions, etc (IEE, 2012; FNR, 2013). It is regularly amended to adjust to the tariffs to the actual market developments and needs. Furthermore, Germany has a very well-developed road and rail infrastructure which supports an efficient delivery of biomass feedstocks to bioenergy plants. In addition, well-established separation and collection systems for bio-waste increase the potential of bio-waste as an energy source. Several emission thresholds need to be met in order for a bioenergy plant to be approved. Some of them comprise air emissions, odor emissions and noise. Nevertheless, a few cases have been reported on people being against bioenergy production due to the large increase of traffic around the bioenergy plants, odor annoyances and decrease of biodiversity through massive energy crops plantations (CrossBorder Bioenergy, 2012b).
Furthermore, in 2012 electricity generation with biomass amounted to 40.9 billion kWh which represented 30% of the total electricity production from RES and 6.9% of the total electricity generation in Germany (See Figure 33) (AGEE, 2013). The total installed capacity for electricity generation from biomass in 2012 was 7,647MW (AGEE, 2013).

According to (EREC, 2011) the share of biomass in the electricity sector in 2020 will reach 9.2%, whereby solid, waste and liquid biomass will contribute to 3.6% and *biogas* to 5.6%. Additionally, Germany's great potential of wooden biomass, strong biomass processing industry, well-developed energy crops cultivation and bio-wastes utilization offer a very favorable ground for the development of the *CHP* energy production in Germany. Until 2011 more than 265 *CHP* plants had been installed with total capacity of 1,210 MW (Foederal erneuerbar, 2012; BBE, 2012; CrossBorder Bioenergy, 2012). *Combustion* technologies with steam turbines are dominating the market and despite only incremental improvements it will still play an important role in the future (Reumerman, 2013; CrossBorder Bioenergy, 2012). Also, *co-firing* has a large potential in Germany especially for large-scale plants due to its cost-effectiveness. Currently there are 27 plants specialized in co-firing of fossil fuels with biomass (KEMA, 2009). No significant share of biomass is used in gasification up to now though an increase is expected as the technology is already being slowly commercialized (Reumerman, 2013). Some of the major *gasification* projects are KIT's bioliq plant, Choren Freiburg, Stadtwerke Ulm *CHP*, Blue Tower *CHP* in Herten, Stadtwerke Duesseldorf (Kolb, 2011).

**Figure 32: Structure of biomass-based electricity supply in Germany in 2012**



Source: (AGEE, 2013)

In addition, Germany is a very attractive market for *biogas* investments as it is global leader in the *biogas* industry and sets forth very ambitious goals for the future. The amount of electricity produced form *biogas* in 2012 was 20.5 billion KWh (15.1% of total renewable-based electricity supply) and it is planned to increase to 23.4 billion kWh in 2020 (AGEE, 2013; CrossBorder Bioenergy, 2012). In addition the German Energy Agency has set the goal of feeding 6 billion $Nm^3$ *biomethane* into the natural gas grid by 2020 which would require the construction of 1,000 medium-sized ($700m^2/h$) or 2,000 small-sized ($350m^2/h$) *biomethane* plants (IEE, 2012; CrossBorder Bioenergy, 2012). As of today there are 7,515 *biogas* plants with total installed capacity of 3,352 MW (BBE, 2012; FNR, 2013). Due to its very high population density and a strong biomass processing industry, Germany accumulates a great amount of energy crops and bio-waste which offers considerable potential for *biogas* and *biomethane* production. The most utilized feedstocks are manure (46%) and energy crops (45%) (IEE, 2012).

Experts claim that the highest uncapped potential is kept within the neglected resources of biowastes and various industry residues. Estimations show that *biomethane* has the potential to supply 10 per cent of Germany's demand for natural gas which is equal to the energy demand for 4 million households (Biogaspartner, 2013). The legal and financial environment in Germany supports the development of the *biogas* industry.

According to the Renewable Energies Heat Act (EEWärmeG) buildings constructed after January, 1 2009 are obliged to employ RES for their heat supply, and if the households opt for *biogas*, the obligation is a 30% rate. Even though *biogas* and *biomethane* still need support in order to stay competitive to fossil fuels and nuclear energy, the conditions for further development of the sector are at place.

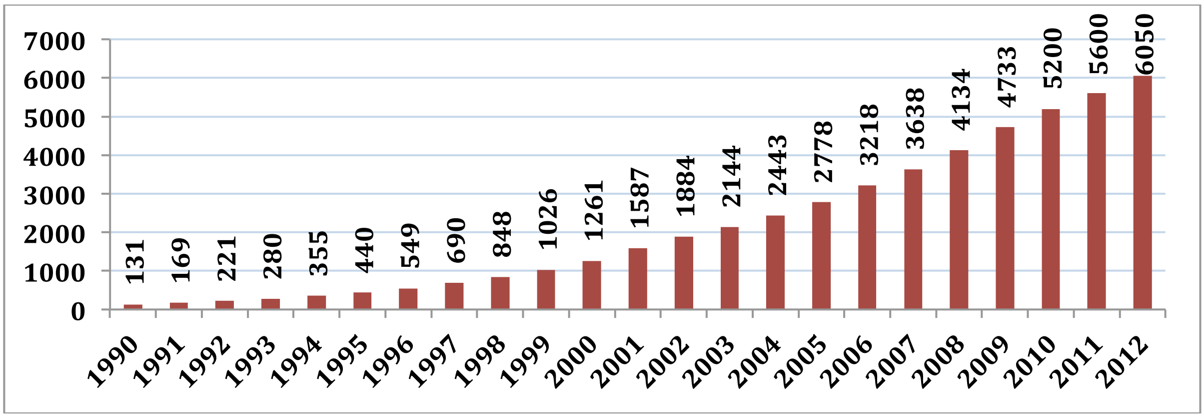
**Biomass in the electricity sector** was rated as having a disruptiveness score of **3.1.**

### 7.6.2. Heating and cooling sector

**Solar thermal energy**
Germany has high ambitions to supply a big share of its heating needs via solar energy. Around 6.1 billion KWh of heating energy were supplied via solar thermal in 2012 which is equal to 4.2% of the heating supplied by RES and 0.4% of the total heating energy in Germany (See Figure 34) (AGEE, 2013; BSW, 2013a; AEE, 2013b). The first technologies were installed in the 1980's and ever since then there has been a steady growth of installed capacities reaching 16.3 million $m^2$ and 11,500MW and the total number of solar thermal systems increasing up to 1,803,000. Newly installed capacities in 2012 amounted to 805 MW and 1.15 million $m^2$ which represented a 7% increase (BSW, 2013a; AEE, 2013b; ESTIF, 2013b; IEA-SHC, 2012). Flat plate collectors had a market share of 88% while *evacuated tube* collectors accounted for 11% of the installed solar thermal systems (Kohlenbach, 2012). More than 95% of the solar thermal market in Germany is from collectors on single or double-family houses with systems ranging from 6 to 12 $m^2$. An increasing market is expected as a result of the improved financial conditions as of August 2012 especially in the industry segment which accounts for 27% of the total final energy consumption in Germany. The main support schemes are European regulations for nearly zero emission buildings in 2020, the Energy Savings Regulation (EnEV) and the Renewable Energies Heat Act (EEWärmeG) (IEA-SHC, 2012). Furthermore, the total investments in the construction of solar thermal plants in 2012 amounted to 990 million EUR while the annual turnover was around 250 million EUR (AGEE, 2013). Also, as of today the German solar thermal industry employs about 20,000 people.

The main barriers for the development of solar thermal are the higher costs for SHC systems compared to PV and the worse funding conditions (IEA-SHC, 2012). Some experts expect that the heating needs in Germany will be fully supplied via electricity (Hoeller, 2013). There have also been some social beliefs that solar energy in general is not worth investments as the government decreased the feed-in tariffs for PV. As of today the solar heating costs are ranging from 17 – 30 ct/KWh which is almost double the gas price (IEA-SHC, 2012). One of the main goals of the German solar heating roadmap is to decrease this cost with 43% by 2030. Solar thermal has been attracting increasing political attention and therefore the German Ministry for the Environment, Nature Conservation and Nuclear Safety invested almost 21 million EUR in new solar thermal projects in 2012 (BMU, 2013a). Also, solar heating for buildings was included in the ENOB program funded by the Federal Ministry for Economics and Technology with an annual budget of 30 million EUR. Furthermore other research institutions like ISE Freiburg, IBP Stuttgart and DLR Koeln also work on projects on solar thermal technologies (IEA-SHC, 2012).

**Figure 33: Total production of solar thermal energy in Germany (1990-2012)**



Source: (AGEE, 2013)

The German Solar Industry Association (BSW) prepared a solar heating roadmap which aims to accelerate the solar heating and cooling market growth and gives goals for 2020 and 2030 (See Table 4). Apart from the general goals for installed capacities, emphasis is put on the reduction of system prices and RES-based heating requirements for the industry. According to the roadmap the total installed capacities will reach 70GW by 2030 (BSW, 2012).

**Table 4: Key objectives of the German Solar Heating Roadmap for 2020 and 2030**

| **Scenario** | **2010** | **2020** | **2030** |
|---|---|---|---|
| **Increase in collector surface in Germany p.a. (in millions of m2)** | 1.2 | **3.6** | **8.1** |
| **Installed collector surface in Germany (cumulative, in millions of m2)** | 14.0 | **39.0** | **99.0** |
| **Installed solar heating capacity (GW)** | 9.8 | **27.0** | **69.0** |
| **Solar heating energy production p.a. (TWh)** | 5.0 | **14.0** | **36.0** |
| **CO2 savings p.a. (in millions of t)** | >1 | **3.2** | **8.0** |
| **Share of solar heat in heating requirement of German households (%)** | <1 | **2.7** | **7.7** |
| **Share of solar heat in heating requirement (to 100°C) of German industry (%)** | 0.0 | **0.4** | **10.2** |
| **Installed systems for industrial process heat1 (cumulative)** | 0.0 | **1.5** | **28.3** |
| **Reduction of system price in residential buildings (%)** | | **14.0** | **43.0** |
| **Domestic turnover of ST industry (in billions of €)** | 1.0 | **2.4** | **3.0** |
| **German value creation rate (%)** | 75.0 | **75.0** | **75.0** |
| Export (in billions of €) | 0.5 | **1.1** | **1.4** |

Source: (BSW, 2012)

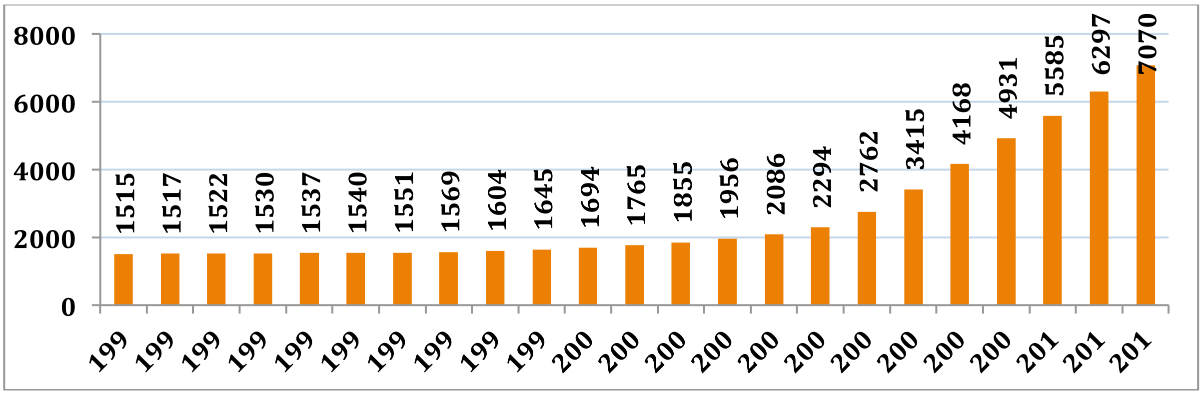
According to Wiesen (2013) solar thermal will be increasingly competitive vis-à-vis fossil fuels and will find vast application in new buildings. Nevertheless, its future is uncertain due to highly efficient PV and the potential perspective for heating needs to be fully supplied by electricity. The German Renewable Energy Federation (BEE) and Wiesen (2013) assume that solar thermal will reach a market share of at least 3% until 2020 and will surpass 10% after 2030 (EREC, 2011).

**Solar thermal in the heating sector** was rated as having a disruptiveness score of **2.9.**

### Geothermal energy

Geothermal energy generated a bit more than 7 TWh of thermal energy which accounted for 4.9% of the heating produced with RES in Germany in 2012 (See Figure 35). The main contribution came from shallow GSHC systems which generated 6.73 TWh, while deep geothermal produced 0.34 TWH. In the big picture, 0.52% of the total heating consumption in German in 2012 was supplied via geothermal energy (BMU, 2013a). In 2012 the total geothermal heating capacities amounted to 3,300 MW (AEE, 2013b). There are around 20 geothermal district heating systems in place in Germany, and their number is expected to increase up to 120 in 4 years. There are 3,200 MW of *GSHP* capacities installed in Germany, which makes it second biggest heating energy producer in Europe. Only in 2012 more than 22,000 new *GSHP* units were installed with total capacity of 230 MW (EGEC, 2013b; AEE, 2013b; GtV-BV, 2013). **Geothermal energy in the heating sector** was rated as having a disruptiveness score of **2.6.**

**Figure 34: Heat supply in GWh from geothermal energy in Germany (1990-2012)**



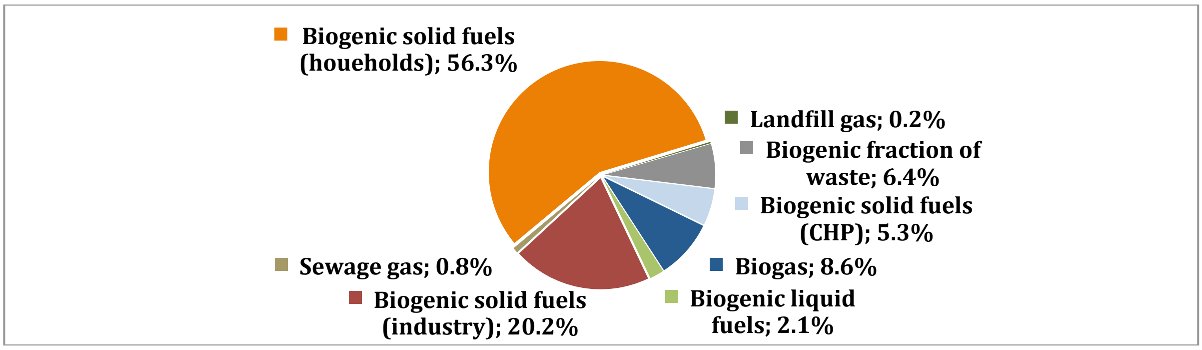
Source: (AGEE, 2013)

### Biomass

Today, biomass accounts for 9.5% of the final energy consumption for heat in Germany which, in fact, represents 91% of the total heat supply from RES in 2012 (AGEE, 2013). More than 80% of the heating energy produced from RES comes from solid biomass (See Figure 36) (AEE, 2013c). According to Reumerman (2013), a senior consultant at BTG World, and Stanev (2013), a project manager at FNR, biomass can reach a market share of 20% in the heating sector in Germany by the year 2035.

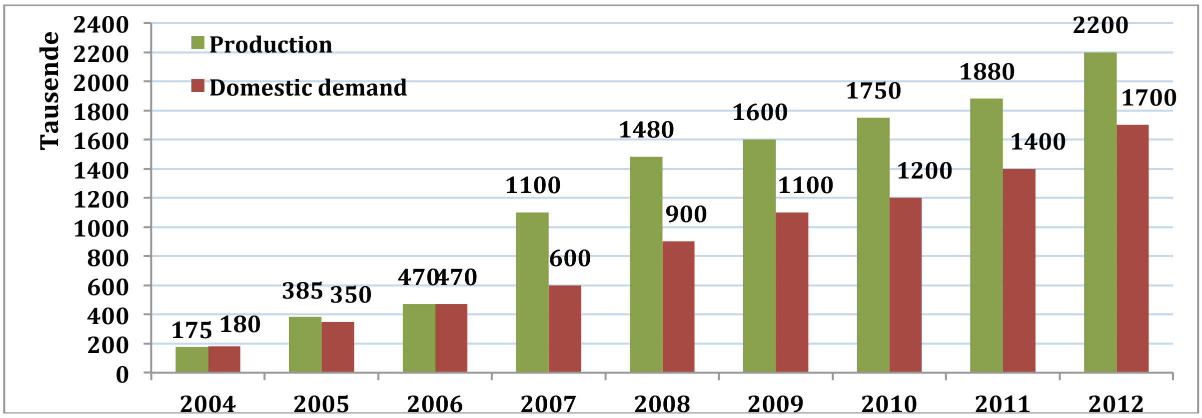
The increasing use of *CHP* plants will be the main driver for this upward trend. Also, wood pellets will play an important role for small-scale heating as they have been on the market in Germany for around 15 years and have been increasing their popularity gradually (See Figure 37). In 2011 there were 60 companies with 70 production facilities for wood pellets and 155,000 registered pellet systems generating 4.2 million MWh of heating energy (CrossBorder Bioenergy, 2012; BBE, 2012). Nevertheless, the maximum production capacity is never fully used, for instance in 2012 the total capacity was 3.1 million tones whereas 2.2 million tons were produced and only 1.7 million tons actually consumed (FNR, 2013; BBE, 2012). Small-scale heating is an important part of the energy consumption of Germany as the temperatures are relatively low and space heating is needed at least during half of the year. Nevertheless the installation of pellet boilers has slowed down due to irregular support by the federal government (CrossBorder Bioenergy, 2012d).

**Figure 35: Structure of biomass-based heat supply in Germany in 2012**



Source: (AGEE, 2013)

**Figure 36: Production and consumption of pellets in Germany since 2004**



Source: (AGEE, 2013)

Nevertheless, electricity and heat production from biomass faces certain barriers. Despite the fact that prices for fossil energy carriers have been rising steadily, the break-even point of bioenergy production has not yet been reached due to the increasing production costs and more particularly the rising feedstock prices (CrossBorder Bioenergy, 2012c). Also many users got anxious concerning the sustainability and the environmental benefits of biomass as a result of aggressive campaigns of various NGOs. Despite that biomass will be an important pillar in the energy transition process in Germany due to its characteristics of being a storable feedstock and a flexible energy supply hence estimations show that its potential will be able to satisfy 23% of the total demand for heat, electricity and transportation fuels by 2050 (BMU, 2012b).

**Biomass in the heating sector** was rated as having a disruptiveness score of **3.1.**

### 7.6.3. Transportation sector

#### Biofuels

Around 52.3% of the territory of Germany is used for agriculture, which offers a great theoretical potential of agricultural feedstock supply for the biofuel industry. At the same time due to its large population, and well-developed economy, there are 42 million registered vehicles in the country consuming more than 52 million tons of diesel and petrol fuel every year (CrossBorder Bioenergy, 2012a). These two factors together with Germany's goal to reach 10% market share of renewables in the transportation sector represent a great market opportunity for the production of biofuels. In 2012 biofuels' share in the transportation fuel industry was 5.7%, with *biodiesel* representing 73% and *bioethanol* almost 27% (BMU, 2012; FNR, 2012; AGEE, 2013; BDEW, 2013). According to the current estimations, *biodiesel* and *bioethanol* will be the main pillars for the 2020 goal with 4,443 ktoe for *biodiesel* and 857 ktoe for *bioethanol* (CrossBorder Bioenergy, 2012a). Considering the status quo in the biofuel industry, additional 1,870 ktoe will have to be produced until 2020.

Due to tax issues, pure biofuels are not likely to dominate in the future transportation fuel market in Germany, hence blending of biofuels with fossil fuels will be the most preferred option (AEE, 2013a). In regards to the feedstock, the most common energy crops are rape seed for *biodiesel* and vegetable oil (0.91 million ha), corn for *biogas* (0.8 million ha) and sugar beet and wheat for bioethnaol (0.25 million ha) (The diversity and area dedicated to biomass cultivation can be seen in Appendix 10) (CrossBorder Bioenergy, 2012; BMU, 2012). The tendency shows that the dedicated land for energy crops cultivation can be doubled from 2 million ha to 4 million ha without affecting food supply. Today, there are 45 *biodiesel* plants and 8 *bioethanol* plants in Germany (BBE, 2012). Nevertheless production capacities for *biodiesel* (4.8 million tons) and *bioethanol* (820,000 tons) are not fully used, for example in 2011 only 2.7 million tons of *biodiesel* and 576,828 tons of bioethnaol were produced (AEE, 2013; BBE, 2012). Also, *biomethane* might also find some application as a transport fuel even though it would be limited as there are only 96,300 gas-powered vehicles in Germany (NGVA Europe, 2013; Boisen, 2009). Also, despite the general positive attitude towards biofuels, some reluctant customer behavior has been observed due to concerns regarding the technical capability of their vehicles' engines and the sustainability of the biofuels (CrossBorder Bioenergy, 2012a). Estimates show that biofuels can cover 20% of the domestic fuel needs in Germany by 2030, and about 70% by 2050 (Fritsche et al., 2012).

Second generation fuels are still in a research and demonstration phase and therefore are not available on the market yet. Production facilities for second generation biofuels are expected to start operating in the upcoming years. The Bioliq pilot plant operated by KIT will utilize biomass residues from straw and wood in order to produce environmentally friendly BtL fuels. The production facility has the capacity of 500kg/h (2MW) of biomass and combines fast *pyrolysis* and gasification treatments for the production of Bioliq SynCrude (Bioliq, 2010; Bacovsky et al., 2013). According to many experts BTL fuels have a high potential to play a major role in the future biofuels market due to the fact that a very wide range of highly unutilized raw materials including all parts of the plants can be used in the production process (CrossBorder Bioenergy, 2012; Reumerman, 2013). Another pilot project for 2$^{nd}$ generation biofuels is managed by Clariant which opened Germany's largest demonstration-scale cellulosic ethanol production plant in Bavaria in July 2012 (Clariant, 2013). It utilizes agricultural residues such as wheat and cereal straws, corn stover and sugar cane bagasse to produce second-generation *bioethanol*. The commercial scale plant has a production capacity of 50,000 to 150,000 tons a year and employs *hydrothermal upgrading*, fermentation, enzymatic hydrolysis and other processes (Clariant, 2013). The investments in the plant were about 16 million EUR for the construction and 12 million EUR for research and development (Clariant, 2013). It also received funds in the form of subsidies from the Bavarian State Government and the Federal Ministry of Education and Research

(BMBF). The market potential for *bioethanol* is increasing due to the demand for climate-friendly second-generation biofuels and the easy adaptability to the already existing infrastructure (Reumerman, 2013; Clariant, 2013; Chemical-technology, 2012; Bacovsky et al., 2013).

Nevertheless, the future of second generation biofuels remains hard to predict. There are significant technological barriers that need to be overcome for the best technology in the sector to be identified and commercialized. Also, despite the rising prices for fossil fuels, the 2nd generation biofuels sector is still highly dependent on government support (IEA Bioenergy, 2008; Reumerman, 2013). Moreover, it is not clear to what extent will electricity- and hydrogen-fueled vehicles develop commercially and potentially dominate the transport fuels market (FNR, 2006). Despite the different obstacles, if successfully developed second generation biofuels might have a quite high impact on the German transport fuels market in the years after 2020. As many experts predict, 1st generation biofuels will be gradually phased out due to sustainability issues, clashes with food industry, devotion of arable land and other social issues, which will give a great opportunity for advanced biofuels to penetrate the market (Reumerman, 2013; Schneider, 2013).

