The Greening of Jobs

Empirical Studies on the Relationship between Environmental Sustainability and the Labor Market

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"One problem today is that people think protecting the environment will be so costly and so hard that they want to ignore the problem and pretend it doesn't exist. Humans are capable of amazing accomplishments if we set our minds to it."

Paul Romer
American Economist, co-recipient of the 2018 Nobel Memorial Prize in Economic Sciences.
Quote at a press conference after the 2018 Nobel Memorial Prize in Economics announcement (Appelbaum 2018).

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List of abbreviations

BA	Bundesagentur für Arbeit (German Federal Employment Agency)
BeH	Beschäftigten-Historik (Employment History: Administrative employee-microdata of the IAB), see also Antoni