**Biofuels in the transportation sector** was rated as having a disruptiveness score of **3.3.**

# 8. Bulgaria – country overview

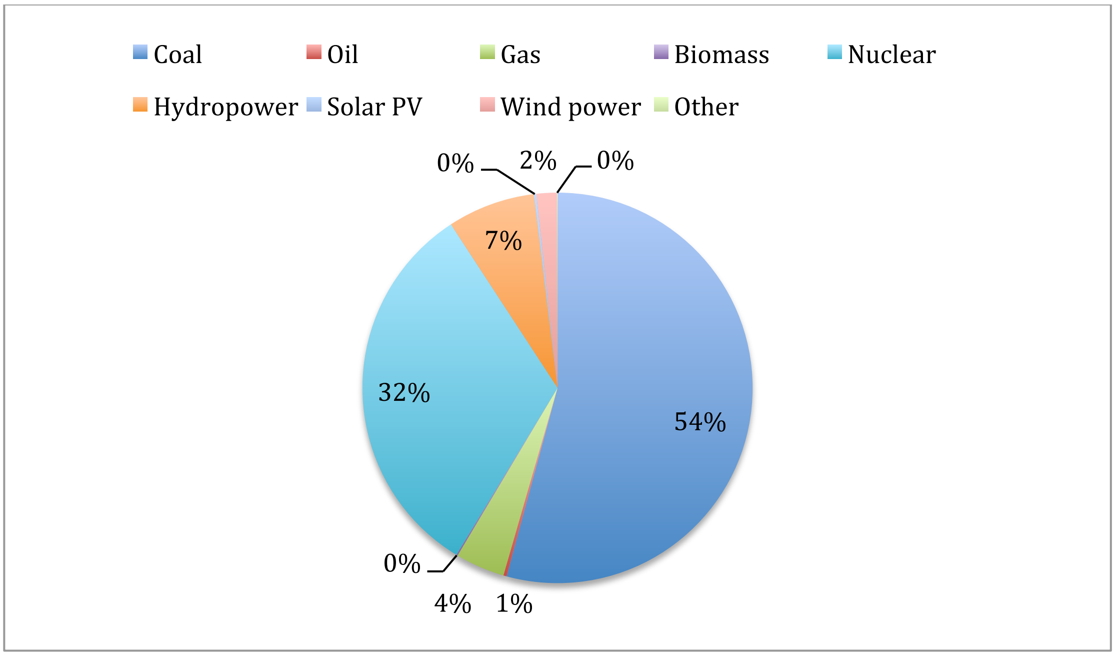
## 8.1. Introduction

Even though Bulgaria is not abundant in natural fuels such as coal, oil or gas it has a very well developed energy sector, in which conventional energy sources are the main component in the energy mix.

## 8.2. Primary energy mix

### 8.2.1. Electricity mix

**Figure 37: Electricity mix in Bulgaria 2011**

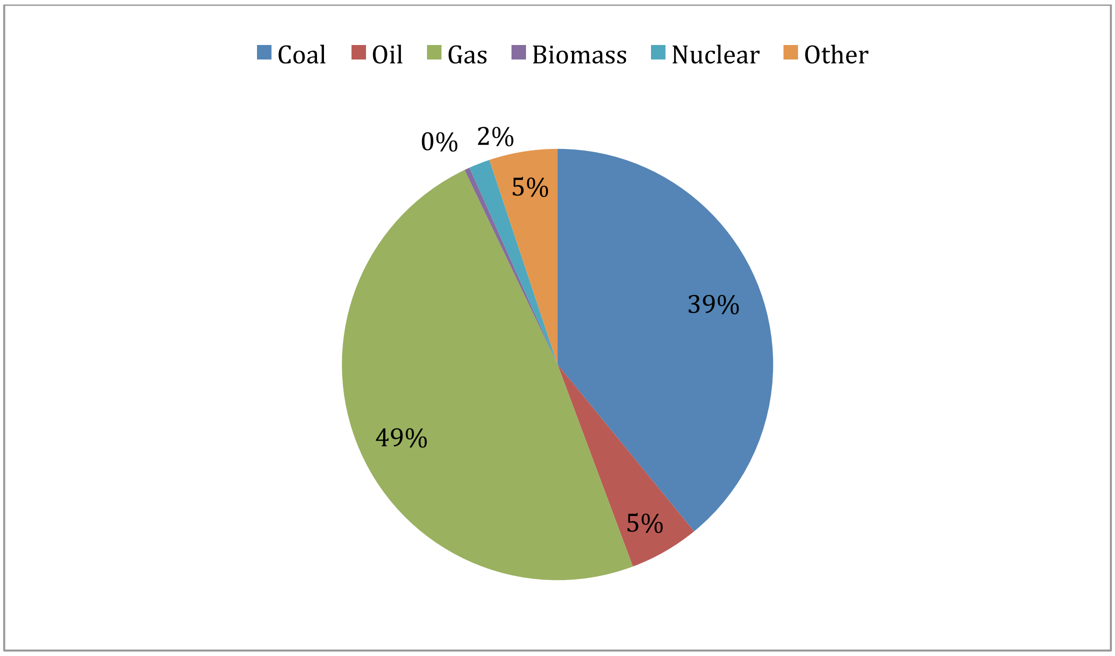


Source: (International Energy Agency, 2011)

The Electricity mix in Bulgaria is dominated by coal (54%) and nuclear (32%) as main sources. Hydropower (7%), gas (4%) and wind power (2%) are the ones following, however they are totaling to just 13% of the total energy consumption, whereas coal and nuclear total to 86%. Thus, one can conclude that the conventional energy sources are still the most important ones in Bulgaria.

### 8.2.2. Heating and cooling mix

**Figure 38: Heating and cooling mix Bulgaria 2011**

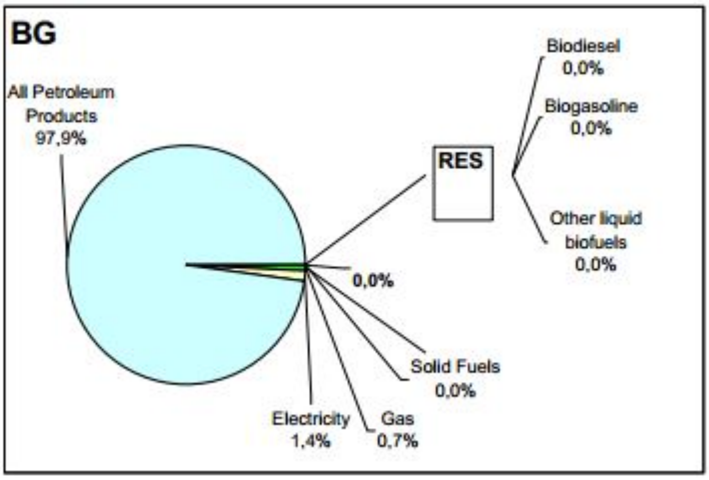


Source: (International Energy Agency, 2011)

Gas is the most important energy source for heating and cooling as it accounts for 49%. The other big part is coming from nuclear energy (39%). Thus nearly 90% of Bulgaria's energy demand for heating and cooling is derived from conventional sources. Nuclear plays – like in the electricity mix – an important role. Renewables like biomass do actually not contribute to the heating and cooling energy mix.

### 8.2.3. Transportation mix

**Figure 39: Transportation mix Bulgaria 2005**



Source: (European Commission 2005)

The main source of energy in the transportation mix in Bulgaria are "All Petroleum products". A small amount is contributed by gas (0.7%). Renewables (such as biofuels) do not contribute at all. The contribution of electricity (1.4%) is rather small as well.

## 8.3. Political situation for renewables

Renewables are recognized as part of the energy mix, however the focal area is technology and efficiency improvement, since renewable energy sources per se are considered too expensive compared to conventional sources. Further, the overall main focus is put on energy security and as the main efforts in Bulgaria are directed on hydro power, energy security might not be given all the time.

There are governmental supports (such as credit incentives or less administrative procedures) for renewables in place. (Government of Bulgaria 2011)

## 8.4. National energy strategy

The main focus of the national energy strategy lies on the energy security. Therefore nuclear energy is an explicit part of the (future) energy mix as well as gas, which is underlined by the planned "Southern gas route".

Besides indigenous coal in combination with newest technology is seen as part of a secured energy mix.

New forms of exploration of fossil resources (e.g. shale gas) are also pursued.

Renewable energy sources are jut considered as diversification factors within the on energy security focused energy mix. (Government of Bulgaria 2011)

## 8.5. Theoretical potential for renewables

The theoretical potential of renewable energy sources in Bulgaria is explained in detail in the Disruptiveness assessment chapter.

## 8.6. Disruptiveness assessment

The proposed assessment tool discussed in the methodology section has been used to analyze and predict which renewable energy technology could have the greatest impact in the three application sectors of interest: electricity, transportation and heating.

### 8.6.1. Electricity sector

**Solar photovoltaic**

The solar PV sector is relatively well-developed in Bulgaria. As of today the total installed capacity of PV systems is 1,013 MW (Alitchkov, 2013; ESO, 2013). The majority of the capacities were installed in 2012 when 767 MW started operating. The PV market boom in 2012 was driven mainly by the relatively high feed-in tariffs and represented 5% of the total new capacities installed in Europe for 2012 (EPIA, 2013). Shortly after that the Bulgarian authorities imposed restrictions which drastically decreased the investment interest. The major market development in Bulgaria in 2012 reached the tremendous level of 2.87% of its GDP invested in one single year and toped the rankings for installed capacities per capita and GDP for 2012. As a result of it today Bulgaria can produce up to 3% of its electricity demand with the installed PV capacities (IEA-PVPS, 2013; Alitchkov, 2013). According to some estimations, Bulgaria can reach 3,000MW of installed PV capacities in the foreseeable future given positive investment and political environment (EPIA, 2013). The quite high annual solar radiation levels of 2,100-2,500

hours and cheap labor are also important factors for the development of the PV industry in Bulgaria (SEC, 2002).
The *single-crystalline silicon* (*sc-Si*) and *multi-crystalline silicon* (*mc-Si*) technologies are dominant on the Bulgarian PV market. Due to their rapid cost reductions it has been very difficult for other technologies to threaten their market positions. The impact of the *crystalline silicon* PV technologies will be high and further deployments are expected when modules with efficiencies of 19% - 21% become commercial in Bulgaria (Alitchkov, 2013). Despite a few attempts for commercialization, other technologies such as *hybrid PV, copper-indium-gallium-(di)selenide (CIGS)* and *cadmium-telluride (CdTe)* did not manage to settle on the market. Furthermore, the ground mounted PVs take up the biggest market segment in Bulgaria. However predictions for the future tendency are disputable as the EPIA (2013) prognoses intensifying of this trend while Alitchkov (2013) sees a tendency towards more capacities installed on facades and rooftops and less ground mounted.

Even though there was a significant market boom of Solar PV installation in 2012 the barriers for the future development have been expanding. The political limitations are the highest concern for PV producers and investors. The rate of decrease of feed-in tariffs has been higher than the rate of decrease of the PV costs. There are serious restrictions for installation of new capacities and currently only small roof-top ones are being granted with contracts. In addition, due to massive protests in February 2013 triggered by high electricity bills drastic restrictions to the production volume of solar parks have been imposed. Furthermore, delayed payments by the National Electricity Distribution Company to the PV producers, recently imposed 20% tax on the revenues of RES producers and constant instability of the regulator additionally have worsened the investment and business climate in the PV industry in Bulgaria (Kiryakov, 2013). Also the lack of project investment opportunities, the high interest rates of the credits offered by the banks and the low price of electricity have further directed investments away from the Bulgarian PV market. Meanwhile, there have not been any significant technological barriers with the core technology. The biggest obstacle for the PV technologies today is the expensive electricity storage facilities. According to (Alitchkov, 2013), deputy chairman of the Bulgarian Photovoltaic Association, this issue will be resolved in 3 to 5 years. Additional concerns with the grid capacity have risen due to the PV installation boom in 2012. Moreover, no major social barriers can be observed either. In fact, solar PV parks are usually located in rural areas with higher unemployment rates and therefore are very welcomed as they open new working places and sponsor local social activities. The only social issue that might exacerbate the image of PV is the negative campaign of certain politicians aiming to accuse the producers of RES for the high electricity bills. In conclusion, a slow-down in the Bulgarian PV market is expected for the near future. However drastic developments will come in place soon due to the high learning rate of the PV technologies which will reach efficiencies allowing them to achieve grid parity.

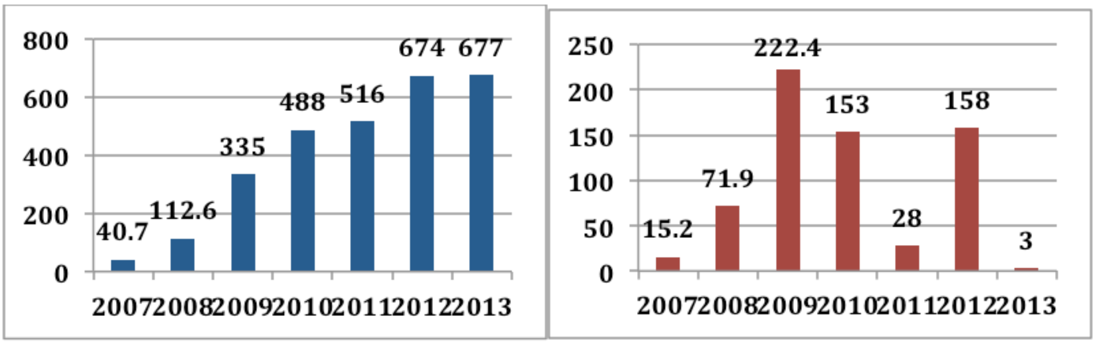
Therefore **solar pv** has a score of **3.1** disruptiveness in the **electricity sector**.

### Wind energy

Bulgaria is one of the big players in the wind energy industry in Eastern Europe. Production capacities in Bulgaria have been growing rapidly during the past seven years however the annual growth rate varied a lot (See Figure 40). According to the

Bulgarian Wind Energy Association, Bulgaria had 674 MW installed capacities until 2012 and 158 MW were installed in 2012 only (BGWEA, 2013). The compound annual growth rate of wind energy capacities in Bulgaria was the second highest in the EU for the period 2007-2011 (EWEA, 2013a). Bulgaria is part of the first wave markets of CEE for wind energy together with Czech Republic, Hungary, Poland and Romania. The five countries together account for 88% of the total installed capacity in the 12 newer EU Member States (EWEA, 2013a).

**Figure 40: Total (left) and annual growth (right) of installed wind energy capacity in Bulgaria (in MW)**



Source: (BGWEA, 2013)

There is a relatively positive environment for the development of the wind energy sector in Bulgaria. Development and construction costs are relatively low and administrative and grid connection processes officially require less time than in most EU countries (EWEA, 2013a). There is a steady annual increase in the electricity consumption, for instance in 2011 it was 5.4%. According to Bulgaria's NREAP, 20.6% of the electricity consumption by 2020 needs to be renewable-based (EWEA, 2013a). In order for the target to be met estimations show that a total capacity of around 1,400MW of wind energy installations is needed (EWEA, 2013; Continental Wind Partners, 2013). The potential mid-term capacities are argued to be around 2.5 – 3 GW (EWEA, 2013; Petkov, 2013). Also, the wind energy supply chain is well-organized with a number of components and service providers represented locally. The majority of the wind farms in Bulgaria are located along the Black Sea coast and in the mountainous regions as the wind speed there is the highest (Petkov, 2013). Wind energy also brings social benefits as wind electricity is around four times cheaper than the one from PVs and direct employment in the wind energy industry has more than tripled during the past three years (Petkov, 2013). The wind power producers in Bulgaria have the option to either participate in the feed-in-tariff system or trade their output on the free market (EWEA, 2013a). Interestingly, the Chinese investors of the most recent wind energy project worth half a billion EUR declared that they will fully trade their production on the free market and will not make use of the feed-in tariffs (Novinite, 2013). This is another example of the increasing cost competitiveness of wind energy in Bulgaria and Europe. As of today there are no offshore wind parks in Bulgaria (Petkov, 2013). According to Kiryakov (2013), chairman of the Bulgarian Association of Producers of Ecological Energy, wind energy will significantly expand its share in the total electricity consumption in Bulgaria reaching 27% by 2035. The main reasons will be the increasing efficiency of the technology, decreasing marginal costs, rising prices for fossil fuels and the decommissioning of polluting energy sources (Kiryakov, 2013).

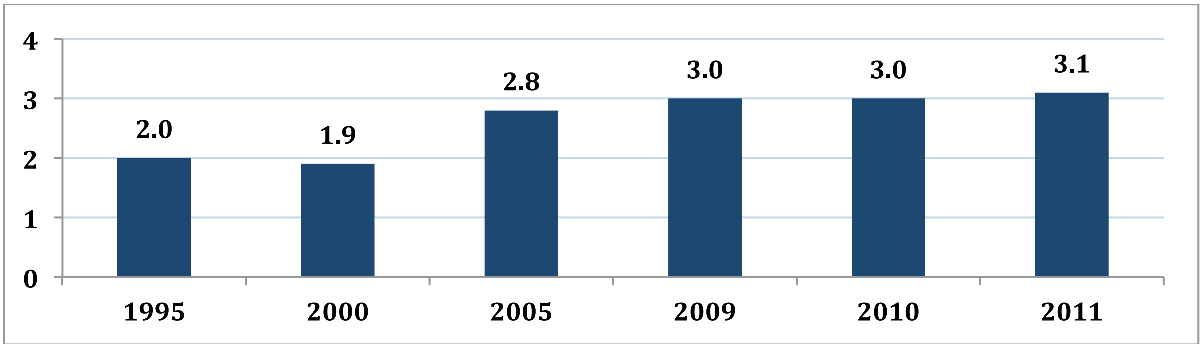
A number of barriers have challenged the wind energy industry during the past years and seem to be persisting in the light of the current political and economic crisis in Bulgaria. The most problematic one is the lack of stability in the regulation processes of the RES sector and the unpredictable price-setting of the regulator (Koleva, 2012; Petkov, 2013). Other barriers are public misinformation by the authorities, constantly changing legal framework, lack of transparency and overall resistance to change (Enchev, 2012). Insufficient grid capacity is another issue with an increasing importance (EWEA, 2013; Enchev, 2012). In addition, a significant number of the most appropriate sites for wind turbines are in nature conservation areas and access to them is highly restrictive. According to Petkov (2013) the low feed-in tariff is also a major obstacle for the investment climate which additionally exacerbated in December 2013 after the government's decision to impose a 20 percent tax on the income from solar and wind energy installations (Reuters, 2013). Nevertheless, wind energy is expected to play an increasingly important role in the energy sector in Bulgaria despite the unclear legal framework at the moment.

The disruptiveness score of **wind power** in **the electricity sector is 3.2**.

### Hydropower

Bulgaria is a relatively poor country in terms of hydro resources because of the low level of annual precipitation. However, there has been constant construction of hydropower facilities during the past 50-60 years and today Bulgaria has utilized more than 50% of its technical potential (See Figure 41) (APEE, 2010). The theoretical hydropower potential in Bulgaria is estimated to be 19,800 GWh of electricity generation per annum or around 7,900 MW of installed capacities. However the technically feasible potential is an annual supply of 14,800 GWh which is equivalent to 5,900 MW of installed capacities. This figure includes 1,100 MW which can be installed on the Danube river (Dilkov, 2013). As of today the installed capacities are 3,100 MW which generated about 4,000 GWh in 2012. The production capacity was not fully used due to decrease in the electricity demand and the priority given to nuclear and coal-fired plants (ESO, 2013; APEE, 2010). According to Dilkov (2013), CEO of PVB Bulgaria and Vice President of the Alliance of the Producers of Ecological Energy in Bulgaria, the remaining 2,800 MW of uncapped hydropower potential can mainly be harnessed through *run-of-river* installations. Investments of around 10 billion EUR will be needed in order for this potential to be utilized. Calculations show that construction of new capacities costs approximately 1 million EUR per GWh of annual production (Dilkov, 2013).

**Figure 41: Total installed capacity (in GW) for hydropower in Bulgaria (1995-2011)**



Source: (EC, 2013)

Changes in the type of new technologies installed and the ownership of the already operating ones are expected. Currently, 2,800 MW of the installed HPPs are state-owned. However Dilkov (2013) expects a privatization wave as a result of which half of these capacities will be sold to private companies. Also, the potential for reservoir and *pumped storage* hydropower plants in the mountains is already capped to a large extent and their future impact on the industry will stay constant. However, *run-of-river* installations are expected to be increasingly installed in the lower sections of the rivers and therefore to be the driving factor for the development of the hydropower sector in Bulgaria. As of today there are only 176 MW of *RoR* installations however most of the 2800 MW of uncapped potential is actually located in the lower parts of the rivers so their deployment will largely increase. The addition electricity production that can be derived is estimated to be 9,800 GWh per year (Dilkov, 2013).

There is a number of barriers that hinder the development of the hydropower industry in Bulgaria, especially in the short-term. The major challenge is the constantly changing regulatory framework. As a result of it banks have been reluctant on issuing credits for new hydropower installations. The recent negative political campaign against the RES sector has created certain social barriers. In addition, due to the maturity of the technology (more than 100 years on the market) today there are no technological issues that cannot be resolved. Certainly, the limited natural resources will remain a bottleneck (Dilkov, 2013).

The hydropower industry in Bulgaria has a great potential in the long term. Nevertheless, in the short-term no major changes are expected due to the operating coal-fired and nuclear plants. However, at some point they will be phased out and hydropower will take up most of their production capacity due to its renewable character and high efficiency (above 90%). Eventually, all three major hydropower sub-technologies will be well-developed as they bring different benefits. *Pumped storage* plants currently represent 800 MW and are very valuable due to their ability to cover peak demands. The large reservoir HPP will continue playing an important role in the electricity supply and their capacities will be more efficiently used in the future. *Run-of-river* installations will be vastly deployed throughout the country in order for the rest of the hydropower potential to be harnessed. Additional advantage will be the investment (1,000 EUR/KW) and production costs (0.4 EUR cent/KWh) for small hydropower plants in Bulgaria which are among the lowest in Europe (EREC, 2010). Until 2020 the share of hydropower is expected to increase to 10.8% and the total capacities installed to 3,951 MW (EREC, 2011). In the long term, according to Dilkov (2013) the electricity output from hydropower will double until 2025 and quadruple until 2035 and eventually reaching 50% of the total electricity mix in Bulgaria in 2050.

Given the above, **hydropower in the electricity sector** has a disruptiveness score of **2.9**.

### Geothermal energy

Bulgaria is rich of geothermal resources with temperatures ranging from 20 – 100°C (APEE, 2010). About 160 hydrothermal fields are located in Bulgaria mostly in the south of the country around the Rila-Rhodope massive (Fytikas & Arvanitis, 2009). The main applications are balneology, space heating and air-conditioning, geothermal ground source heat pumps (*GSHP*). Electricity generation from geothermal is currently not available in the country (BGA, 2010; Energia, 2010). Moreover there are no goals for the production of electricity from geothermal energy in the NREAP for 2020 (MEET, 2011a).

**Geothermal in the electricity sector** has received a score of **1.8.**

**Biomass**

Bulgaria has a huge potential for development of its biomass sector. Traditionally well-developed agricultural and forestry sectors, favorable climate and low population density are some of the basic conditions that will contribute to the prosperity of the biomass industry in the country. Arable land represents about 4.9 million hectares and the total forested area amounts to 3.7 million hectares which represent 44% and 33% of the territory of the country respectively (MEE, 2008). The overall annual biomass resource potential which is currently unutilized is estimated to be 2 million tones of wood, 1 million tones of municipal solid waste (MSW), 5 million tones of agricultural solid waste, 500 million cubic meters of agricultural wet wastes and 2 million tones of energy crops (BSPB, 2012). According to the Bulgarian Ministry of Economy and Energy the potential of the unused biomass in the country equals 809,900 TOE per year, which can satisfy around 9% of the final energy consumption in the country (MEE, 2008). Another important stimulating factor is Bulgaria's mandatory national target which under Directive 2009/28/EC is fixed at 16% share of energy from renewable sources in the gross final consumption of energy, including a 10% share of energy from renewable sources in the consumption of energy in the transport sector (MEET, 2011a).

Nevertheless the biomass energy production in Bulgaria is still at its early stage. As of today, the installed capacities in Bulgaria are 25MW for electricity production from biomass (Bachvarov, 2012). In 2012, 31,657 MWh of electricity were produced from biomass which represents 0.067% of the total electricity production (ENO, 2012). There is an increasing number of new projects for energy production from biomass especially in big industrial production plants such as Mondi's paper factory in Stamboliyski and Svilocell's bleached kraft pulp factory in Svishtov (MEE, 2008). Still, Bulgaria's goal to have 158MW of installed capacities for electricity production until 2020 is hardly reachable mainly due to a number of challenges.

The two main technologies on the Bulgarian biomass energy market are *direct combustion* and *thermal gasification*. While *combustion* is a well-known and fully commercialized technology, *thermal gasification* is still in the niche market level in Bulgaria and it will take 5 to 10 years for its full commercialization (Damyanov, 2013). The investment costs per megawatt installed capacity are 2 to 3 million EUR and 4 to 7 million EUR for *direct combustion* and *thermal gasification* plants respectively (Damyanov, 2013). As of today the total *thermal gasification* installed capacities are 6,5MW (1,5MW in Dospat and 5MW in Etropole). Even though it is less efficient, *combustion* will remain a preferred technology for large-scale projects of more than 5MW installed capacity. All in all, both *combustion* and *thermal gasification* are expected to have a high impact of the development of the biomass energy sector (Damyanov, 2013).

The most problematic barrier that hinders the biomass development in Bulgaria is the strict and unstable regulatory environment. The State Energy and Water Regulatory

Commission (SEWRC) declared that as of 01.07.2012 it will not settle contracts with and give access to the grid to new biomass power plants with installed capacities above 1.5 MW (Damyanov, 2013). According to Lyubomir Damyanov (2013), Chief Operations Coordinator at the Bulgarian Association for Biomass, a realistic figure for the total installed capacities for electricity production from biomass until 2020 would be 50-60 MW. Hence regulation is currently the biggest barrier for the development of the biomass energy production industry in the country. Another important barrier is the supply of biomass resources for big power plants as it is hard to find large agricultural producers who can secure this amount of biomass resources (Damyanov, 2013). Another potential barrier will be the changes to the "Law for the Forests" which are being currently disputed and if accepted would prohibit biomass power plants to use any kind of wood except wood waste which will additionally increase the supply risk (Damyanov, 2013). However, the production of energy from biomass does not face any significant social barriers except for the low awareness of the potential of certain biomass technologies. New biomass projects are required to undergo strict ecological permission-granting procedures as well as thorough communication with the local governance and citizens. In fact, the society sees the benefits from the biomass energy production as new workplaces are created (around 100 for a medium-sized plant) and they have the possibility to receive very cheap or even granted heating due to the cogeneration technologies that are usually installed for new projects (Damyanov, 2013; Bachvarov, 2012).

Despite the negative political and legal circumstances, from a resource-based point of view there is a big potential for the biomass energy development in Bulgaria (ECON, 2011; ExEA, 2012; BSPB, 2012; Hinovski, 2012). In addition the relatively high and long-term (20 years) feed-in-tariffs for electricity produced from biomass make Bulgaria an attractive destination for biomass investments (See Appendix 6) (MEET, 2011a; Renewable Market Watch, 2013). Even though no boom is expected due to the naturally limited biomass resources, the prognoses for the maximum capacity vary from 160-200MW, according to the Bulgarian Association for Biomass, to 500MW according the Bulgarian Energy Forum (Damyanov, 2013; Hinovski, 2012). All in all, no big disruption can be expected in the electricity sector from biomass. The main reason is the limited and dispersed biomass resources which restrict the potential production volumes. Furthermore, strict and unpredictable regulations together with low interest in investments in the sector are additional obstacles for the biomass *CHP* development. Nevertheless, certain improvements will take place as biomass is a storable source of renewable energy and has the potential to serve as a back-up capacity.
Given the above, **biomass in the electricity sector** was rated with **2.4.**

### 8.6.2. Heating and cooling sector

#### Solar thermal

Due to its southern location and relatively high levels of solar radiation Bulgaria has good conditions for the development of solar thermal technologies. The average solar radiation is 1,517 KWh/m$^2$ and the average annual period of sunshine is between 2,100 and 2,500 hours (Trans-Solar, 2009). As of the end of 2012, there were around 122,000 m$^2$ and 85.5 MW of installed solar thermal capacities in Bulgaria (ESTIF, 2013b). The average annual growth is about 8,000m$^2$ of new installations (SEC, 2009) Flat plate collectors are most popular solar thermal technology in the country and accounts for 50,500 m$^2$ of installed capacities. The main reason for this trend is their 3-4 times lower price than the one for *evacuated tube* collectors. Furthermore, hotels at the Black Sea coast and in the mountains side are the most common customers, followed by state and municipality buildings (BRAEM, 2010; APEE, 2010; Markova et al., 2011).

The reasons for the negligible size of the Bulgarian SHC market are mainly economical and technological. The economical barriers include high initial investment costs, insufficient financial support schemes and increased costs due to low technical competence of installers (Trans-Solar, 2009). Also, the political and legal obstacles are the lack of clear policies and support schemes for the usage of RES in the heating and cooling sectors. Nevertheless some tax relief systems exist for energy efficient buildings where renewable energy sources are integrated. Also, the proposed changes to the Renewable and Alternative Energy Sources and Biofuels Act will contain requirements for minimum levels of RES in newly constructed buildings (EREC, 2011).Technological barriers are also the low level of competence of the installers and the low level of efficiency of the current technologies (APEE, 2010). Moreover, certain social barriers exist such as the low level of awareness of the society, the reluctance for change of the heating and cooling systems and lack of scientific bodies and institutions in the area (Trans-Solar, 2009).

To sum up, certain developments in the solar heating and cooling market are expected however they will only have marginal impact on the heating energy market. According to the NREAP solar thermal will account for 0.5% of the heating energy demand in Bulgaria in 2020 (EREC, 2011). Kiryakov (2013) the chairman of the Association of Producers of Ecological Energy prognoses a slight increase to 1.5% market share of solar thermal in the heating sector in 2035.

**Solar thermal in the heating sector** was rated as having a disruptiveness score of **2.3.**

### Geothermal

Technologies for harnessing the heating energy from the geothermal resources are in place as opposed to the electricity sector. The total geothermal heating installed capacities in Bulgaria are 98.3 MW producing about 380 GWh per year. Around 30 MW are geothermal heat pumps and other technologies for space heating while 6.7 MW are for cooling purposes (IGA, 2010). According to Kiryakov (2013) geothermal energy will contribute to 0.3% of the total heating consumption in 2020 and its share will gradually increase reaching 1% by 2035.

There are several barriers for the development of geothermal energy in Bulgaria. The main technological challenge for geothermal power generation is the low temperature of the resources available in Bulgaria. Also there are no geothermal electricity generating capacities installed in the country. In addition, there is a lack of information about the location of energy resources as well as lack of knowledge and awareness among the policy makers (Kiryakov, 2013). The high capital intensity associated with the geothermal heat and power projects is another big barrier especially in the light of no significant supportive mechanisms. The social acceptance has not been tested yet due to the negligible capacities installed. However, given the social objection to the drilling methods employed for shale gas exploration and production, one can expect certain challenges in the area.

In general no disruption of the energy market in Bulgaria can be expected from geothermal heat and power technologies. Unless there is a technological break-through that increases their efficiency and decreases drastically their cost, geothermal energy technologies will increase their share only incrementally.

**Geothermal in the heating sector** was rated as having a disruptiveness score of **2.2.**

**Biomass**

There are three biomass plants that only produce heating energy in Bansko (10MW), Ihtiman (3MW) and Haskovo (2MW). However they will be transformed in to *CHP* plants due to efficiency issues as well as stimulations from the European Commission. In the near future the sole production of heating energy from biomass in Bulgaria will disappear as it only uses 35-40% of the energy capacity of the resources while cogeneration uses 70-80% (Damyanov, 2013). In addition, *co-firing* of biomass finds a wider application in gas-fired district heating plants, for instance the one in Burgas will substitute 31% of the natural gas used with wood chips (Infrastructure.bg, 2013). Moreover, in Bulgaria there is a significant potential for the production of *biogas* from agricultural residues and wet wastes such as manure, sewage sludge, etc. Biowastes represent 55% of the total generated wastes in Bulgaria (Dimitrova et al., 2009). The real potential for *biogas* production is estimated to be around 30% of the total potential which accounts for 7,50GWh (Dimitrova et al., 2009). Currently there are only two operating *biogas* power plants, one in Kubratovo, using *biogas* from sewage sludge, and one in Suhodol which uses landfill gas. The construction of *small-scale biogas* installations (30-75KW) for the utilization of manure is a technology currently being analyzed which might find vast application in the rural areas of the country (Dimitrova et al., 2009). Furthermore, small-scale heating with pellets has a big potential for development in Bulgaria due to the significant wood resource available which is a result of the large-scale forestration activities during the second half of the 20th century (MEE, 2008) (See Appendix 5). The *pelletizing* market is still at its initial stage of development with 17 relatively small pellet-manufacturers with a total production capacity of 62,000 tons per annum, 80-90% of which are exported (Pellet Plants, 2012). Nevertheless a growth is expected due to the increasing live standards and the general political support for more efficient energy production from biomass (Steiner, Pichler, & Golser, 2009; Damyanov, 2013).

Similar to the electricity sector, a boom in the use of biomass in the heating sector is likely to happen.

**Biomass in the heating sector** was rated as having a disruptiveness score of **2.6.**

### 8.6.3. Transportation sector

**Biofuels**

There is a big potential for 1st generation biofuels production in Bulgaria due to the large areas of unutilized land which can be used for oil, sugar and starch crops. The Bulgarian government has declared the following indicative target for biofuels 2015 – 8.00 % and 2020 – 10.00 % (MEET, 2011b). However they seem to be quite ambitious considering the 0.4% market share of biofuels in 2011 (Eurostat, 2013). There are 10 production plants for *biodiesel* and 6 for *bioethanol*, however only the *biodiesel* production plant owned by Astra Bioplant Ltd. is currently operating (Astra Bioplant, 2010; Bachvarov, 2012). Even though the production capacity for biofuels in Bulgaria is 408,000 tones, only 26,000 tones are actually produced (EBB, 2013). Main reason for the termination of work of the other biofuel plants is the introduction of revenue tax on biofuels on January, 1, 2007. Since June, 1 2012 every liter of diesel sold needs to contain 6% of *biodiesel* and every liter of gasoline sold needs to contain 2% of *bioethanol* (Bachvarov, 2012). Though it is not clear to what extent this law is abided. By the year 2020 the estimated production of *bioethanol* and *biodiesel* is 37,000 tones and 277,500 tones, respectively. If the EU binding target of 10% of biofuels by 2020 is to be met only with first generation biofuels the total area need will be around 510 000 hectares (MEE, 2007). There are 61,270 gas-powered vehicles in Bulgaria which is about 3% of the total number of vehicles in the country. The number is expected to increase due to the economic advantage of natural gas or *biomethane* for transportation power (Boisen, 2009; NGVA Europe, 2013). Should the production of biofuels proves to be economically advantageous without causing any social conflicts one can expect a higher concentration of biofuels in blends with conventional fuels and therefore less dependence on increasingly expensive imported fossil fuels. An additional advantage is the fact that biofuels do not require any significant investments in complementary infrastructure.

Similar to biomass for heat and power, the main barriers for the biofuels industry are the unpredictable regulatory environment and the lack of financial incentives and investments in the sector. An additional challenge in the biofuels sector is the technological burden for the development of 2nd and 3rd generation biofuels as they will certainly be the driving factor in the future as 1st generation biofuels are expected to be phased out. At the moment, there is no development regarding second and third generation biofuels production and consumption in Bulgaria. However a technological break-through on a global level is expected towards 2030 which will tremendously increase the 2nd and 3rd generation biofuels' economic and social advantage (Kardashliev, 2013). According to, Kardashliev (2013), Research Associate at the Institute for Biotechnology at RWTH Aachen, biofuels will contribute to the total transportation fuel demand in Bulgaria with 20% in 2030 and 50% in 2050.

**Biofuels in the transportation sector** was rated as having a disruptiveness score of **2.8.**

# 9. Conclusion

Besides the process of reviewing and clustering the available literature on innovation, with a strong focus on disruptive innovation in particular, the present paper also represents an expansion on the knowledge of disruptiveness by practically applying the theoretical definitions and translating them into an assessment tool. By means of desk research and semi-structured interviews, the assessment framework was further used to discover the potential disruptiveness of renewable energy technologies in two countries of interest, namely Austria, Romania, Germany and Bulgaria.

Moreover, this study represents a significant contribution to the theory of disruptiveness because so far all the available predictive frameworks are highly qualitative in their nature and they usually study disruptiveness from an ex-post perspective. In contrast, by using predictions until 2035 and taking into consideration energetic strategies as well as current market and industry conditions, the present assessment studied ex-ante, the potential disruptiveness of energy technologies. By identifying quantifiable figures during desk research and later intertwining it with qualitative in-depth information provided by the interview partners, it resulted in a holistic, comprehensible view regarding the energy sources. Consequently this meant a decrease in the degree of subjectiveness in the final assessment. However, the main goal of this paper was to determine which technologies will be disruptive in the future. Following the evaluation of the four countries, the following energy technologies have distinguished themselves as having the most potential for being disruptive:

In Austria, the top technologies that might experience a significant disruptive behavior in the future are biomass in the heating sector (score 3.86) followed by solar photovoltaic in the electricity sector (score 3.71), biofuels in the transportation sector (score 3.64) and wind power (score 3.50) in the electricity sector.

In the case of Romania, the technologies with the highest score in the assessment were biomass in the heating sector (3.79), wind energy in the electricity sector (score 3.57) and biofuels in the transportation sector (3.43). Solar photovoltaic has scored the top position as being the potentially most disruptive energy source in the Austrian electricity market receiving support in the form of various promotion schemes of the federal provinces as well as the government. In the past years Austria has experienced an exponential growth in this sector. Even taking into account the assumption that this trend will slowly decrease, it still remains a threat for the other electricity generating technologies.

It is worth noting that both countries do seem to have a predilection for biomass in the heating sector. This comes as a consequence of the abundant biomass resources that they both possess, and also an already well developed district-heating system in the case of Austria, and a tradition of using biomass in the case of Romania. Another mutual interest is represented by wind power in the electricity sector. Even though Austria does not have particular suitable meteorological conditions for the utilization of this energy (in comparison to Romania), this technology is bound to have a future disruptive behavior in both countries due to its high efficiency and its relative robustness. In good weather conditions wind power can be comparable to fossil fuel power. Finally, biofuels are estimated to have an impact in the transportation sector of both countries in the near future. This comes as no surprise because both Austria and Romania have to reach the 10% target imposed by the European Union to all member states and therefore the government supports the cultivation of transportation fuels rather than drilling for them.

Rapid improvements of the efficiency of some technologies in the electricity sector combined with the 16% goal for 2020 (and potentially much higher for 2030, etc.) set up a ground for disruption of the energy market in Bulgaria. Solar PV and wind energy are probably the technologies with the highest chances to gradually increase their piece of the pie and hence eventually replace conventional sources of electricity to high extent. According to the assessment, their scores for disruptiveness are respectively 3.1 and 3.2, which is right above the threshold for disruptiveness. Hydropower with a score of 2.9 is also very close to the disruption line. Its importance is expected to increase once nuclear and coal-fired power plants are phased out and therefore substituted in large extent by hydropower.

The new technologies in the heating sector will generally have a sustaining effect on the energy market in Bulgaria. Biomass heat achieved a score of 2.6 and might penetrate the market a bit further due to the tradition of using wood materials for heating and the comparatively low infrastructure adaptation required. Also, high electricity bills which triggered massive protests could push the demand for biomass sources of heating energy, such as pellets, wood chips, etc. Solar thermal and geothermal heat are still rather exotic sources of energy in Bulgaria and their scores on the assessment of around 2.2 show that this status-quo will most probably remain as such in the future. Some of the main obstacles are the high investment costs, low technological efficiency, lack of financial support schemes as well as low political and social awareness.

No disruption is expected in the transportation energy sector in Bulgaria. Even though biofuels have a score of 2.8 they are currently not popular in Bulgaria due to their higher price than fossil fuels and the practical absence of a requirement for their usage.

Today, Germany is a global leader in the electricity generation from solar PV and wind turbines. Great emphasis is put on these two technologies not only in the current installation of new capacities but also in the research and development that aim to increase further their efficiency and reach grid parity. According to our assessment solar PV scores 3.6 and wind energy scores 3.7 which make these two technologies the most probable for causing disruption in the electricity market in Germany. Furthermore, even though not that promising, biomass power technologies with a score of 3.1 also make it to the ‘disruptive’ section of the results. Despite its limitation there is an abundance of unutilized biomass material in Germany and the authorities are aiming at tapping this potential. Especially important will be the biogas production which will be the driving factor in the biomass power generation.

Estimations show that biomass (score 3.1) will be preferred source of heating energy and will be highly stimulated by the authorities who aim to reduce the natural gas import dependence of Germany. The expansion of biomass combined heat and power installations will also boost the heating generation with biomass. Another important renewable energy technology for heating will be solar thermal which scored 2.9.

Germany also puts great emphasis on the renewable energy sources in the transportation sector. The 5.75% goal for 2010 was reached and the market share of biofuels will continue to grow. A number of car manufacturers have already started developing models running on a range of renewable fuels. The 'disruptive' score of 3.3 for the biofuels in Germany is mainly due to the high expectations for 2nd and 3rd generation biofuels which are expected to drastically change the transportation fuel market in 10 – 20 years from now. Biofuels' expansion will also be driven by the EU binding targets for RES in the transportation sector.

In conclusion, the main goal of the report was to apply the most up-to-date development of the theory of *disruptive innovation* on the energy markets in Austria, Romania, Bulgaria and Germany. Apart from the extensive desk research, a great contribution came also from the interviews conducted with various experts in the energy industry in Europe. Even though all resources have been fully utilized, due to a number of limitations the report does not perfectly answer the fundamental question of what the next big technology in the energy markets in Bulgaria and Germany will be. Due to the vast scope of the research project, a larger number of interviews should be done in order for all areas to be fully covered and to have big enough samples for statistically significant conclusions. In addition, the experts who participated in the study might not be perfectly representative for the industry. Also, the information and data derived from the interviews is subject to potentially biased opinions of the interviewees. Another limitation of the study is the equal treatment of all criteria for 'disruptiveness'. In reality these criteria have different levels of importance, hence further research should be directed towards studying in detail the criteria and assigning weighting to the individual measurements. In general, there is a high need for further research on the interrelatedness of the factors that drive disruptive innovations in the energy market. The present study can serve as a reliable basis for additional studies in this direction which can also be applied on other geographical regions.

# 10. Appendices

## Appendix 1 – Interview guideline

# INTERVIEW GUIDELINE

Disruptive Technologies

### Interview Information

| | |
|---|---|
| **Interviewer** | [Name Surname] |
| **Interviewee** | [Name Surname, Company, Position, Country] |
| **Date** | [DDMMYY] |
| **E-Mail** | [enter e-mail here] |
| **Phone Number** | [enter phone number here] |
| **Contact Source** | ☐ Personal referral (enter source name below)<br>☐ Found in forum/user community/web (enter source name below)<br>☐ Found in literature (enter source below)<br>☐ Own idea<br>☐ No answer |
| **Contact Source** | [Name Surname] |
| **Area of Expertise** | [e.g. Renewable Energies] |
| **Name Confidential?** | [Is it ok, to quote the interviewee per name, company and position **(or at least the company)** in report? YES, NO] |
| **Recording?** | [YES, NO] |

## Interview Questions

## Energy Technology and Markets Focus

<table>
<tr><th colspan="2">POTENTIAL _ POWER GENERATION</th></tr>
<tr><td colspan="2"><b>Q1: How would you judge that the share of ____________ [energy technology, e.g. solar PV] in ____________ [country/general] in the <i>power generation</i> sector will develop till 2020/2025/<br>2030/2035?<br>Please give reasons that support your opinion.</b></td></tr>
<tr><td><b>POTENTIAL (% market share) for Country: _____________</b><br>2020:<br>2025:<br>2030:<br>2035:</td><td><b>REASONS:</b><br>1. _______________________<br>2. _______________________<br>3. _______________________<br>4. _______________________</td></tr>
</table>

<table>
<tr><th colspan="2">POTENTIAL _ HEATING</th></tr>
<tr><td colspan="2"><b>Q2: How would you judge that the share of ____________ [energy technology, e.g. solar thermal] in ____________ [country/general] in the <i>heating</i> sector will develop till 2020/2025/<br>2030/2035? Please give reasons that support your opinion.</b></td></tr>
<tr><td><b>POTENTIAL (% market share) for Country: _____________</b><br>2020:<br>2025:<br>2030:<br>2035:</td><td><b>REASONS:</b><br>1. _______________________<br>2. _______________________<br>3. _______________________<br>4. _______________________</td></tr>
</table>

| **POTENTIAL _ TRANSPORTATION** | |
|---|---|
| **Q3: How would you judge that the share of ____________ [energy technology, e.g. biomass] in ____________ [country/general] in the *transportation* sector will develop till 2020/2025/<br>2030/2035? Please give reasons that support your opinion.** | |
| **POTENTIAL (% market share) for Country: ____________**<br>2020:<br>2025:<br>2030:<br>2035: | **REASONS:**<br>1. ________________________<br>2. ________________________<br>3. ________________________<br>4. ________________________ |

| **POTENTIAL _ OIL AND GAS DERIVATIVES** | |
|---|---|
| **Q4: How would you judge that the share of ____________ [energy technology, e.g. biomass] in ____________ [country/general] in the *oil and gas derivatives* sector will develop till 2020/2025/2030/2035? Please give reasons that support your opinion.** | |
| **POTENTIAL (% market share) for Country: ____________**<br>2020:<br>2025:<br>2030:<br>2035: | **REASONS:**<br>1. ________________________<br>2. ________________________<br>3. ________________________<br>4. ________________________ |

**DEVELOPMENT CYCLE**

**Q5: *In general*, where does ____________ [energy technology, e.g. solar PV] currently stand in terms of development stage?**

| **Basic R&D** | **Applied R&D** | **Demonstration** | **Pre-Commercial** | **Niche Market & Supported Commercial** | **Fully Commercial** |
|---|---|---|---|---|---|
| | | | | | |

- In general, what would it take to make this energy technology fully commercial? (in terms of years, money)

## Advanced Technologies Focus

| **ADVANCED TECHNOLOGIES** | |
|---|---|
| **Q6**: ***<u>In general</u>*, what are the current "advanced or sub-technologies" (e.g. organic solar cells for solar PV) in the field of _______ [energy technology, e.g. solar PV] that could potentially make ________ [energy technology, e.g. solar PV] more competitive in future?**<br>**How would you judge the (potential) impact of these technologies on the commercialization/diffusion of the main technology and its market share in _____ [country/general]?** | |
| **TECHNOLOGIES:**<br>**1.**<br>**2.**<br>**3.** | **IMPACT (general or with reference to market share in specific country, depending on the expert background):**<br>☐ high ☐ medium ☐ low<br>☐ high ☐ medium ☐ low<br>☐ high ☐ medium ☐ low |

**ADVANCED TECHNOLOGIES**

**Q7**: ***<u>In general</u>*, where do these (or just one of them, if he/she is a specialist in one field) technologies currently stand in terms of development stage?**

| **Basic R&D** | **Applied R&D** | **Demonstration** | **Pre-Commercial** | **Niche Market & Supported Commercial** | **Fully Commercial** |
|---|---|---|---|---|---|
| 1.<br>2.<br>3.<br>4. | | | | | |

- In general, what would it take to fully commercialize this/these technology/ies? (in terms of years, money)

## Barriers Focus

**BARRIER CATEGORIES**

**Q8: What are the major barriers in ________ [country/general] that hinder the development of __________ [energy technology, e.g. solar PV] in general and/or these/this advanced technology/ies in particular? Please give reasons that support your opinion.**

| **BARRIERS:** | **REASONS:** |
|---|---|
| TECHNOLOGICAL BARRIERS<br>________________________<br>________________________<br>________________________<br>________________________ | 1. ____________________<br>2. ____________________<br>3. ____________________<br>4. ____________________ |
| ECONOMIC AND FINANCIAL BARRIERS<br>________________________<br>________________________<br>________________________<br>________________________ | 1. ____________________<br>2. ____________________<br>3. ____________________<br>4. ____________________ |
| POLITICAL AND LEGAL BARRIERS<br>________________________<br>________________________<br>________________________<br>________________________ | 1. ____________________<br>2. ____________________<br>3. ____________________<br>4. ____________________ |
| SOCIAL BARRIERS<br>________________________<br>________________________<br>________________________<br>________________________ | 1. ____________________<br>2. ____________________<br>3. ____________________<br>4. ____________________ |
| **(Clearly mark which barriers are general energy technology barriers and which are for (a) certain advanced technology/ies in particular!)** | |

**BARRIER RANKING**

**Q9: Please prioritize the barriers you have mentioned. Start with the most important one.**
**Do you think, these barriers will be overcome within the next 10 years? If not, what do you think how long/what it takes to overcome these barriers?**

**BARRIERS RANKING:**

1.
2.
3.
4.
5.

## Referrals

| | Name | E-mail | Telephone | Area of Expertise |
|---|---|---|---|---|
| **Person 1** | | | | |
| **Person 2** | | | | |
| **Person 3** | | | | |
| **Person 4** | | | | |
| **Person 5** | | | | |

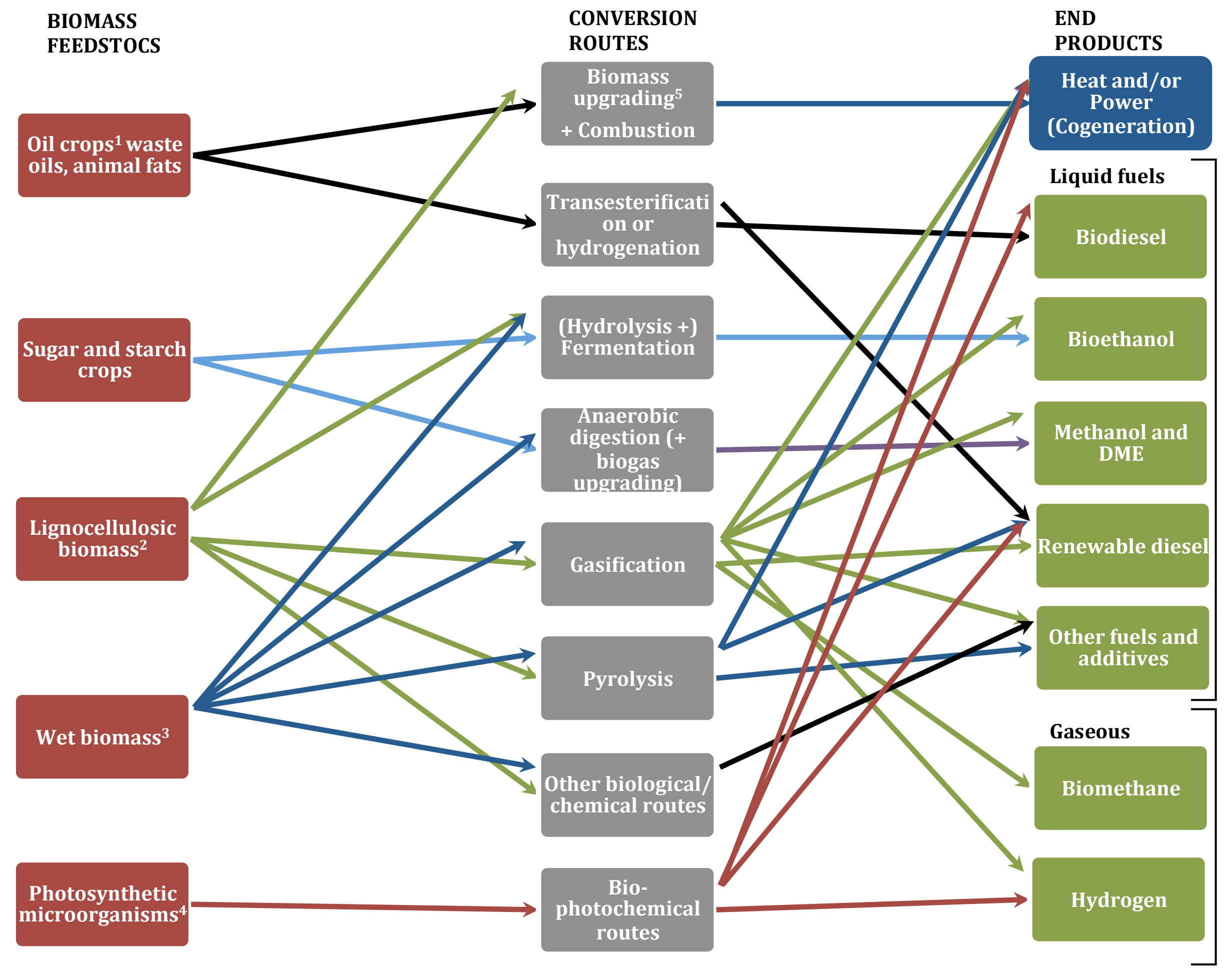
## Closing

| | |
|---|---|
| **Receive Summary of Main Results?** | [Is the interviewee interested in receiving a summary of the study's main results? YES, NO] |
| **Available for Follow-up Interview or Very Short Survey?** | [YES, NO] |

## Additional Information of Interest

______________________________________________________________________________
______________________________________________________________________________
__________________________________

# Appendix 2: Schematic illustration of the bioenergy conversion routes



[1] Oil crops include oilseed rape, sunflower, jatropha, palm oil, etc

[2] Lignocellulosic biomass includes wood, straw, energy crops, MSW, vegetative crops, sawdust, etc.

[3] Wet biomass includes biodegradable MSW, green crops, farm and food wastes, sewage sludge, manure, macroalgae

[4] Photosynthetic microorganisms includes (microalgae, bacteria, etc.)

[5] Biomass upgrading includes (*pelletizing*, pyrolysis, *torrefaction*, etc.)

Sources: (IEA Bioenergy, 2009a; AEBIOM, 2012; EREC, 2012a; FNR, 2009; Fritsche et al.,2012)

# Appendix 3: Biorefineries

IEA Bioenergy gives biorefineries the following definition: "Biorefinery is the processing of biomass into a spectrum of marketable products and energy" (IEA Bioenergy, 2013; The Federal Government, 2012). Biorefineries can prove to be the key to make bioenergy more competitive to fossil energy. Biorefineries can co-produce together with energy products other high-value products from the same biomass feedstock.

Biorefineries are a cluster of facilities, processes and industries that aim in a sustainable way to maximize profit, minimize environmental impact and replace fossil fuels (The Federal Government, 2012).  They consist of a number of processing steps: upstream processing, transformation, fractionation, thermochemical and biochemical conversion, extraction, separation and downstream processing. Biorefineries can use any type of biomass to produce more than one final or intermediary product including energy as fuels, power and/or heat (IEA Bioenergy, 2009a).

# Appendix 4: Glossary of Biomass technologies

| | |
|---|---|
| **Combined heat and power (*CHP*)** | Combined heat and power (*CHP*) or cogeneration is a conversion technology that produces electrical and useful thermal energy from the same primary energy source (EUBIA, 2012; AEBIOM, 2013). It includes a wide variety of technologies but always includes an electricity generator and a heat recovery system. It has been proved that the combined production of heat and electricity is by far more efficient than heat production only. Biomass-based cogeneration (*CHP*) plants typically have overall (thermal and electric) efficiency in the range of 80 to 90 percent provided that the heat production and demand are matching (IEA, 2008; EUBIA, 2012). The electrical efficiency is comparatively low (10%-40%) but nevertheless this technology proved to be the cheapest and most reliable one for power generation from biomass in stand-alone applications (IEA, 2008b). Economies of scale have proven to be very important for the economical viability of biomass *CHP* plants and therefore they usually have power capacities of 30-100 MW and are located in proximity to feedstocks available in large volumes (IEA Bioenergy, 2009a). Nevertheless smaller plants of 5-10 MW using wood and straw can be found throughout Europe. Co-generation has been shown to reduce the cost of power generation for plants with capacities of 1-30MW with 40-60%. One of the biggest obstacles that biomass *CHP* plants face is the limitation of the local heat demand and the seasonal variation. Tri-generation which also involves absorption cooling can potentially tackle this problem to a high extent (IEA Bioenergy, 2009). |
| **Combustion** | Combustion is a process by which flammable materials are allowed to burn in the presence of oxygen with the release of heat (Biomass Energy Centre, 2011b). The three main applications of *combustion* for heating only are domestic heating systems, district heating and cooling and industrial heating systems (IEA Bioenergy, 2009a). Since the beginning of civilization people have been using woody feedstocks for direct burning and even today it is the biomass conversion technology that makes the biggest contribution to the global energy supply (IEA Bioenergy, 2009; AboutBioenergy, 2013). |

| | |
|---|---|
| | The main obstacles are the high cost of new heat distribution networks and the difficulty of guaranteeing high overall efficiency. Industrial heating systems are appropriate for industries that consume considerable amount of heat and at the same time have large volumes of biomass residues at disposal (IEA Bioenergy, 2009a). |
| **Thermal gasification** | Gasification is a thermo-chemical process by which biomass is transformed into a mixture of several combustive gasses called fuel gas or producer gas (IEA Bioenergy, 2009a). Gasification has the advantage that any type of biomass feedstock can be converted into fuel gas with a conversion rate of 70%-80%. Also, gasification can serve several market segments as fuel gas can find direct application for heating and power generation or be upgraded to syngas for biofuel production (EUBIA, 2012g). Important challenges for biomass gasification are the sensitivity to the feedstock quality and moisture content, reliability of feedstock feeding systems, replication of commercial applications and the removal of tar, alkali, chloride and ammonia (Babu, 2005). |
| **Co-firing** | Co-firing is the co-*combustion* of biomass materials with fossil fuels in thermal processes for heat and electricity production (IEA Bioenergy, 2009a). The most popular approach is direct co-firing of coal and solid biomass feedstocks in existing coal plants, with biomass resources representing from 3% to 20% of total fuel weight or energy (EUBIA, 2012d). Direct co-firing achieves electric efficiencies for the biomass portion of 35% to 45% which is higher than the efficiency of biomass-dedicated plants (IEA, 2007). Potential challenges may arise from the biomass properties on the operation and lifetime of the coal plants, especially if a feedstock other than wood is used. Indirect and parallel co-firing are alternative options to avoid these issues however they are very costly (IEA Bioenergy, 2009a). |
| **Anaerobic digestion** | Anaerobic digestion is the biological degradation of biomass in oxygen-free conditions (EUBIA, 2012b). Its main product is *biogas* which is a methane-rich gas (50%-70%) (AEBIOM, 2013) (*Biogas*partner, 2013). *Biogas* can be either burnt in power generation devices for electricity generation or cogeneration, or upgraded to natural gas standards and injected into the natural gas network or used as a gaseous biofuel. Anaerobic digestion can degrade all types of biomass feedstocks except wood and it is very well-suited for wet feedstocks such as sewage sludge, manure and wet agricultural residues (IEA Bioenergy, 2009; AboutBioenergy, 2013). |

# Appendix 5: Total timber stock in Bulgaria for 2000 and 2005

| **Indicators** | **2000** | **2005** |
|---|---:|---:|
| **Forested area, ha** | 3,398,300 | 3,651,243 |
| **Total timber stock, m3** | 526,063,100 | 590,780,000 |
| **Annual growth, m3** | 13,695,149 | 14,120,179 |

Source: (MEE, 2008)

# Appendix 6: Preferential rates for electricity produced from biomass in Bulgaria

| **Preferential prices (Feed-in-tariffs) for the electricity produced from biomass Effective as of 1.8.2013** | |
|---|---|
| **Type of power plant** | **Preferential price (EUR/MW)** |
| Wood residues up to 5MW | 136.55 |
| Wood residues up to 5MW with combined cycle | 146.89 |
| Wood residues over 5MW | 119.85 |
| Agricultural waste up to 5MW | 98.32 |
| Energy crops up to 5MW | 93.49 |
| Waste power plants up to 150kW | 115.18 |
| Waste power plants from 150kW to 500kW | 109.36 |
| Waste power plants from 500kW to 5MW | 105.48 |
| Sewage sludge up to 150kW | 73.17 |
| Sewage sludge from 150kW to 1MW | 61.43 |
| Sewage sludge from 1MW to 5MW | 56.16 |
| Thermal gasification up to 5MW | 188.09 |
| Thermal gasification up to 5MW with combined cycle | 205.01 |
| Thermal gasification over 5MW | 183.03 |
| Thermal gasification over 5MW with combined cycle | 199.95 |

Source: (APEE, 2013a)

# Appendix 7: General info on the energy sector in Germany

Germany is the strongest economy in Europe and aims to be a leader in renewable energy and energy efficiency. The German government aims at a 20% share of renewable sources of energy in the final energy consumption, thereof 35% in the electricity sector by 2020 (CrossBorder Bioenergy, 2012b). The share of RES in Germany's final energy consumption is supposed to increase up to 80% by 2050 (CrossBorder Bioenergy, 2012b; BMU, 2012b; BDEW, 2013).

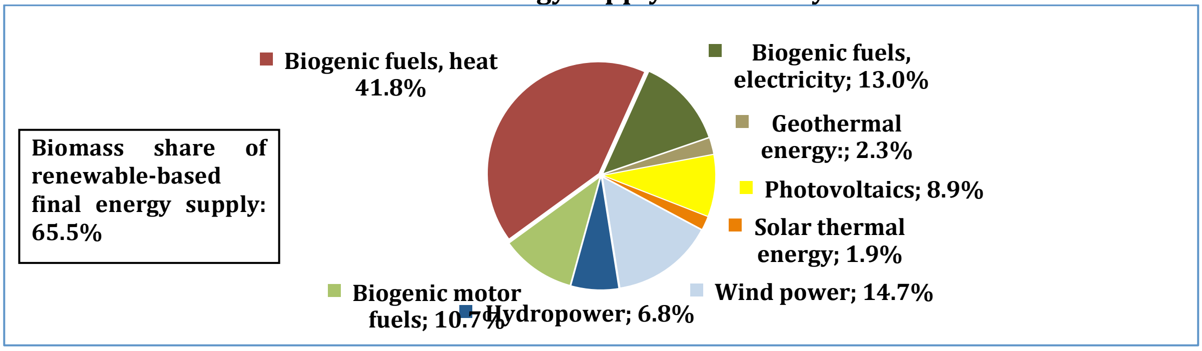
**German government's targets for renewable sources of energy.**

| | **Share in electricity consumption** | **Share in gross final energy consumption** |
|---|---|---|
| **At the latest by** | **[%]** | **[%]** |
| **2020** | at least 35 | 18 |
| **2030** | at least 50 | 30 |
| **2040** | at least 65 | 45 |
| **2050** | at least 80 | 60 |

** "At the latest by" refers only to the "share in electricity consumption" column*

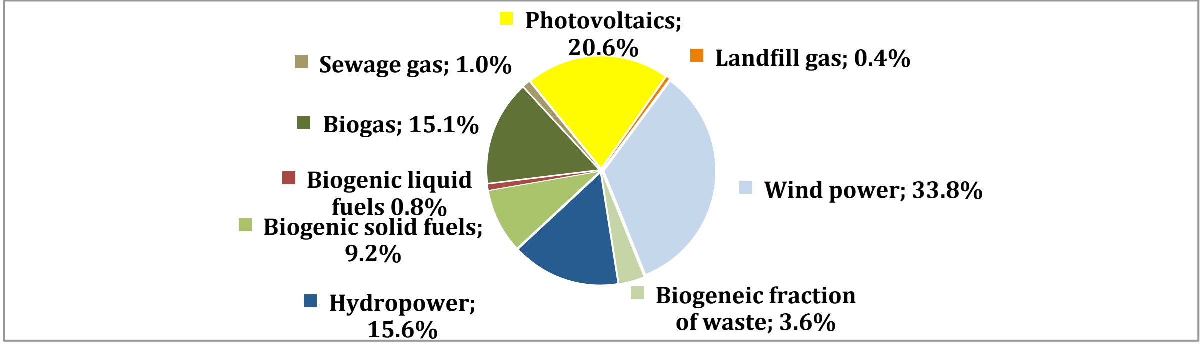
Source: (BMU, 2012b) (BDEW, 2013)

**Structure of renewable-based final energy supply in Germany in 2012**



Source: (AGEE, 2013)

**Structure of renewable-based electricity supply in Germany in 2012**



Source: (AGEE, 2013)

**Renewables' share in Germany's total final energy consumption in 2011 and 2012**

| | Electricity | | Heat | | Vehicle fuel | | Total | | Changes |
|---|---|---|---|---|---|---|---|---|---|
| | 2011 | **2012** | 2011 | **2012** | 2011 | **2012** | 2011 | **2012** | 2011/2012 |
| | **[billion KWh]** | | | | | | | | **[%]** |
| Hydropower | 17.7 | **21.2** | - | - | - | - | 17.7 | **21.2** | +20% |
| Wind power | 48.9 | **46.0** | - | - | - | - | 48.9 | **46.0** | -5.9 |
| Biomass | 37.6 | **40.9** | 123.1 | **131.2** | 34.2 | **33.5** | 194.9 | **205.5** | +5.4 |
| *Photovoltaics* | 19.3 | **28.0** | - | - | - | - | 19.3 | **28.0** | +20.6 |
| Solar thermal | - | - | 5.6 | **6.1** | - | - | 5.6 | **6.1** | +8 |
| Geothermal | <0.1 | **<0.1** | 6.3 | **7.1** | - | - | 6.3 | **7.1** | 12.7 |
| Total | 123.5 | **136.1** | 135.0 | **144.3** | 34.2 | **33.5** | 292.7 | **313.9** | +7.2 |

Source: (BMU, 2013b)

# Appendix 8: Biorefineries in Germany

Biorefineries moved into the focus of the EU and Germany only in 2009 (IEA Bioenergy, 2009b). The German government has provided funding totaling 2.4 billion EUR over a period of 6 years for the "National Research Strategy BioEconomy 2030", part of which includes projects supporting biorefinery concepts (IEA Bioenergy, 2013). There are several pilot biorefinery projects in Germany that use various feedstocks. For example, Suedzucker and CropEnergies utilize sugar and grain for the production of sugar, palatinose, food additives, feed, ethanol, *biogas* and electricity. Others like Zellstoff Stendal uses wood for the production of cellulose, paper, tall oil, methanol, turpentine and electricity while Biower utilizes grass and manufactures *biogas*, insulation material and biocomposites (IEA Bioenergy, 2009b). Considerable technological advancements and innovation are necessary for the biorefinery concepts to be applied commercially. Some of the major steps required are integration of process steps and sub-concepts into coherent overall concepts as well as into product development and product refinement (The Federal Government, 2012).

# Appendix 9: Attractiveness of the German energy sector

Generally, the German energy market provides very attractive conditions for investments. With a total length of 1.7 million km, Germany's dense and far-reaching electricity grid is widely available for electricity feed-in (CrossBorder Bioenergy, 2012b). In addition, from a country-risk perspective investments in the German economy are considered 'safe' as the country score on the top at Standard & Poor's and Moody's country risk rankings. It also scores very high on a number of indices for transparency, ease of doing business and corruption perception (CrossBorder Bioenergy, 2012c). Moreover, no major issues with currency exchange rate or inflation rate can be expected in Germany as it is a member of the quite stable Euro zone. Also, the accelerated development of the sources of renewable energy is accepted by 95% of the German population, even if their direct neighborhood is concerned 60-70% remain in favor (CrossBorder Bioenergy, 2012c). Furthermore, strict environmental regulations are in place.

## Appendix 10: Cultivation of renewable sources in Germany (in hectares) Data for 2012 and 2013

| Plants | Resource | 2012 | 2013* |
|---|---|---:|---:|
| Industrial crops | Industrial starch | 121,500 | 121,500 |
| | Industrial sugar | 10,000 | 9,000 |
| | Technical rapeseed oil | 125,000 | 125,000 |
| | Technical sunflower oil | 7,500 | 7,500 |
| | Technical linseed oil | 4,000 | 4,000 |
| | Plant fibres | 500 | 500 |
| | Medical crops and vegetable dyes | 13,000 | 13,000 |
| | **Industrial crops, total** | **281,500** | **280,500** |
| Energy crops | Rapeseed and *biodiesel*/vegetable oil | 786,000 | 746,500 |
| | Crops for *bioethanol* | 201,000 | 200,000 |
| | Crops for *biogas* | 1,158,000 | 1,157,000 |
| | Crops for solid fuels (among others: agroforestry, miscanthus) | 11,000 | 11,000 |
| | **Energy crops, total** | **2,156,000** | **2,114,500** |
| **Cultivation of renewable resources, total** | | **2,437,500** | **2,395,000** |

*Estimated figures

## Appendix 11: Feed-in tariffs for hydropower in Germany as of January 1, 2012

| | | | | |
|---:|---|---|---:|---|
| 12.7 | c€/kWh | < | 500 | kW |
| 8.3 | c€/kWh | < | 2 | MW |
| 6.3 | c€/kWh | < | 5 | MW |
| 5.5 | c€/kWh | < | 10 | MW |
| 5.3 | c€/kWh | < | 20 | MW |
| 4.2 | c€/kWh | < | 50 | MW |
| 3.4 | c€/kWh | > | 50 | MW |

Source: (ESHA, 2012)

# Appendix 12: Description of agricultural byproducts in Bulgaria

| **Types of solid agricultural byproducts** | **Available unused quantities** | **Humidity** | **Carbon content** | **Lower calorific value** | **Energy equivalent** |
|---|---|---|---|---|---|
| | **t/yr** | **%** | **% usable mass** | **kcal/kg** | **toe/yr** |
| Straw | 542,900 | 10 - 20 | 42 | 3,400 | 184,500 |
| Vine prunings | 136,000 | 30 - 40 | 32 | 2,200 | 29,900 |
| Fruit tree prunings | 47,120 | 40 - 50 | 27 | 2,000 | 9,400 |
| **Total (staw, vine prunings and fruit tree prunings)** | | | | | **223,800** |
| Maize stems | 1,079,808 | 40 - 60 | 24 | 1,800 | 194,400 |
| Sunflower stems | 762,000 | 30 - 40 | 30 | 2,200 | 167,600 |
| Tobacco stems | 40,000 | 40 | 28 | 2,000 | 8,000 |
| **Total** | | | | | **593,800** |

Source: (MEE, 2008)

# Appendix 13: Waste and unutilised biomass and its energy potential in Bulgaria

| | **Unused quantities** | **Energy equivalent, toe/yr** |
|---|---|---|
| Branches and twigs | 315,000 m3/yr | 65,100 |
| Industrial wood waste | 50,000 t dry matter/yr | 23,000 |
| Solid agricultural waste, including: | | |
| Straw | 542,900 t/yr | 184,500 |
| Vine prunings | 136,000 t/yr | 29,900 |
| Fruit tree prunings | 47,120 t/yr | 9,400 |
| Maize stems | 1,079,808 t/yr | 194,400 |
| Sunflower stems | 762,000 t/yr | 167,600 |
| Tobacco stems | 40,000 t/yr | 8,000 |
| Waste from live-stock breeding (only from large farms) and energy potential of *biogas* | 325,453 t/yr | 70,000 |
| Solid household waste and fuel equivalent when using in *combustion* installation | 361,700 t/yr | 36,300 |
| Landfil gas | 37,729,971 m3/yr | 12,600 |
| Gas from waste water treatment plants | 21,424,500 m3/yr | 9,100 |
| **Total** | | **809,900** |

Source: (MEE, 2008)

# Appendix 14: E-mail template

Dear Sir/Madam X,

We are contacting you as you have been identified **as an expert in the area of renewable energy** and would kindly ask you for an interview in this field.

The Institute for Strategic Management of the Vienna University of Economics and Business is conducting a research project that aims to **analyze new technologies in the energy sector and their impact on the energy industry as well as their business models in the years to come** (target regions: Austria, Bulgaria, Germany and Romania). We therefore need to talk to experts from various fields to get a better understanding of the development landscape and potential of new energy technologies.

The interviews can be conducted via Skype, telephone or in person in Vienna.

We look forward to your reply and thank you in advance for your support on this important project.

Please do not hesitate to contact us in case of any further questions.

**IMPORTANT – PLEASE NOTE:** All information provided in the interview will be treated in **strict confidence** and will **only be for research purposes**.

# Appendix 15: Germany disruptiveness assessment

| GERMANY | | Market share development (Annual percentage point increase) | | | | | | | Value proposition | Cost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology | Main application field | Current Market Share | Estimated Market share | | | | | Disrupt. index | Superior value proposition | Initial costs | Maintenance cost | Disrupt. index |
| | | 2012 | 2020 | 2025 | 2030 | 2035 | 2050 | | | | | |
| **Biomass** | **Heating** | 9.50% | 14% | 15% | 18% | 20% | 23% | **3** | FL, CO2 (partially) | High | High | **2** |
| | | % point increase: | 0.56% | 0.42% | 0.47% | 0.46% | 0.36% | | **1.5** | **2** | **2** | |
| **Biomass** | **Electricity** | 6.90% | 9.2% | 14% | 18% | 20% | 23% | **3** | FL, CO2 (partially) | High | High | **2** |
| | | % point increase: | 0.29% | 0.55% | 0.62% | 0.57% | 0.42% | | **1.5** | **2** | **2** | |
| **Biofuels** | **Transportation** | 5.70% | 10% | 15% | 20% | | 50% | **5** | FL, CO2 (partially) | High | Medium | **3** |
| | | % point increase: | 0.54% | 0.72% | 0.79% | | 1.17% | | **1.5** | **2** | **3** | |
| **Wind energy** | **Electricity** | 7.70% | 25% | 25% | 33% | 42% | | **5** | CO2,EO, LP (partially) | High | Very Low | **4** |
| | | % point increase: | 2.16% | 1.33% | 1.41% | 1.49% | | | **2.5** | **2** | **5** | |
| **Solar PV** | **Electricity** | 4.70% | 7% | 9% | 12% | 15% | 20% | **2** | CO2, EO, HP (Partially) | High | Very Low | **4** |
| | | % point increase: | 0.29% | 0.33% | 0.41% | 0.45% | 0.40% | | **2.5** | **2** | **5** | |
| **Solar thermal** | **Heating** | 0.4% | 3.0% | 6% | 10% | 15% | | **3** | CO2, EO | High | Low | **3** |
| | | % point increase: | 0.33% | 0.43% | 0.53% | 0.63% | | | **2** | **2** | **4** | |
| **Hydropower** | **Electricity** | 3.6% | 5% | 5% | 5% | 5% | 5% | **1** | CO2, FL, HP & LP (part.) | High | Low | **3** |
| | | % point increase: | 0.18% | 0.11% | 0.08% | 0.06% | 0.04% | | **3** | **2** | **4** | |
| **Geothermal** | **Electricity** | 0.005% | 0.7% | | | | 3% | **1** | CO2, FL | Very High | Low | **3** |
| | | % point increase: | 0.09% | | | | 0.08% | | **2** | **1** | **4** | |
| **Geothermal** | **Heating** | 0.52% | 0.8% | | 2.5% | | 7.6% | **1** | CO2, FL | High | Low | **3** |
| | | % point increase: | 0.04% | | 0.11% | | 0.19% | | **2** | **2** | **4** | |

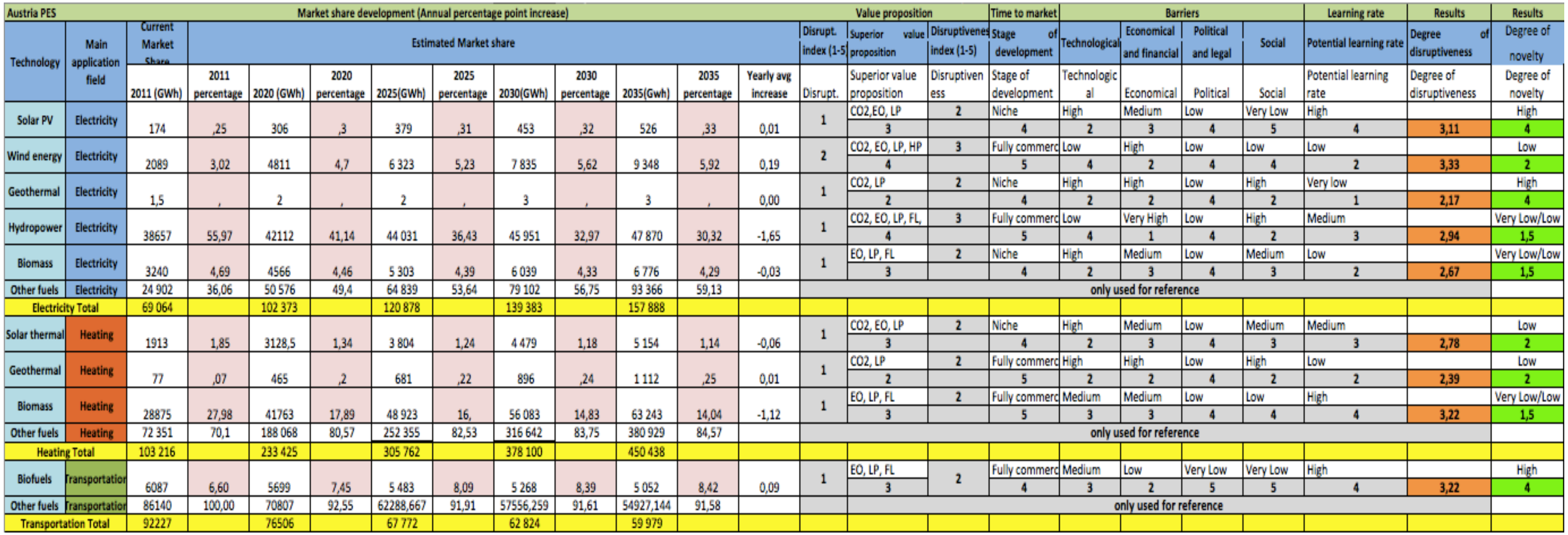
| GERMANY | | Time to market | Barriers | | | | Learning rate | Results | Results |
|---|---|---|---|---|---|---|---|---|---|
| **Technology** | **Main application field** | **Stage of development** | **Technological** | **Economical and financial** | **Political and legal** | **Social** | **Potential learning rate** | **Degree of disruptiveness** | **Degree of novelty** |
| | | | | | | | | | |
| **Biomass** | **Heating** | Fully commercial | Medium | Medium | Low | Low | Low | | Low/Very Low |
| | | **5** | **3** | **3** | **4** | **4** | **2** | **3.1** | **1.5** |
| **Biomass** | **Electricity** | Fully commercial | Medium | Medium | Low | Low | Low | | Low/Very Low |
| | | **5** | **3** | **3** | **4** | **4** | **2** | **3.1** | **1.5** |
| **Biofuels** | **Transportation** | Pre-commercial | High | Medium | Low | Low | Very High | | High |
| | | **3** | **2** | **3** | **4** | **4** | **5** | **3.3** | **4** |
| **Wind energy** | **Electricity** | Fully commercial | Medium | Low | Medium | Low | Medium | | Low |
| | | **5** | **3** | **4** | **3** | **4** | **3** | **3.7** | **2** |
| **Solar PV** | **Electricity** | Fully commercial | Medium | Low | Medium | Very Low | Very High | | High |
| | | **5** | **3** | **3** | **3** | **5** | **5** | **3.6** | **4** |
| **Solar thermal** | **Heating** | Fully commercial | Medium | High | Medium | Medium | Low | | Low |
| | | **5** | **3** | **2** | **3** | **3** | **2** | **2.9** | **2** |
| **Hydropower** | **Electricity** | Fully commercial | High | Medium | Medium | High | Very Low | | Very Low/Low |
| | | **5** | **2** | **3** | **3** | **2** | **1** | **2.6** | **1.5** |
| **Geothermal** | **Electricity** | Pre-commercial | Very High | High | Medium | Medium | Low | | High |
| | | **3** | **1** | **2** | **3** | **3** | **2** | **2.2** | **4** |
| **Geothermal** | **Heating** | Niche | High | Medium | Medium | Medium | Low | | Low |
| | | **4** | **2** | **3** | **3** | **3** | **2** | **2.6** | **2** |

# Appendix 16: Bulgaria disruptiveness assessment

| BULGARIA | | Market share development (Annual percentage point increase) | | | | | | | Value proposition | Cost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology | Main application field | Current Market Share | Estimated Market share | | | | | Disrupt. index | Superior value proposition | Initial costs | Maintenance cost | Disrupt. index |
| | | 2012 | 2020 | 2025 | 2030 | 2035 | 2050 | | | | | |
| **Biomass** | **Heating** | 0.400% | 5% | 7% | 9% | 11% | | **3** | FL, CO2 (partially) | High | High | **2** |
| | | % point increase: | 0.58% | 0.51% | 0.48% | 0.46% | | | **1.5** | **2** | **2** | |
| **Biomass** | **Electricity** | 0.067% | 0.15% | | | 0.45% | | **1** | FL, CO2 (partially) | High | High | **2** |
| | | % point increase: | 0.01% | | | 0.02% | | | **1.5** | **2** | **2** | |
| **Biofuels** | **Transportation** | 0.40% | 5% | | 20% | | 50% | **5** | FL, CO2 (partially) | High | Medium | **3** |
| | | % point increase: | 0.58% | | 1.09% | | 1.31% | | **1.5** | **2** | **3** | |
| **Wind energy** | **Electricity** | 2.580% | 7% | 13% | 23% | 27% | | **5** | CO2, EO, LP (partially) | High | Very Low | **4** |
| | | % point increase: | 0.55% | 0.80% | 1.13% | 1.06% | | | **2.5** | **2** | **5** | |
| **Solar PV** | **Electricity** | 1.700% | 3.00% | 5.00% | 9.00% | 10.0% | | **2** | CO2, EO, HP (partially) | High | Very Low | **4** |
| | | % point increase: | 0.16% | 0.25% | 0.41% | 0.36% | | | **2.5** | **2** | **5** | |
| **Solar thermal** | **Heating** | 0.200% | 0.50% | 0.80% | 1.20% | 1.50% | | **1** | CO2, EO | High | Low | **3** |
| | | % point increase: | 0.04% | 0.05% | 0.06% | 0.06% | | | **2** | **2** | **4** | |
| **Hydropower** | **Electricity** | 8.422% | 11% | 17% | | 35% | 50% | **4** | CO2, FL, HP & LP (part.) | High | Low | **3** |
| | | % point increase: | 0.30% | 0.66% | | 1.16% | 1.09% | | **3** | **2** | **4** | |
| **Geothermal** | **Electricity** | 0% | 0% | | | | | **1** | CO2, FL | Very High | Low | **3** |
| | | % point increase: | 0% | | | | | | **2** | **1** | **4** | |
| **Geothermal** | **Heating** | 0.05% | 0.3% | 0.6% | 0.8% | 1.0% | | **1** | CO2, FL | High | Low | **3** |
| | | % point increase: | 0.03% | 0.04% | 0.04% | 0.04% | | | **2** | **2** | **4** | |

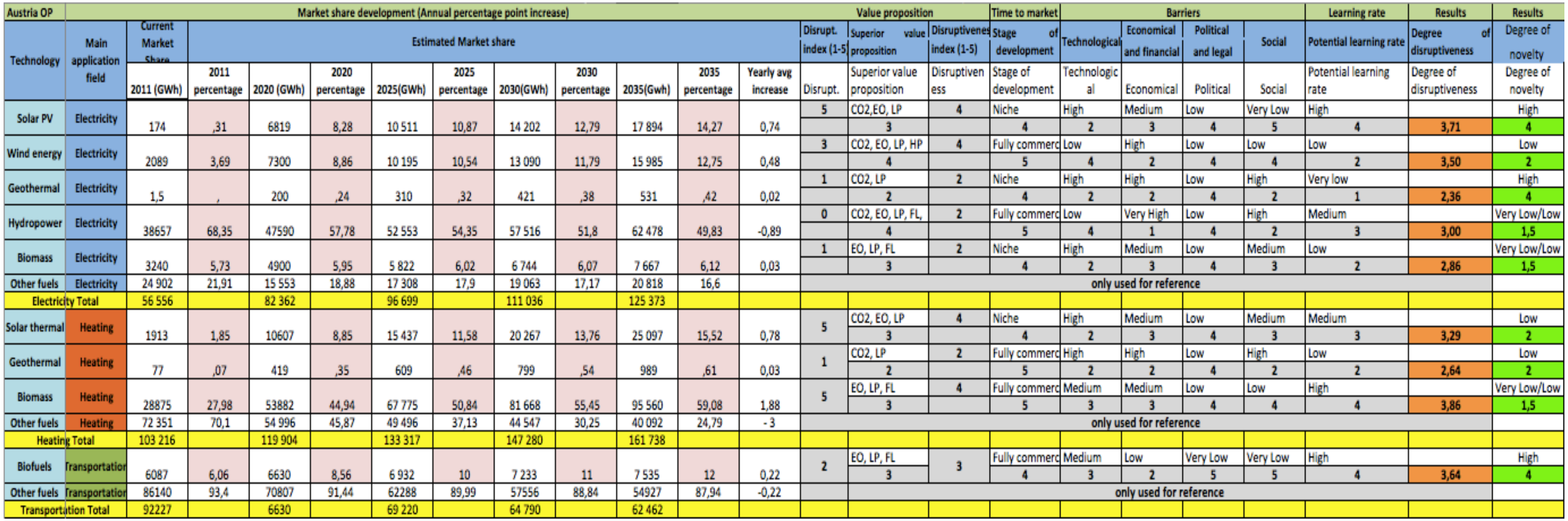
| BULGARIA | | Time to market | Barriers | | | | Learning rate | Results | Results |
|---|---|---|---|---|---|---|---|---|---|
| Technology | Main application field | Stage of development | Technological | Economical and financial | Political and legal | Social | Potential learning rate | Degree of disruptiveness | Degree of novelty |
| | | | | | | | | | |
| Biomass | Heating | Fully commercial | Medium | High | Very High | Low | Low | | Very Low/Low |
| | | 5 | 3 | 2 | 1 | 4 | 2 | 2.6 | 1.5 |
| Biomass | Electricity | Fully commercial | Medium | High | Very High | Low | Low | | Very Low/Low |
| | | 5 | 3 | 2 | 1 | 4 | 2 | 2.4 | 1.5 |
| Biofuels | Transportation | Demonstration | High | High | High | Low | High | | High |
| | | 2 | 2 | 2 | 2 | 4 | 4 | 2.8 | 4 |
| Wind energy | Electricity | Fully commercial | Medium | High | Very High | Low | Medium | | Low |
| | | 5 | 3 | 2 | 1 | 4 | 3 | 3.2 | 2 |
| Solar PV | Electricity | Niche | Low | High | Very High | Low | Vey High | | High |
| | | 4 | 4 | 2 | 1 | 4 | 5 | 3.1 | 4 |
| Solar thermal | Heating | Fully commercial | High | High | High | High | Low | | Low |
| | | 5 | 2 | 2 | 2 | 2 | 2 | 2.3 | 2 |
| Hydropower | Electricity | Fully commercial | Medium | High | High | Medim | Very Low | | Very Low/Low |
| | | 5 | 3 | 2 | 2 | 3 | 1 | 2.9 | 1.5 |
| Geothermal | Electricity | Pre-commercial | Very High | Very High | High | High | Low | | High |
| | | 3 | 1 | 1 | 2 | 2 | 2 | 1.8 | 4 |
| Geothermal | Heating | Niche | High | High | High | High | Low | | Low |
| | | 4 | 2 | 2 | 2 | 2 | 2 | 2.2 | 2 |

# Appendix 17: Austria Pessimistic Disruptiveness Assessment



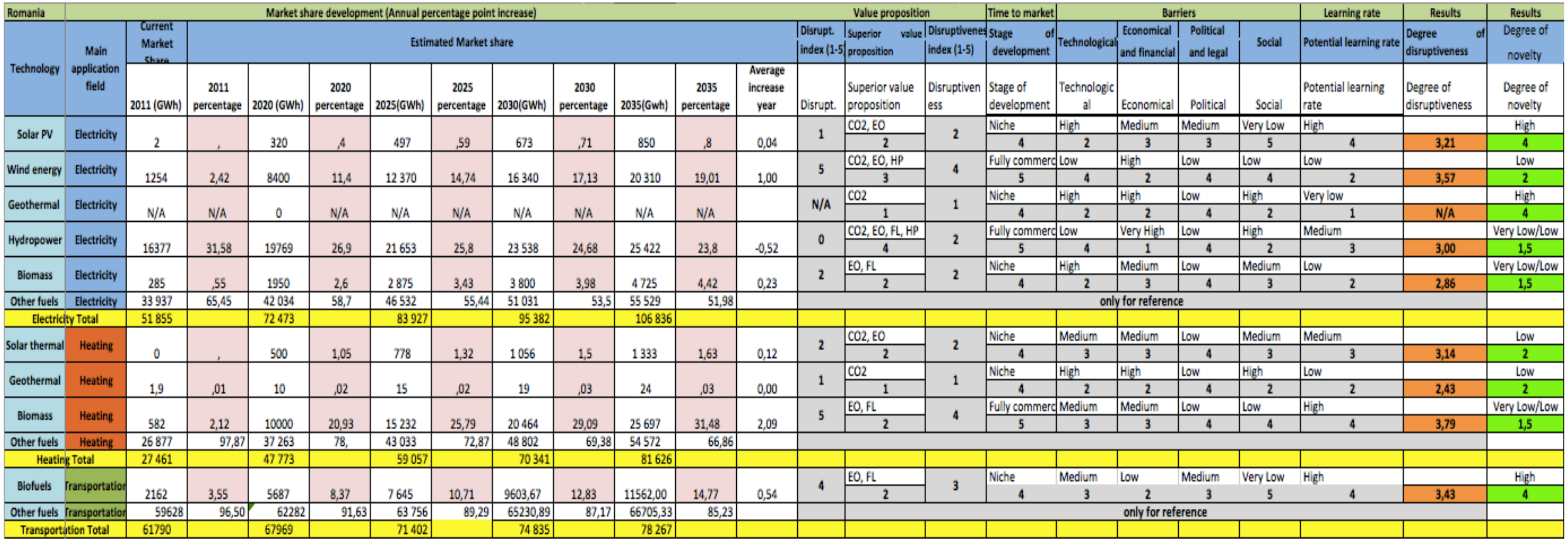
| Austria PES | | Market share development (Annual percentage point increase) | | | | | | | | | | | Value proposition | | | Time to market | Barriers | | | | Learning rate | Results | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology | Main application field | Current Market Share | Estimated Market share | | | | | | | | | | Disrupt. index (1-5) | Superior value proposition | Disruptiveness index (1-5) | Stage of development | Technological | Economical and financial | Political and legal | Social | Potential learning rate | Degree of disruptiveness | Degree of novelty |
| | | 2011 (GWh) | 2011 percentage | 2020 (GWh) | 2020 percentage | 2025(GWh) | 2025 percentage | 2030(GWh) | 2030 percentage | 2035(Gwh) | 2035 percentage | Yearly avg increase | Disrupt. | Superior value proposition | Disruptiveness | Stage of development | Technological | Economical | Political | Social | Potential learning rate | Degree of disruptiveness | Degree of novelty |
| Solar PV | Electricity | 174 | ,25 | 306 | ,3 | 379 | ,31 | 453 | ,32 | 526 | ,33 | 0,01 | 1 | CO2,EO, LP | 2 | Niche | High | Medium | Low | Very Low | High | | High |
| | | | | | | | | | | | | | | 3 | | 4 | 2 | 3 | 4 | 5 | 4 | 3,11 | 4 |
| Wind energy | Electricity | 2089 | 3,02 | 4811 | 4,7 | 6 323 | 5,23 | 7 835 | 5,62 | 9 348 | 5,92 | 0,19 | 2 | CO2, EO, LP, HP | 3 | Fully commerc | Low | High | Low | Low | Low | | Low |
| | | | | | | | | | | | | | | 4 | | 5 | 4 | 2 | 4 | 4 | 2 | 3,33 | 2 |
| Geothermal | Electricity | 1,5 | , | 2 | , | 2 | , | 3 | , | 3 | , | 0,00 | 1 | CO2, LP | 2 | Niche | High | High | Low | High | Very low | | High |
| | | | | | | | | | | | | | | 2 | | 4 | 2 | 2 | 4 | 2 | 1 | 2,17 | 4 |
| Hydropower | Electricity | 38657 | 55,97 | 42112 | 41,14 | 44 031 | 36,43 | 45 951 | 32,97 | 47 870 | 30,32 | -1,65 | 1 | CO2, EO, LP, FL, | 3 | Fully commerc | Low | Very High | Low | High | Medium | | Very Low/Low |
| | | | | | | | | | | | | | | 4 | | 5 | 4 | 1 | 4 | 2 | 3 | 2,94 | 1,5 |
| Biomass | Electricity | 3240 | 4,69 | 4566 | 4,46 | 5 303 | 4,39 | 6 039 | 4,33 | 6 776 | 4,29 | -0,03 | 1 | EO, LP, FL | 2 | Niche | High | Medium | Low | Medium | Low | | Very Low/Low |
| | | | | | | | | | | | | | | 3 | | 4 | 2 | 3 | 4 | 3 | 2 | 2,67 | 1,5 |
| Other fuels | Electricity | 24 902 | 36,06 | 50 576 | 49,4 | 64 839 | 53,64 | 79 102 | 56,75 | 93 366 | 59,13 | | only used for reference | | | | | | | | | | |
| Electricity Total | | 69 064 | | 102 373 | | 120 878 | | 139 383 | | 157 888 | | | | | | | | | | | | | |
| Solar thermal | Heating | 1913 | 1,85 | 3128,5 | 1,34 | 3 804 | 1,24 | 4 479 | 1,18 | 5 154 | 1,14 | -0,06 | 1 | CO2, EO, LP | 2 | Niche | High | Medium | Low | Medium | Medium | | Low |
| | | | | | | | | | | | | | | 3 | | 4 | 2 | 3 | 4 | 3 | 3 | 2,78 | 2 |
| Geothermal | Heating | 77 | ,07 | 465 | ,2 | 681 | ,22 | 896 | ,24 | 1 112 | ,25 | 0,01 | 1 | CO2, LP | 2 | Fully commerc | High | High | Low | High | Low | | Low |
| | | | | | | | | | | | | | | 2 | | 5 | 2 | 2 | 4 | 2 | 2 | 2,39 | 2 |
| Biomass | Heating | 28875 | 27,98 | 41763 | 17,89 | 48 923 | 16, | 56 083 | 14,83 | 63 243 | 14,04 | -1,12 | 1 | EO, LP, FL | 2 | Fully commerc | Medium | Medium | Low | Low | High | | Very Low/Low |
| | | | | | | | | | | | | | | 3 | | 5 | 3 | 3 | 4 | 4 | 4 | 3,22 | 1,5 |
| Other fuels | Heating | 72 351 | 70,1 | 188 068 | 80,57 | 252 355 | 82,53 | 316 642 | 83,75 | 380 929 | 84,57 | | only used for reference | | | | | | | | | | |
| Heating Total | | 103 216 | | 233 425 | | 305 762 | | 378 100 | | 450 438 | | | | | | | | | | | | | |
| Biofuels | Transportation | 6087 | 6,60 | 5699 | 7,45 | 5 483 | 8,09 | 5 268 | 8,39 | 5 052 | 8,42 | 0,09 | 1 | EO, LP, FL | 2 | Fully commerc | Medium | Low | Very Low | Very Low | High | | High |
| | | | | | | | | | | | | | | 3 | | 4 | 3 | 2 | 5 | 5 | 4 | 3,22 | 4 |
| Other fuels | Transportation | 86140 | 100,00 | 70807 | 92,55 | 62288,667 | 91,91 | 57556,259 | 91,61 | 54927,144 | 91,58 | | | only used for reference | | | | | | | | | |
| Transportation Total | | 92227 | | 76506 | | 67 772 | | 62 824 | | 59 979 | | | | | | | | | | | | | |

# Appendix 18: Austria Optimistic Disruptiveness Assessment



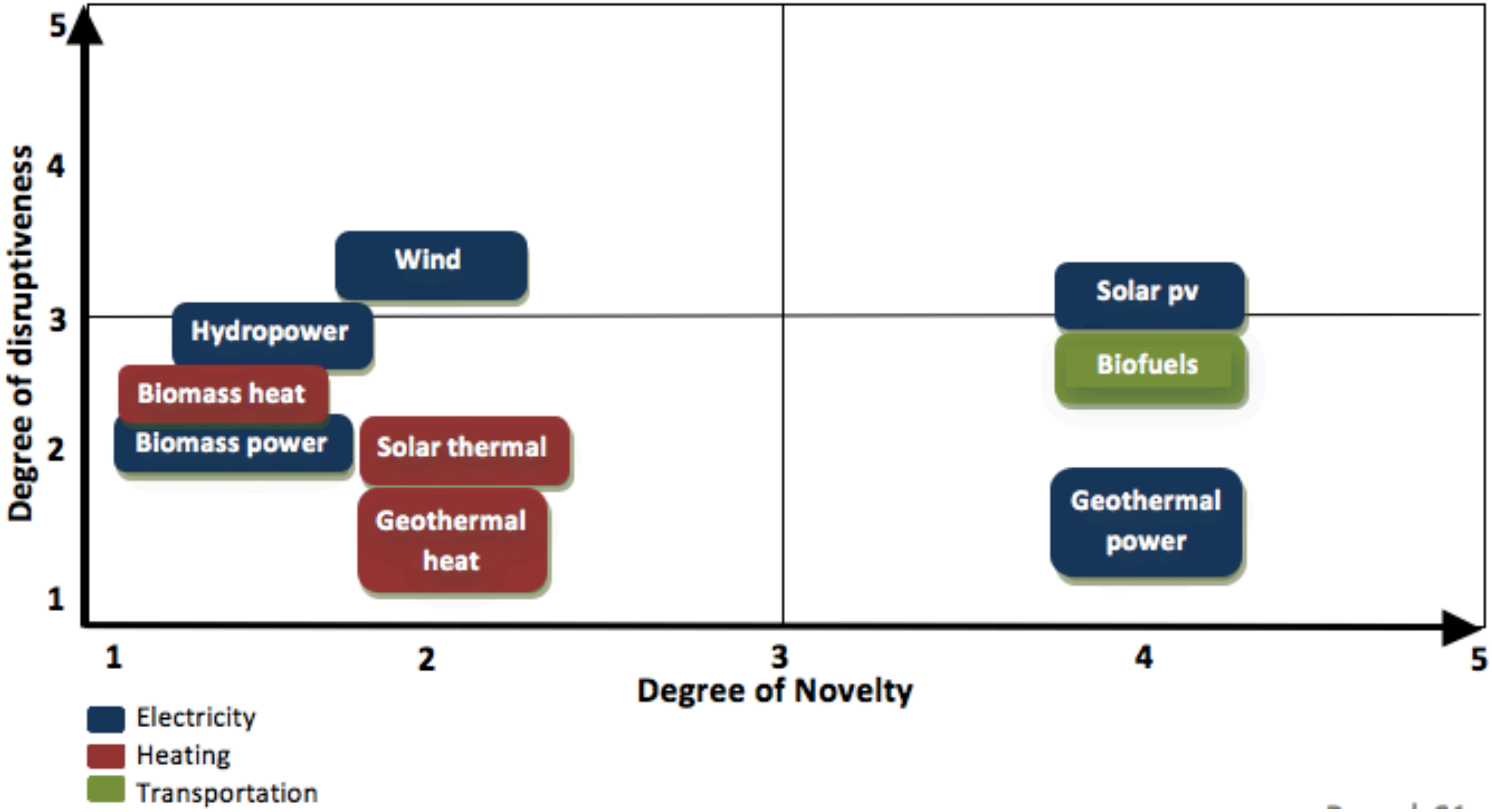
| Austria OP | Market share development (Annual percentage point increase) | | | | | | | | | | | | Value proposition | | | Time to market | Barriers | | | | Learning rate | Results | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology | Main application field | Current Market Share | Estimated Market share | | | | | | | | | | Disrupt. index (1-5) | Superior value proposition | Disruptiveness index (1-5) | Stage of development | Technological | Economical and financial | Political and legal | Social | Potential learning rate | Degree of disruptiveness | Degree of novelty |
| | | 2011 (GWh) | 2011 percentage | 2020 (GWh) | 2020 percentage | 2025(GWh) | 2025 percentage | 2030(GWh) | 2030 percentage | 2035(Gwh) | 2035 percentage | Yearly avg increase | Disrupt. | Superior value proposition | Disruptiveness | Stage of development | Technological | Economical | Political | Social | Potential learning rate | Degree of disruptiveness | Degree of novelty |
| Solar PV | Electricity | 174 | ,31 | 6819 | 8,28 | 10 511 | 10,87 | 14 202 | 12,79 | 17 894 | 14,27 | 0,74 | 5 | CO2,EO, LP | 4 | Niche | High | Medium | Low | Very Low | High | | High |
| | | | | | | | | | | | | | | 3 | | 4 | 2 | 3 | 4 | 5 | 4 | 3,71 | 4 |
| Wind energy | Electricity | 2089 | 3,69 | 7300 | 8,86 | 10 195 | 10,54 | 13 090 | 11,79 | 15 985 | 12,75 | 0,48 | 3 | CO2, EO, LP, HP | 4 | Fully commerc | Low | High | Low | Low | Low | | Low |
| | | | | | | | | | | | | | | 4 | | 5 | 4 | 2 | 4 | 4 | 2 | 3,50 | 2 |
| Geothermal | Electricity | 1,5 | , | 200 | ,24 | 310 | ,32 | 421 | ,38 | 531 | ,42 | 0,02 | 1 | CO2, LP | 2 | Niche | High | High | Low | High | Very low | | High |
| | | | | | | | | | | | | | | 2 | | 4 | 2 | 2 | 4 | 2 | 1 | 2,36 | 4 |
| Hydropower | Electricity | 38657 | 68,35 | 47590 | 57,78 | 52 553 | 54,35 | 57 516 | 51,8 | 62 478 | 49,83 | -0,89 | 0 | CO2, EO, LP, FL, | 2 | Fully commerc | Low | Very High | Low | High | Medium | | Very Low/Low |
| | | | | | | | | | | | | | | 4 | | 5 | 4 | 1 | 4 | 2 | 3 | 3,00 | 1,5 |
| Biomass | Electricity | 3240 | 5,73 | 4900 | 5,95 | 5 822 | 6,02 | 6 744 | 6,07 | 7 667 | 6,12 | 0,03 | 1 | EO, LP, FL | 2 | Niche | High | Medium | Low | Medium | Low | | Very Low/Low |
| | | | | | | | | | | | | | | 3 | | 4 | 2 | 3 | 4 | 3 | 2 | 2,86 | 1,5 |
| Other fuels | Electricity | 24 902 | 21,91 | 15 553 | 18,88 | 17 308 | 17,9 | 19 063 | 17,17 | 20 818 | 16,6 | | only used for reference | | | | | | | | | | |
| Electricity Total | | 56 556 | | 82 362 | | 96 699 | | 111 036 | | 125 373 | | | | | | | | | | | | | |
| Solar thermal | Heating | 1913 | 1,85 | 10607 | 8,85 | 15 437 | 11,58 | 20 267 | 13,76 | 25 097 | 15,52 | 0,78 | 5 | CO2, EO, LP | 4 | Niche | High | Medium | Low | Medium | Medium | | Low |
| | | | | | | | | | | | | | | 3 | | 4 | 2 | 3 | 4 | 3 | 3 | 3,29 | 2 |
| Geothermal | Heating | 77 | ,07 | 419 | ,35 | 609 | ,46 | 799 | ,54 | 989 | ,61 | 0,03 | 1 | CO2, LP | 2 | Fully commerc | High | High | Low | High | Low | | Low |
| | | | | | | | | | | | | | | 2 | | 5 | 2 | 2 | 4 | 2 | 2 | 2,64 | 2 |
| Biomass | Heating | 28875 | 27,98 | 53882 | 44,94 | 67 775 | 50,84 | 81 668 | 55,45 | 95 560 | 59,08 | 1,88 | 5 | EO, LP, FL | 4 | Fully commerc | Medium | Medium | Low | Low | High | | Very Low/Low |
| | | | | | | | | | | | | | | 3 | | 5 | 3 | 3 | 4 | 4 | 4 | 3,86 | 1,5 |
| Other fuels | Heating | 72 351 | 70,1 | 54 996 | 45,87 | 49 496 | 37,13 | 44 547 | 30,25 | 40 092 | 24,79 | - 3 | only used for reference | | | | | | | | | | |
| Heating Total | | 103 216 | | 119 904 | | 133 317 | | 147 280 | | 161 738 | | | | | | | | | | | | | |
| Biofuels | Transportation | 6087 | 6,06 | 6630 | 8,56 | 6 932 | 10 | 7 233 | 11 | 7 535 | 12 | 0,22 | 2 | EO, LP, FL | 3 | Fully commerc | Medium | Low | Very Low | Very Low | High | | High |
| | | | | | | | | | | | | | | 3 | | 4 | 3 | 2 | 5 | 5 | 4 | 3,64 | 4 |
| Other fuels | Transportation | 86140 | 93,4 | 70807 | 91,44 | 62288 | 89,99 | 57556 | 88,84 | 54927 | 87,94 | -0,22 | | only used for reference | | | | | | | | | |
| Transportation Total | | 92227 | | 6630 | | 69 220 | | 64 790 | | 62 462 | | | | | | | | | | | | | |

# Appendix 19: Romania disruptiveness assessment

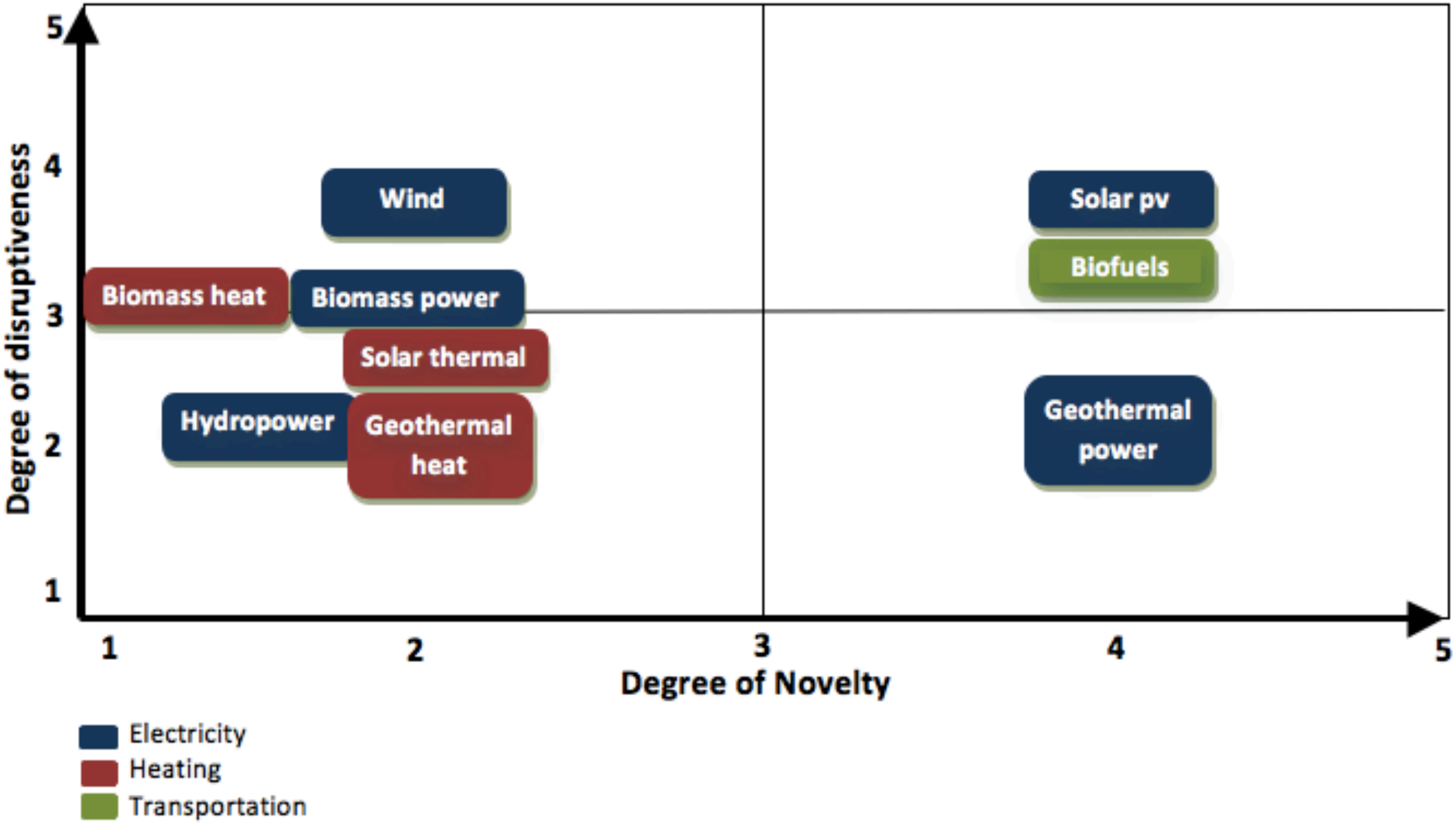


| Romania | Market share development (Annual percentage point increase) | | | | | | | | | | | | Value proposition | | | Time to market | Barriers | | | | Learning rate | Results | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology | Main application field | Current Market Share | Estimated Market share | | | | | | | | | | Disrupt. index (1-5 | Superior value proposition | Disruptiveness index (1-5) | Stage of development | Technological | Economical and financial | Political and legal | Social | Potential learning rate | Degree of disruptiveness | Degree of novelty |
| | | 2011 (GWh) | 2011 percentage | 2020 (GWh) | 2020 percentage | 2025(GWh) | 2025 percentage | 2030(GWh) | 2030 percentage | 2035(Gwh) | 2035 percentage | Average increase year | Disrupt. | Superior value proposition | Disruptiveness | Stage of development | Technological | Economical | Political | Social | Potential learning rate | Degree of disruptiveness | Degree of novelty |
| Solar PV | Electricity | 2 | , | 320 | ,4 | 497 | ,59 | 673 | ,71 | 850 | ,8 | 0,04 | 1 | CO2, EO<br>2 | 2 | Niche<br>4 | High<br>2 | Medium<br>3 | Medium<br>3 | Very Low<br>5 | High<br>4 | 3,21 | High<br>4 |
| Wind energy | Electricity | 1254 | 2,42 | 8400 | 11,4 | 12 370 | 14,74 | 16 340 | 17,13 | 20 310 | 19,01 | 1,00 | 5 | CO2, EO, HP<br>3 | 4 | Fully commerc<br>5 | Low<br>4 | High<br>2 | Low<br>4 | Low<br>4 | Low<br>2 | 3,57 | Low<br>2 |
| Geothermal | Electricity | N/A | N/A | 0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | | N/A | CO2<br>1 | 1 | Niche<br>4 | High<br>2 | High<br>2 | Low<br>4 | High<br>2 | Very low<br>1 | N/A | High<br>4 |
| Hydropower | Electricity | 16377 | 31,58 | 19769 | 26,9 | 21 653 | 25,8 | 23 538 | 24,68 | 25 422 | 23,8 | -0,52 | 0 | CO2, EO, FL, HP<br>4 | 2 | Fully commerc<br>5 | Low<br>4 | Very High<br>1 | Low<br>4 | High<br>2 | Medium<br>3 | 3,00 | Very Low/Low<br>1,5 |
| Biomass | Electricity | 285 | ,55 | 1950 | 2,6 | 2 875 | 3,43 | 3 800 | 3,98 | 4 725 | 4,42 | 0,23 | 2 | EO, FL<br>2 | 2 | Niche<br>4 | High<br>2 | Medium<br>3 | Low<br>4 | Medium<br>3 | Low<br>2 | 2,86 | Very Low/Low<br>1,5 |
| Other fuels | Electricity | 33 937 | 65,45 | 42 034 | 58,7 | 46 532 | 55,44 | 51 031 | 53,5 | 55 529 | 51,98 | | only for reference | | | | | | | | | | |
| Electricity Total | | 51 855 | | 72 473 | | 83 927 | | 95 382 | | 106 836 | | | | | | | | | | | | | |
| Solar thermal | Heating | 0 | , | 500 | 1,05 | 778 | 1,32 | 1 056 | 1,5 | 1 333 | 1,63 | 0,12 | 2 | CO2, EO<br>2 | 2 | Niche<br>4 | Medium<br>3 | Medium<br>3 | Low<br>4 | Medium<br>3 | Medium<br>3 | 3,14 | Low<br>2 |
| Geothermal | Heating | 1,9 | ,01 | 10 | ,02 | 15 | ,02 | 19 | ,03 | 24 | ,03 | 0,00 | 1 | CO2<br>1 | 1 | Niche<br>4 | High<br>2 | High<br>2 | Low<br>4 | High<br>2 | Low<br>2 | 2,43 | Low<br>2 |
| Biomass | Heating | 582 | 2,12 | 10000 | 20,93 | 15 232 | 25,79 | 20 464 | 29,09 | 25 697 | 31,48 | 2,09 | 5 | EO, FL<br>2 | 4 | Fully commerc<br>5 | Medium<br>3 | Medium<br>3 | Low<br>4 | Low<br>4 | High<br>4 | 3,79 | Very Low/Low<br>1,5 |
| Other fuels | Heating | 26 877 | 97,87 | 37 263 | 78, | 43 033 | 72,87 | 48 802 | 69,38 | 54 572 | 66,86 | | | | | | | | | | | | |
| Heating Total | | 27 461 | | 47 773 | | 59 057 | | 70 341 | | 81 626 | | | | | | | | | | | | | |
| Biofuels | Transportation | 2162 | 3,55 | 5687 | 8,37 | 7 645 | 10,71 | 9603,67 | 12,83 | 11562,00 | 14,77 | 0,54 | 4 | EO, FL<br>2 | 3 | Niche<br>4 | Medium<br>3 | Low<br>2 | Medium<br>3 | Very Low<br>5 | High<br>4 | 3,43 | High<br>4 |
| Other fuels | Transportation | 59628 | 96,50 | 62282 | 91,63 | 63 756 | 89,29 | 65230,89 | 87,17 | 66705,33 | 85,23 | | | only for reference | | | | | | | | | |
| Transportation Total | | 61790 | | 67969 | | 71 402 | | 74 835 | | 78 267 | | | | | | | | | | | | | |

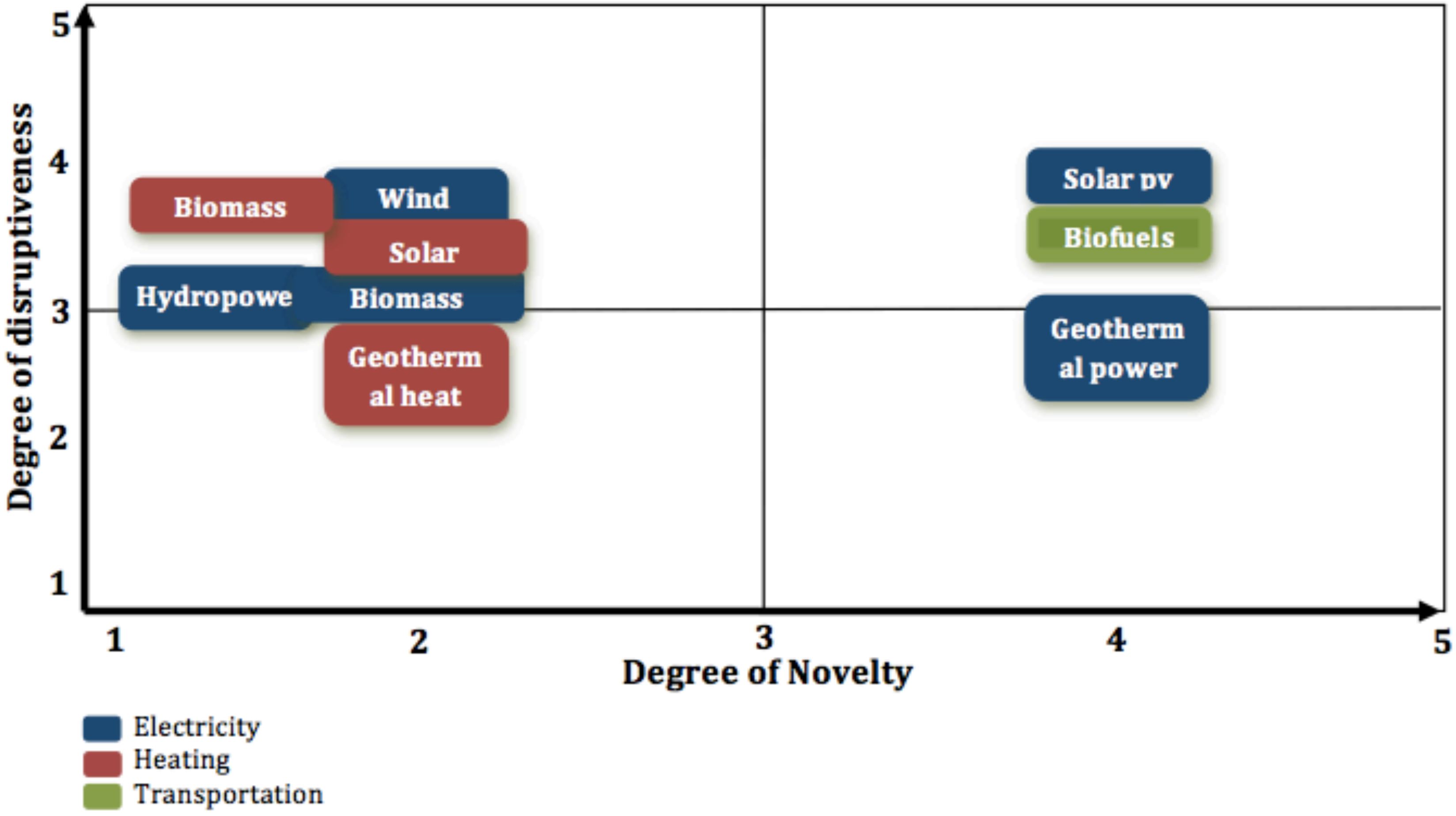
# Appendix 20: Energy technologies in Bulgaria categorized against degree of disruptiveness and novelty



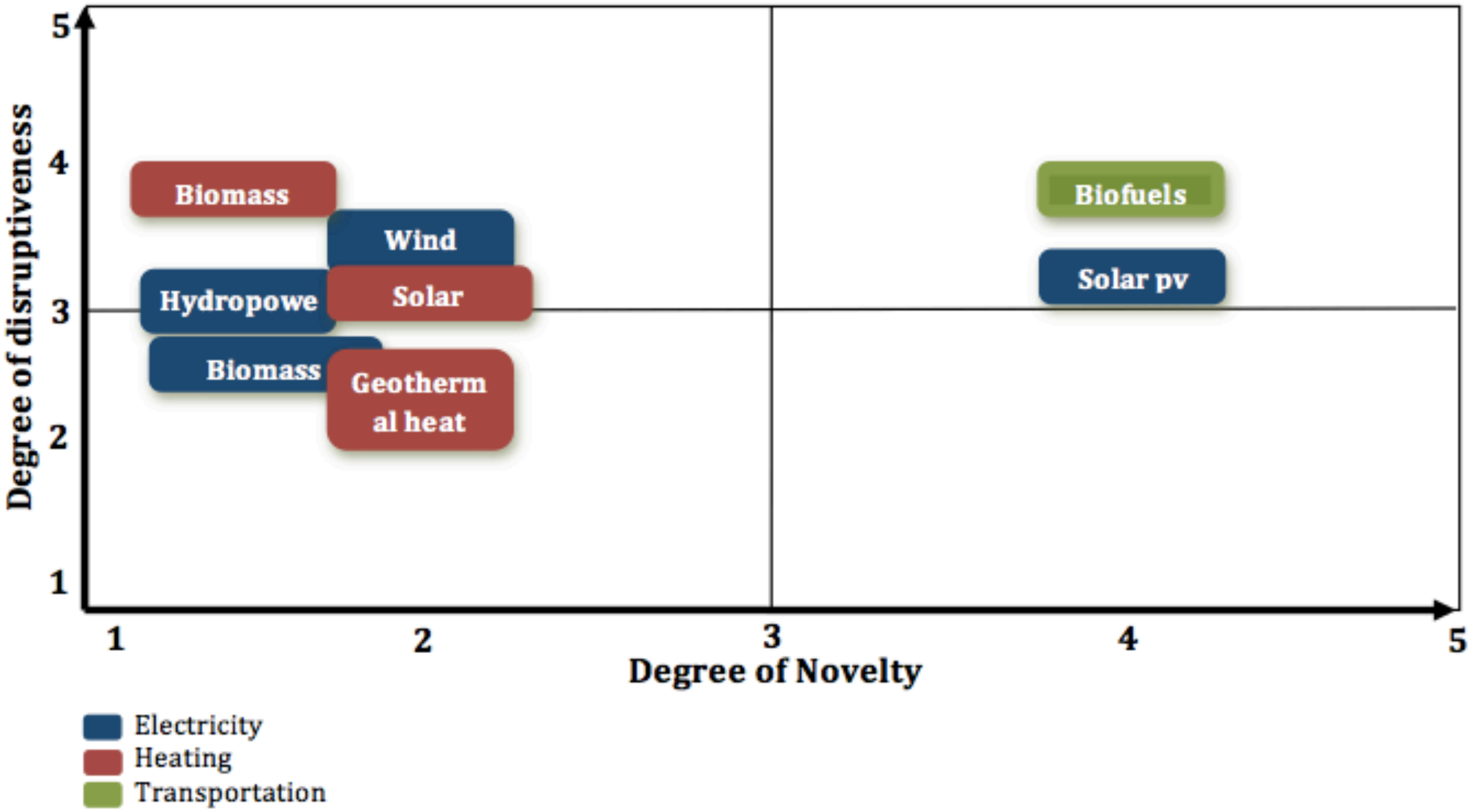
## Appendix 21: Energy technologies in Germany categorized against degree of disruptiveness and novelty



## Appendix 22: Energy technologies in Austria categorized against degree of disruptiveness and novelty



## Appendix 23: Energy technologies in Romania categorized against degree of disruptiveness and novelty



# 11. References

ABB. (2011). Austria Energy Efficiency Report. Retrieved 2013 30-October from: ABB Group. http://www05.abb.com/global/scot/scot316.nsf/veritydisplay/00e3b8735587fad9c12578aa004bb3c1/$file/austria.pdf

Abernathy, W. (1978). The Productivity Dilemma. Baltimore: The Johns Hopkins University Press.

Abernathy, W. J., & Clark, K. B. (1984). Innovation: Mapping the winds of creative destruction. Research policy , 3-22.

Abernathy, W., & Clark, K. B. (1985). Mapping the winds of creative destruction. Research Policy , pp. 3-22.

AboutBioenergy. (2013a). Definition of Biomass. Retrieved October 23, 2013, from What is Biomass?:

Abrihan, R. (2013, June 9). Printre eoliene. Investiţiile în energia verde pe ultima sută de metri. Forbes Romania .

Adner, R. (2002). When are technologies diruptive? A demand-based view of the emergence of competition. Strategic Management Journal, Vol. 23, Issue 8, pp. 667-688.

Adner, R., & Zemsky, P. (2005). Disruptive Technologies and the Emergence of Competition. The Rand Journal of Economics , pp. 229-254.

Advantage Austria. (2013, July 11). Retrieved November 01, 2013, from Advantage Austria: http://www.advantageaustria.org/international/zentral/business-guide-oesterreich/importieren-aus-oesterreich/branchen/erneuerbare-energien/Ueberblick.en.html

AEBIOM. (2013). Glossary. Retrieved 2013 30-October from European Biomass Association: http://www.aebiom.org/wp-content/uploads/2012/08/GLOSSARY.pdf

AEBIOM. (2013). Glossary. Retrieved October 30, 2013, from European Biomass Association: http://www.aebiom.org/wp-content/uploads/2012/08/GLOSSARY.pdf

AEE. (2013a April). Biofuels – climate protectors cultivated in Germany. Retrieved 2013 15-Novemeber from German Renewable Energies Agency: http://www.unendlich-viel-energie.de/en/biomass/details/article/159/biofuels-climate-protectors-cultivated-in-germany.html

AEE. (2013b). FAKTEN Die wichtigsten Daten zu den Erneuerbaren Energien. Agentur fuer Erneuerbare Energien.

AEE. (2013c February). Heat from renewable energies 2012. Retrieved 2013 15-November from German Renewable Energies Agency: http://www.unendlich-viel-energie.de/en/details/article/530/heat-from-renewable-energies-2012.html

Afuah, A. (1998). Innovation management: Strategies, implementation, and profits. New York: Oxford University Press.

AGEE. (2013). Development of renewable energy sources in Germany 2012. Arbeitsgruppe Erneuerbare Energien.

Alitchkov, V. (2013 28-October). Potential of Solar PV technologies in Bulgaria. (M. Totev, Interviewer)

ANRE. (2011). Raport privind rezultatele monitorizarii piete de energie electrica in luna decembrie 2011. Autoritatea nationala de reglementare a energiei.

APEE. (2010). Future development of RES in the energy system in Bulgaria. Association of Producers of Ecological Energy.

APEE. (2013a 28-June). Feed-in Tariffs. Retrieved 2013 5-November from Association of Producers of Ecological Energy: http://apee.bg/documents/legislation/tariffs/

Astra Bioplant. (2010). Plant, location, production capacity. Retrieved November 5, 2013, from Astra Bioplant: http://www.astrabioplant.bg/bg/index.html

Austrian Energy Agency. (2012, October). Energy efficiency policies and measures in Austria in 2010. Retrieved October 27, 2013, from Austrian Energy Agency: http://www.odyssee-indicators.org/publications/PDF/austria_nr.pdf

Babu, S. P. (2005). Observations on the current status of biomass gasification. IEA Bioenergy.

Bachvarov, A. (2012). Energy production from biomass is at its birth stage. Retrieved 2013 5-November from Energia: http://energia.elmedia.net/bg/2012-6/interview

Bacovsky, D., Ludwiczek, N., Ognissanto, M., & Woergetter, M. (2013). Status of Advanced Biofuels Demonstration Facilities in 2012. International Energy Agency.

Bauen, A., Berndes, G., Junginger, M., Londo, M., & Vuille, F. (2009). Bioenergy - a Sustainable and Reliable Energy Source. Utrecht: IEA Bioenergy.

BBE. (2012). Der Bioenergiemarkt in Zahlen 2012. Retrieved 2013 15-November from Bundesverband BioEnergie e.V.: http://www.bioenergie.de/index.php?option=com_content&view=article&id=290&Itemid=6

BDEW. (2013). Erneuerbare Energien und das EEG: Zahlen, Fakten, Grafiken. Bundesverband der Energie- und Wasserwirtschaft e.V.

BDEW. (2013, 01 31). Erneuerbare Energien und das EEG: Zahlen, Fakten, Grafiken .

BDW. (2011). Installed capacity and electricity production. Retrieved December 18, 2013, from German Hydropower Association: http://www.wasserkraft-deutschland.de/wasserkraft/installierte-leistungstromproduktion.html

BEE. (2012). Hydropower: Renewable energy with tradition. Retrieved December 18, 2013, from German Renewable Energy Federation: http://www.bee-ev.de/Energieversorgung/ErneuerbareEnergien/Wasserkraft.php

Befu, D. (2011, December 16). Ce şanse are energia geotermală în Bucureşti şi în România. Romania Libera .

BGA. (2010). Geothermal energy in Bulgaria. Retrieved December 20, 2013, from Bulgarian Geothermal Association: http://www.geothermalbg.org/geothermal.html

BGWEA. (2013 November). Installed wind energy in Bulgaria. Retrieved 2013 8-December from Bulgarian Wind Energy Association: http://bgwea.org.server14.host.bg/English/Installed_Wind_in_Bulgaria_EN.html

Biermayr, P. (2011). Erneuerbare Energie in Zahlen. Die Entwicklung erneuerbarer Energie in Österreich im Jahr 2011. Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Umweltökonomie und Energie. Wien: Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

Biogaspartner. (2013). Biogas Grid Injection in Germany and Europe – Market, Technology and Players. Berlin: DENA German Energy Agency.

Bioliq. (2010). Biomass to Liquid - the bioliq Process. Retrieved November 21, 2013, from Biomass to Liquid Karlsruhe: http://www.bioliq.de/english/55.php

Biomass Energy Centre. (2011b). Combustion. Retrieved 2013 30-October from http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,17502&_dad=portal&_schema=PORTAL

Biomass Energy Centre. (2011c). Other thermal conversion processes. Retrieved 2013 30-October from http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,17508&_dad=portal&_schema=PORTAL

BMLFUW. (2009, March). Erneuerbare energie 2020 - potentiale und verwendung in Oesterreich. Bundesministerium fuer Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

BMU. (2012b). Renewable Energies Driving Germany's Energiewende. Berlin: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

BMU. (2013a). Erneuerbare Energien in Zahlen - Nationale und internationale Entwicklung. Berlin: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit.

BMU. (2013b). Renewable Energy Sources 2012. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

Boisen, P. (2009a). Biomethane potentials as a vehicle fuel. Madrid: NGVA Europe.

Boisen, P. (2009b). NGVA Europe position on fuel tax for NG/biomethane powered vehicles. Madrid: NGVA Europe.

Bolintineanu, C. (2013). Is Germany on track? Retrieved March 1, 2014, from Bundesverband Erneuerbare Energie e.V. (BEE): http://www.keepontrack.eu/contents/keeptrackcountryfactsheet/germany-roadmap.pdf

Borbely, L. (2012, February 28). Potentialul hidroenergetic poate ajunge la 8000 MW. Retrieved January 21, 2014, from Business24: http://www.business24.ro/energie/energie-regenerabila/borbely-potentialul-hidroenergetic-poate-ajunge-la-8-000-mw-1508794

Bower, J., & Chrisensen, C. (1995). Disruptive technologies: catching the wave. Harvard Business Review , pp. 43-53.

BPVA. (2012). Photovoltaics. Retrieved 2013 11-December from Bulgarian Photovoltaic Association: http://www.bpva.org/en/pages/photovoltaics.html

BRAEM. (2010). BULGARIA National Report. Bourgas Regionam Agency for Energy Management.

Bruckner, B. (2010, November). Electric mobility in Austria. Retrieved January 9, 2014, from Finpro: http://www.finpro.fi/documents/10304/681aef63-e1b6-480b-b280-2dcc704eb07d

BSPB. (2012). Risk and Opportunity in Bulgaria's Biomass Industry. Bulgarian Society for the Protection of Birds/BirdLife Bulgaria.

BSW. (2012). Solar Heating Roadmap. German Solar Industry Association.

BSW. (2013a). Deutsche Solarbranche. Retrieved December 16, 2013, from Solarenergie fuer Deutschland: http://www.solarbusiness.de/daten-a-fakten/zahlen

BSW. (2013b). Statistic data on the German Solar power (photovoltaic) industry. German Solar Industry Association.

Buerer, M. J., & Wuestenhagen, R. (2009). Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international cleantech investors. Energy Policy , pp. 4997-5006.

Bundesministerium fuer Umwelt, Naturschutz, Bau und Reaktorsicherheit. (2013, December). Entwicklung der erneuerbaren Energien in Deutschland im Jahr 2012. Retrieved February 28, 2014, from Erneuerbare Energien: http://www.erneuerbare-energien.de/fileadmin/Daten_EE/Dokumente__PDFs_/ee_in_zahlen_ppt_bf.pdf

Bundesministerium fuer Wirtschaft und Technologie. (2012). Energiestatistiken. Retrieved February 23, 2014, from BMWI: http://www.bmwi.de/BMWi/Redaktion/PDF/E/energiestatistiken-energiegewinnung-energieverbrauch,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

Bundesverband Photovoltaik Austria. (2013, November 12). Bilanz Photovoltaic Jahr 2013.

BWE. (2013 9-August). Stable upward trend in German wind market in 2013 - Production volume of manufacturers grown in 2012. Retrieved 2013 4-December from German Wind Energy Association: http://www.wind-energie.de/en/press/press-releases/2013/stable-upward-trend-german-wind-market-2013-production-volume

Capital. (2013, March 27). Biomasa scapă de reducerea schemei de sprijin. La eoliene, microhidrocentrale şi solar scade numărul de certificate verzi. Retrieved January 22, 2014, from Capital: http://www.capital.ro/biomasa-scapa-de-reducerea-schemei-de-sprijin-la-eoliene-microhidrocentrale-si-solar-scade-numa.html

Chandy, R. et al. (2010). Evolution or revolution: Business model innovation in network markets. Working Paper.

Chandy, R., & Prabhu, J. (2011). Innovation Typologies. Wiley International Encyclopedia of Marketing .

Chandy, R., & Tellis, G. (1998, Nov). Organizing for Radical Product Innovation: The Overlooked Role of Willingness to Cannibalize. Journal of Marketing Research , pp. 474-487.

Chemical-technology. (2012). Clariant's Cellulosic Ethanol Production Plant, Straubing, Bavaria, Germany. Retrieved November 21, 2013, from Chemical technology projects: http://www.chemicals-technology.com/projects/sud-chemie-ethanol/

Chesbrough, H. (1999). Arrested development: the experience of European hard disk drive firms in comparison with US and Japanese firms. Journal of Evolutionary Economics,Vol.9, Issue 3, pp. 287–329.

Chesbrough, H. (2003). Environmental Influences upon Firm Entry into New Submarkets: Evidence from the Worldwide Hard-Disk-Drive Industry Conditionally. Research Policy, Vol.32, Issue 4, pp. 659-678.

Christensen, C. (1997). The Innovator's Dilemma. Boston: Harvard Business School Press.

Christensen, C., & Bower, J. (1996). Customer Power, Strategic Investment, and the Failure of Leading Firms. Strategic Management Journal , pp. 197-218.

Christensen, C., & Raynor, M. (2003). The Innovator's Solution. Boston: Harvard Business School Press.

Christensen, C., Anthony, S., & Roth, E. (2004). Seeing What's Next. Boston: Harvard Business School Press.

Clariant. (2013). SUNLIQUID. Retrieved 2013 21-November from Clariant: http://www.clariant.com/micro/biotech/internet.nsf/023cfbb98594ad5bc12564e400555162/de93f8953c430324c1257b2000425ebd?OpenDocument

Cohut, I., & Bendea, C. (2000). Romania update report for 1995-1999. World Geothermal Congress 2000, Japan.

Colesca, S., & Ciocoiu, C. (2013). An overview of the Romanian renewable energy sector. Renewable and Sustainable Energy Reviews , 149-158.

Continental Wind Partners. (2013). Bulgaria. Retrieved December 9, 2013, from Continental Wind Partners: http://www.continentalwind.com/bulgaria-1

CrossBorder Bioenergy. (2012a). EU Handbook Biofuel markets. Intelligent Energy Europe.

CrossBorder Bioenergy. (2012b). EU Handbook Biogas Markets. Intelligent Energy Europe.

CrossBorder Bioenergy. (2012c). EU Handbook CHP Markets. Intelligent Energy Europe.

CrossBorder Bioenergy. (2012d). EU Handbook Small Scale Heating Markets. Intelligent Energy Europe.

Damanpour, F. (1991). Organizational Innovation: A Meta-Analysis Of Effects Of Determinants and Moderators. Academy of Management Journal, Vol. 34, No.3, pp. 555-590.

Damyanov, L. (2013 26-September). Potential of the biomass sector in Bulgaria. (M. Totev, Interviewer)

Danneels, E. (2004). Disruptive Technology Reconsidered: A Critique and Research Agenda. The Journal of Product innovation Management , pp. 246-258.

Deutsche WindGuard. (2012). Status of Wind Energy Development in Germany. Deutsche WindGuard.

Deutsche WindGuard. (2013). Status of Wind Energy Development in Germany. Deutsche WindGuard.

DEWI. (2012, December 31). Statistics Archive. Retrieved December 3, 2013, from Deutsches Windenergie Institut: http://www.dewi.de/dewi/index.php?id=66&tx_ttnews%5Btt_news%5D=132&cHash=bf592fbf4e46a345475aa6c10cf83f41

Diac, M. (2011, November 23). Energia geotermala poate fi poluanta in Romania. Retrieved January 22, 2014, from Green Report: http://www.green-report.ro/energia-geotermala-poate-fi-poluanta-romania/

Dilkov, P. (2013 3-October). Hydropower potential in Bulgaria. (M. Totev, Interviewer)

Dimitrova, D., Cheriyska, I., Georgiev, K., Marinova-Garvanska, S., & Kolev, N. (2009). Biogas Potential in Bulgaria. Summary Report. Sofia: Big East Biogas for Eastern Europe.

Dumas, P. (2013 22-October). Potential of geothermal energy techhnologies in the EU. (M. Totev, Interviewer)

EBB. (2013). Statistics. Retrieved 2013 6-November from European Biodiesel Board: http://www.ebb-eu.org/stats.php

EC. (2013). EU Energy in Figures. European Commission.

ECON. (2011, April 19). Retrieved November 4, 2013, from Bulgaria to warm itself with wood biomass: http://econ.bg/

EGEC. (2009a). Geothermal Electricity and Combined Heat and Power. European Geothermal Energy Council.

EGEC. (2009b). Geothermal Heat Pumps: Ground Source Heat Pumps. Brussels: European Geothermal Energy Council.

EGEC. (2011). EGEC Final Evaluation of the National Renewable Energy Action Plans. Brussels: European Geothermal Energy Council.

EGEC. (2013a). GEOELEC Summary. Brussels: European Geothermal Energy Council.

Eisenhardt, K., & Graebner, M. (2007). Theory building from cases: opportunities and challenges. Academy of Management Journal, Vol. 50, No.1, pp. 25-32.

Enchev, D. (2012). Dealing with an insecure legal framework. Sofia: Continental Wind Partners.

Ender, C. (2013). Wind Energy Use in Germany. Deutsches Windenergie Institut.

Energia. (2010). Geothermal Energy in Bulgaria. Retrieved December 20, 2013, from Energia: http://www.energia.gr/geofar/page.asp?p_id=51

Energy Transition. (2012, 09). The german Energiewende. Retrieved February 28, 2014, from Energy transition: http://energytransition.de/2012/09/e-biomass/

ENO. (2012). Annual report. Sofia: Electricity Newtork Operator.

EPIA. (2013). Global Market Outlook for Photovoltaics 2013-2017. Brussels: European Photovoltaic Industry Association.

EREC. (2010). RE-thinking 2050. Brussels: European Renewable Energy Council.

EREC. (2011). Mapping Renewable Energy Pathways Towards 2020. Brussels: European Renewable Energy Council.

EREC. (2012b). Wind Energy. Retrieved 2013 6-December from European Renewable Energy Council: http://www.erec.org/renewable-energy/wind-energy.html

EREF. (2013). Newsletter September 2013. European Renewable Energies Federation.

ESHA. (2012). Small Hydropower Roadmap. European Small Hydropower Association.

ESO. (2013). Annual Report 2012. Sofia: Electricity System Operator.

Estela. (2012). Strategic Research Agenda 2020 - 2025. European Solar Thermal Electricity Association.

ESTIF. (2013a). Cooling with solar thermal. Retrieved 2013 15-December from European Solar Thermal Industry Association: http://www.estif.org/st_energy/technology/solar_thermal_cooling_and_air_conditioning/

ESTIF. (2013b). Solar Thermal Markets in Europe. European Solar Thermal Industry Federation.

EUBIA. (2012a). About Biomass. Retrieved October 24, 2013, from European Biomass Industry Association: http://www.eubia.org/index.php/about-biomass

EUBIA. (2012b). Anaerobic digestion. Retrieved 2013 31-October from European Biomass Industry Association: http://www.eubia.org/index.php/about-biomass/anaerobic-digestion

EUBIA. (2012c). Biomass procurement. Retrieved October 31, 2013, from European Biomass Industry Association: http://www.eubia.org/index.php/about-biomass/biomass-procurement

EUBIA. (2012d). Co-Combustion with Biomass. Retrieved October 31, 2013, from European Biomass Industry Association: http://www.eubia.org/index.php/about-biomass/co-combustion-with-biomass

EUBIA. (2012e). Cogeneration. Retrieved November 1, 2013, from European Biomass Industry Association: http://www.eubia.org/index.php/about-biomass/combustion/cogeneration

EUBIA. (2012f). Densification-related advantages. Retrieved October 31, 2013, from European Biomass Industry Association: http://www.eubia.org/index.php/about-biomass/biomass-pelleting

EUBIA. (2012g). Pyrolysis. Retrieved 2013 31-October from European Biomass Industry Association: http://www.eubia.org/index.php/about-biomass/pyrolysis-and-gasification/pyrolysis

EUROBSERV'ER. (2012). Solar thermal and concentrated solar power barometer. Le journal de photovoltaique (209), 47-69.

EUROBSERV'ER. (2012, April). Photovoltaic barometer. Le journal de photovoltaique , 108-131.

European Comission (2005). Bulgaria Renewable Energy Fact Sheet. Retrieved June 14, 2014, from: http://www.rgs.org/NR/rdonlyres/504085DF-2C49-4931-8408-006D99BC449E/0/EUBulgarianEnergyFactSheet.pdf

European Comission. (2009). Directive 2009/28/EC of the European Parliament and of the Council. Official Journal of the European Union.

European Commission. (2010). Bioenergy. Retrieved October 24, 2013, from Energy: http://ec.europa.eu/energy/renewables/bioenergy/bioenergy_en.htm

European Commission. (2012). Country Factsheets. European Commission.

European Oil and Gas. (2012). European Oil and Gas. Building for the future , pp. 22-23.

European Renewa ble Energy Council. (2011, March) . Mappin energy pathways towards 2020. EREC.

European Renewable Energy Council. (2009, March). Renewable Energy Policy Review. Retrieved October 8, 2013, from European Renewable Energy Council: http://www.erec.org/fileadmin/erec_docs/Projcet_Documents/RES2020/AUSTRIA_RES_Policy_Review_09_Final.pdf

European Renewable Energy Council. (2011, March). Mappin energy pathways towards 2020. EREC.

European Wind Energy Association. (2003). Wind energy - The facts. Cost and prices. Retrieved December 28, 2013, from EWEA: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/WETF/Facts_Volume_2.pdf

Eurostat. (2013 30-October). Share of energy from renewable sources. Retrieved 2013 2-December from http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

EWEA. (2013a). Eastern winds - Emerging European wind power markets. European Wind Energy Association.

EWEA. (2013b). The European offshore wind industry - key trends and statistics 2012. European Wind Energy Association.

EWEA. (2013c). Wind Energy Basics. Retrieved 2013 6-December from European Wind Energy Association: http://www.ewea.org/wind-energy-basics/

ExEA. (2012). CO2 consumption of the forests. Retrieved November 4, 2013, from Executive Environmental Agency: http://eea.government.bg/bg/output/unfccc/2004/ch7/ch71.html

Fagernäs, L., Johannson , A., Wilén , C., Sipillä, K. , Mäkinen, T., Helynen, S., et al. (2006). Bioenergy in Europe: opportunity and barriers. Retrieved January 3, 2014, from VTT: http://www.vtt.fi/inf/pdf/tiedotteet/2006/T2352.pdf

Fechner, H., & Leonhartsberger, K. (2012). National survey report of PV power applications in Austria 2012. International Energy Agency.

FNR. (2006). Biofuels. Guelzow: Fachagentur Nachwachsende Rohstoffe e. V.

FNR. (2013). BIOENERGY the multifaceted renewable energy. Guelzow-Prüzen: Fachagentur Nachwachsende Rohstoffe e. V.

Foederal erneuerbar. (2012). Bioenergie. Retrieved November 15, 2013, from Bundelaender mit neuer Energie: http://www.foederal-erneuerbar.de/landesinfo/bundesland/D/kategorie/bioenergie

Fritsche, U., Fehrenbach, H., Köppen, S., Adolf, J., & Liebig, D. (2012). Nach Super E10: Welche Rolle für Biokraftstoffe? Shell Oil Deutschland.

Fytikas, M., & Arvanitis, A. (2009). Geothermal Potential in South-east Europe. Aristotle University of Thessaloniki, Department of Geology.

Garcia, R., & Calantone, R. (2001). A critical look at technological innovation typology and innovativeness terminology: a literature review. The Journal of Product Innovation Management , pp. 110-132.

Gatignon, H. et al. (2002). A structural Approach to Assessing Innovation: Construct Development of Innovation Locus, Type and Characteristics. Management Science, Vol.48, Issue 9, pp. 1103-1122.

GEOELEC. (2013a). About Geothermal Electricity. Retrieved 2013 19-December from: http://www.geoelec.eu/about-geothermal-electricity/

GEOELEC. (2013b). Factsheets on Geothermal Electricity. EGEC.

GEOELEC. (2013b). Factsheets on Geothermal Electricity. EGEC.

Ghita, S. A. (2013, September 23). Disruptive energy technologies. (A. Stoiciu, Interviewer) Bucharest, Romania.

Government of Bulgaria (2011). Energy Strategy of the Republic of Bulgaria till 2020. For reliable, efficient and cleaner energy. June 2011. Retrieved June 16, 2014, from Government of Bulgaria: http://www.mi.government.bg/files/useruploads/files/epsp/23_energy_strategy2020Eng_.pdf

Govindarajan, V., & Kopalle, P. (2006 b). The Usefulness of Measuring Disruptiveness of Innovations Ex Post in Making Ex Ante Predictions. The Journal of Product Innovation Management , pp. 12-18.

Green, S. (1995, August). Asessing a Multidimnesional Measure of Radical Technological Innovation. IEEE Transactions on Engineering Management, pp. 203-214.

GtV-BV. (2013). Use of Geothermal Energy in Germany. Retrieved December 21, 2013, from German Geothermal Association: http://www.geothermie.de/wissenswelt/geothermie/in-deutschland.html

GWEC. (2012). Global Wind Report Annual market update 2012. Global Wind Energy Council.

Hamilton, W., Wagner, L., & Wessely, G. (2000, July). Oil and gas in Austria. Mitt. Oesterr. Geol. Ges. (92) . Vienna, Austria.

Henderson, R., & Clark, K. B. (1990). Architectural innovation: The reconfiguration of existing product technologies and the failure of estabilished firms. Administrative Science Quarterly , pp. 9-22.

Herrmann, A., et al. (2006). Determinants of radical product innovations. European Journal of Innovation Management, Vol.8, No.1, pp. 20-43.

Hidroelectrica. (2011). Annual Report. Hidroelectrica.

Hill, C., & Rothaermel, F. (2003). The Performance of Incumbent Firms in the Face of Radical Technological Innovation. Academy of Management Review , pp. 257-274.

Hinovski, I. (2012, February 10). Electricity from Biomass - A resources for 500MW. Retrieved November 9, 2013, from Economy News: http://www.economynews.bg/%D1%82%D0%BE%D0%BA-%D0%BE%D1%82%D0%B1%D0%B8%D0%BE%D0%BC%D0%B0%D1%81%D0%B0%E2%86%92-500mw-%D1%80%D0%B5%D1%81%D1%83%D1%80%D1%81-news30406.html

Hinrichs-Rahlwes, R. (2012). Renewable Energy Development in Germany (Status and Outlook). Berlin: Bunderverband Erneuerbare Energie e.V. (BEE).

Hoeller, S. (2013 23-October). Disruptive potential of renewable energy sources in Germany. (M. Totev, Interviewer)

http://www.aboutbioenergy.info/definition_characteristics.html

IEA Bioenergy. (2009a). Bioenergy - a Sustainable and Reliable Energy Source. Utrecht: International Energy Agency Bioenergy.

IEA Bioenergy. (2009b). Biorefineries: adding value to the sustainable utilisation of biomass. International Energy Agency.

IEA Bioenergy. (2013 1-January). Biorefining – Sustainable Processing of Biomass into a Spectrum of Marketable Biobased Products and Bioenergy. Retrieved 2013 29-October from http://www.ieabioenergy.com/task/biorefining-sustainable-processing-of-biomass-into-a-spectrum-of-marketable-biobased-products-and-bioenergy/

IEA WIND. (2013). Annual Report 2012. International Energy Agency.

IEA. (2007). Energy Technology Essentials, ETE03, Biomass for power generation and CHP. International Energy Agency.

IEA. (2008a). Energy technology perspectives: Scenarios and strategies for 2050. Paris: International Energy Agency.

IEA. (2008b). The handbook of biomass combustion and co-firing. International Energy Agency.

IEA. (2010a). Renewable Energy Essentials: Hydropower. International Energy Agency.

IEA. (2011a). Solar Energy Perspectives. International Energy Agency.

IEA. (2011b). Technology Roadmap Geothermal Heat and Power. International Energy Agency.

IEA. (2012b). Technology Roadmap Hydropower. International Energy Agency.

IEA. (2012c July). Technology Roadmap: Solar Heating and Cooling. Retrieved 2013 14-December from International Energy Agency: http://www.iea.org/publications/freepublications/publication/name,28277,en.html

IEA. (2013b). Technology Roadmap Wind Energy. International Energy Agency.

IEA. (2013c). Wind power. Retrieved 2013 5-December from International Energy Agency: http://www.iea.org/topics/windpower/

IEA-PVPS. (2013). Trend in Photovoltaic applications . International Energy Agency.

IEA-SHC. (2012). Country Report - Germany. Retrieved 2013 15-December from International Energy Agency : http://www.iea-shc.org/country-report-germany

IEE. (2012). CrossBorder Bioenergy. Intelligence Energy Europe.

IGA. (2010). Bulgaria - Direct Uses. Retrieved 2013 20-December from International Geothermal Association: http://www.geothermal-energy.org/geothermal_energy/direct_uses/bulgaria.html

Infrastructure.bg. (2013 18-July). "District Heating Burgas" invests in biomass cpacities. Retrieved 2013 11-November from http://infrastructure.bg/show.php?storyid=2105225

Institutul National de Statistica. (2013, July 4). Comunicat de presa privind rezultatele definitive ale Recensamântului Populatiei şi al Locuintelor – 2011 (caracteristici demografice ale populatiei). Recensamantul populatiei si al locuitorilor . Romania.

International Energy Agency. (2000). Experience curves for energy technology policy. OECD/IEA.

International Energy Agency. (2011). International Energy Agency Country Statistics. Retrieved 12 01, 2013, from International Energy Agency: http://www.iea.org/statistics/statisticssearch/report/?&country=AUSTRIA&year=2011&product=ElectricityandHeat

International Energy Agency. (2011). Romania: electricity and heat for 2011. Retrieved December 26, 2013, from IEA: http://www.iea.org/statistics/statisticssearch/report/?&country=ROMANIA&year=2011&product=ElectricityandHeat

IRENA. (2013). Renewable Power Generation Costs in 2012: An Overview. International Renewable Energy Agency.

ISM. (2013). Research project on disruptive technologies in the energy market. Institute for Strategic Management.

Kalt, G., & Kranzl, L. (2009, March). Renewable energy in the heating and cooling sector in Austria. Retrieved October 25, 2013, from RES-H Policy: http://www.res-h-policy.eu/RES-H_Policy_Market-Report-AT-Styria_(D3)_english.pdf

Kardashliev, T. (2013 14-October). Potential of new technologies in the bioenergy sector to disrupt the energy market.. (M. Totev, Interviewer)

Keller, A., & Hüsig, S. (2009). Ex ante identification of disruptive innovations in the software industry applied to web applications: the case of Microsoft's vs. Google's office applications. Technological Forecasting and Social Change , pp. 1044–1054.

KEMA. (2009). Technical status of biomass co-firing. Arnhem: International Energy Agency.

Kiryakov, V. (2013 8-October). Potential of renewable energy technologies in Bulgaria. (M. Totev, Interviewer)

Klenner et al. (2013). Ex-ante evaluation of disruptive susceptibility in established value networks – When are markets ready for disruptive innovations? Research Policy, Vol.42, pp. 914-927.

Kohlenbach, P. (2012). Solar Thermal Energy in Germany. Federal Ministry of Economics and Technology.

Kolb, T. (2011). Country Report Germany for IEA Task 33 Thermal Gasification of Biomass. International Energy Agency.

Koleva, D. (2012). Legal analysis of the situation . Sofia: Energy Lawyers.

KPMG International. (2012). Taxes and incentives for renewable energy. KPMG.

Markides, C. (2006). Disruptive Innovation: In Need of Better Theory. Product Innovation Management , pp. 19-25.

Markova, D., Platikanov, S., Konstantinoff, M., & Tsankov, P. (2011). Opportunities for Using Renewable Energy Sources in Bulgaria. Contemporary Materials (Renewable energy sources) , 178-184.

Massachusetts Environmental Energy Alliance. (2013). The harmful impacts of biomass energy generation: undermining the fight against global warming. Retrieved January 30, 2014, from Massachusetts Environmental Energy Alliance: http://massenvironmentalenergy.org/docs/biomass%20factsheet%20from%20MEEA.pdf

MEE. (2007). National Long-term Programme to Ecnourage the Use of Biofuels in the Transport Sector 2008 - 2020. Sofia: Ministry of Economy and Energy.

MEE. (2008). National Long-term Programme to Encourage the Use of Biomass for the Period 2008-2020. Sofia: Ministry of Economy and Energy.

MEET. (2011a). National Renewable Energy Action Plan. Sofia: Ministry of Economy, Energy and Tourism.

MEET. (2011b). Report on the Achievement of the National Indicative Targets for the Use of Biofuels and Other Renewable Fuels in the Transport Sector in 2010. Sofia: Ministry of Economy, Energy and Tourism.

Meyer, R., & Trandafir, D. (2013, August 7). Renewable energy: Romania and legislative instability. Retrieved September 24, 2013, from Hot News: http://english.hotnews.ro/stiri-business-15334553-renewable-energy-romania-and-legislative-instability.htm

Ministerul Economiei, NL Agency, ENERO Romania. (2010, June 20). Master Plan Biomasa pentru Romania. Retrieved January 22, 2014, from Ministerul industriilor: http://www.minind.ro/biomasa/Plan_de_Actiune_pentru_Biomasa.pdf

Ministry of Industry. (2010). Planul Naţional de Acţiune în Domeniul Energiei din Surse Regenerabile (PNAER). Retrieved January 21, 2014, from Ministerul de industrie: http://www.minind.ro/pnaer/pnaer_29%20iunie_2010_final_alx.pdf

Ministry of Industry. (2011). Elements of energetic strategy for 2011-2035. Retrieved November 20, 2013, from Ministry of industry: http://www.minind.ro/dezbateri_publice/2011/strategia_energetica_20112035_20042011.pdf

Ministry of Regional Development and Public Administration. (2012, December 10). Thermical rehabilitation program. Retrieved January 14, 2014, from MDRT: http://www.mdrt.ro/programul-national-privind-cresterea-performantei-energetice-la-blocurile-de-locuinte

Mueller-Syring, G., & Huettenrauch, J. (2012, November 16). Erarbeitung von Basisinformationen zur Positionierung des Energietraegers Erdgas im zukuenftigen Energiemix in Oesterreich. Oesterreichische Vereinigung fuer das Gas und Wasserfach . Leipzig.

National Press Agency. (2014, January 6). The production of renewable energy has reached historic record. Bucharest, Romania.

Neddermann, B. (2013). Wind Energy Development 2012 in Germany Benefits from Repowering. Wilhelmshaven: Deutsches Windenergie Institut.

NGVA Europe. (2013). NG/Biomethane Fuel Specification in Europe. Brussels: UNECE GFV Informal Group.

Novinite. (2013 5-December). Renewables' producer invests 1 billion in our economy. . Retrieved 2013 7-December from Novinite: http://novinite.bg/articles/58094/VEI-proizvoditel-investira-1-mlrd-v-ikonomikata-ni

OECD. (2008). OECD Glossary of Statistical Terms. OECD.

OECD/EUROSTAT. (2005). Oslo Manual. Guidelines forcollecting and interpreting innovation data. The Measurement of Scientific and Technological Activities.Third Edition. Oslo: A joint publication of OECD and Eurostat.

Official Monitor. (2013). Emergency government ordinance. Monitorul oficial , I (335).

Pambuccian, V., & Iusein, I. (2007). Legislative initiative. Retrieved November 8, 2013, from Romanian Chamber of Deputies: http://www.cdep.ro/proiecte/2007/000/90/8/em98.pdf

Pellet Plants. (2012). Wood Pellet Potential in Bulgaria. Retrieved 2013 7-November from Best peletizing solution: http://www.pellet-plants.com/news/pellet_mill/Bulgaria-wood-pellets-market.html

Petkov, I. (2013 30-September). Potential of wind energy techologies in Bulgaria. (M. Totev, Interviewer)

Philibert, C. (2006). Barriers to technology diffusion: the case of solar thermal technologies. International Energy Agency. IES.

Poenaru, E. (2013, 09 18). Costurile experimentului de energie regenerabila din Germania. Retrieved February 28, 2014, from Curs de guvernare:

http://cursdeguvernare.ro/costurile-experimentului-de-energie-regenerabila-din-germania.html

Popadiuk, S., & Choo, C. (2006). Innovation and knowledge creation: How are these concepts related. International Journal of Infomation Management , pp. 302-312.

Popadiuk, S., & Choo, C. W. (2006). Innovation and knowledge creation: How are these concepts related? International Journal of Information Management , 302-312.

Popadiuk, S., & Choo, C. W. (2006). Innovation and knowledge creation: How are these concepts related? International Journal of Information Management , pp. 302-312.

Quaschning, V. (2013, September 26). Disruptive energy technologies. (A. Stoiciu, Interviewer) Vienna, Austria.

Raykov, A. (2013 13-October). Potential of solar energy technologies in Germany. (M. Totev, Interviewer)

Renewable Market Watch. (2013). Bulgaria Biomass Market 2013. First steps are taken. Retrieved November 6, 2013, from Renewable Market Watch: http://renewablemarketwatch.com/news-analysis/78-bulgaria-biomass-market-2013

Rettenmaier, N., Reinhardt, G., Schorb, A., Köppen, S., & von Falkenstein, E. (2008). Status of Biomass Resource Assessments. Freiburg: Biomass Energy Europe.

Reumerman, P. (2013 26-September). The potential of biomass technologies in the EU and Germany. (M. Totev, Interviewer)

Reuters. (2013 5-December). Bulgaria imposes 20 pct fee on solar and wind power. Retrieved 2013 9-December from Reuters: http://www.reuters.com/article/2013/12/05/bulgaria-renewables-idUSL5N0JK1BF20131205

RHC. (2012a). Strategic Research Priorities for Geothermal Technology. European Technology Platform on Renewable Heating and Cooling.

RHC. (2012b). Strategic Research Priorities for Solar Thermal Technology. Brussels: European Technology Platform on Renewable Heating and Cooling.

RHC. (2013). Strategic Research and Innovation Agenda for Renewable Heating & Cooling. European Technology Platform on Renewable Heating and Cooling.

Rogers, E. M. (2003). Diffusion of innovations (Fifth ed.). New York: Free Press.

Rosenbloom, R., & Christensen, C. (1994). Technological discontinuities, organizational capabilities, and strategic commitments. Industrial and Corporate Change , pp. 655-695.

RWEA. (2012, January 23). Romania va absorbi investitii pentru 400-500 MW eolieni pe an. Retrieved January 30, 2014, from Romanian wind energy association: http://rwea.ro/2012/01/23/wall-street-ro-ge-energy-romania-va-absorbi-investitii-pentru-400-500-mw-eolieni-pe-an/

Sainio, L.-M., & Puumalainen, K. (2006). Evaluating technology disruptiveness in a strategic corporate context. Technological forecasting and social change , 1315-1333.

Sandulescu, A. (2010). National Renewable Energy Strategy. Bucharest: Ministry of Economy.

Sanyal, S.K. & Morrrow, J.W. (2012, February 1). Success and the learning curve effect in geothermal well drilling. Thirty-seventh workshop on geothermal reservoir engineering. Richmond, California, USA.

Sav, O. (2013, October 25). Inovatia disruptiva: scurt si cuprinzator. Institutul de marketing .

Schernhammer, A. (2013, September 29). Disruptive energy technologies. (A. Stoiciu, Interviewer) Vienna, Austria.

Schneider, U. (2013, September 26). Potential of biomass technologies in Germany. (M. Totev, Interviewer)

Schumpeter, J.A. (1942). Capitalism, Socialism and Democracy (New York: Harper, 1975)

SEC. (2002). Widening the Use of European Solar Thermal Technologies in Mediterranean Countries Following the Successful Model of Greece and Cyprus. Part B: I, F, RO, BG, TR. Sofia: Sofia Energy Center.

SEC. (2009). Transfer of experience for the development of solar thermal products. Sofia Energy Center.

Sims, R., Taylor, M., Sadler, J., & Mabee, W. (2008). From 1st to 2nd generation biofuel technologies . International Energy Agency. IEA.

Sood, A., & Tellis, G. (2011). Demystifying Disruption: A New Model for Understanding and Predicting Disruptive Technologies. Marketing Science, Vol. 30, No.2, pp. 339-354.

Sood, A., & Tellis, G. J. (2005). Technological Evolution and Radical Innovation. Journal of Marketing , pp. 152-168.

Statista. (2013). Erneuerbare Energien in Deutschland. Statista.

Steiner, M., Pichler, W., & Golser, M. (2009). Pellet market country report: Bulgaria. Vienna: Holzforschung Austria.

Stoiciu, A. (2014). Potential disruptive technologies in the renewable energy sector. An assessment of Austria and Romania. Master thesis, Vienna University of Economics and Business.

Szabo, E. (2014). Assessment of potential disruptive technologies in the natural gas value chain. Master thesis, Vienna University of Economics and Business.

Tellis, G. (2006). Disruptive technology or visionary leadership? Product Innovation Management, Vol.23, Issue1, pp. 34-38.

Tellis, G., Chandy, R., & Prabhu, J. (2012). Key questions on innovation in the B2B context. In G. Tellis, R. Chandy, & J. Prabhu, Handbook on business-to-business marketing (Vols. ISBN 978-184-980-142-3, pp. 582-595). London.

Terra Mileniul III. (2013). Energie regenerabila. Retrieved January 22, 2014, from Terra Mileniul III: http://www.terraiii.ngo.ro/index.stm?apc=ei-r0x1--&x=28288

The Economist. (2014, January 18). Sunny, windy, costly and dirty. Retrieved March 1, 2014, from The Economist: http://www.economist.com/news/europe/21594336-germanys-new-super-minister-energy-and-economy-has-his-work-cut-out-sunny-windy-costly

The Federal Government. (2012). Biorefineries Roadmap. Berlin: The German Federal Government.

Tinteanu, G. (2013, September 26). UE îngroapă afacerile fermierilor şi producătorilor de biocombustibili. Retrieved January 22, 2014, from Capital: http://www.capital.ro/186998.html

Totev, M. (2014). Disruptive potential of new technologies in the energy markets of Bulgaria and Germany. Master thesis, Vienna University of Economics and Business.

TPA Horvath. (2013, May). Wind energy and other renewable energy sources in Romania. Retrieved January 12, 2014, from http://www.wall-street.ro/files/149896-446.pdf

Trabish, H. (2013, April 17). Geothermal energy industry looks to confront investment risk. Retrieved January 22, 2014, from The energy collective: http://theenergycollective.com/hermantrabish/211016/geothermal-looks-confront-risk

Transelectrica. (2014, January). Press release. Retrieved January 12, 2014, from Transelectrica: http://vvv.transelectrica.ro/media.php

Transgaz. (2013, May 15). Natural Gas Transmission – Challenges and Opportunities. Retrieved January 12, 2014, from CRENERG: http://www.crenerg.org/conf-15.05.2013/MARES_TRANSGAZ_Bruxelles%20-%2015%20May,%202013.pdf

Trans-Solar. (2009). BULGARIAN NATIONAL REPORT. Center for Renewable Energy Sources (CRES).

Universitatea Tehnica Cluj. (2008). Energia solara in Romania. Retrieved January 20, 2014, from Cluj technical university: http://www.termo.utcluj.ro/regenerabile/2_1.pdf

Uslu, A., Faaij, A., & Bergman, P. C. (2008). Pre-treatment technologies, and their effect on international bioenergy supply chain logistics - Techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation. Energy , 1206-1223.

Utterback, J. M. (1996). Mastering the Dynamics of Innovation. Boston: Harvard Business Press.

Utterback, J., & Acee, H. (2005). Disruptive Technologies: An expanded view. International Journal of innovation Management , pp. 1-17.

Van Strien, W. (2013, October 3). Potential of Solar energy techologies in Europe. (M. Totev, Interviewer)

Vasiescu, A. (2013, September 25). Avem nevoie de retehnologizare nu de investitii noi in productia de energie. Retrieved January 22, 2014, from Bursa: http://www.bursa.ro/companii-afaceri/conferinta-bursa-energia-in-priza-borza-hidroelectrica-avem-nevoie-de-retehnologizare-nu-de-inves...&articol=217623.html

Vladescu, M. (2013, September 21). Disruptive energy technologies. (A. Stoiciu, Interviewer) Bucharest, Romania.

Waldner, W. (2010). The Proneness of Network Industries to Disruptive Innovations: Case Study of the European Airline Industry. Dissertation. Wien: WU Wien.

Wiesen, K. (2013 22-October). Potential of new renewable energy technologies in Germany. (M. Totev, Interviewer)

WindEIS. (2013). Wind Energy Basics. Retrieved 2013 6-December from Wnd Wnergy Development Programmatic EIS: http://windeis.anl.gov/guide/basics/

Winkel, T., Rathmann, M., Ragwitz, M., Steinhilber, S., Winkler, J., Resch, G., et al. (2011, November). Renewable Energy Policy: Country Profiles. Retrieved

October 22, 2013, from Re-Shaping: http://www.reshaping-res-policy.eu/downloads/RE-Shaping_CP_final_18JAN2012.pdf

WWINDEA. (2013). The Structure of a Modern Wind Turbine – An Overview. Retrieved 2013 7-December from World Wind Energy Association: http://www.wwindea.org/technology/ch01/en/1_2.html

Yu, D., & Hang, C. C. (2010). A Reflective Review of Disruptive Innovation Theory. International Journal of Management Reviews , pp. 435-452.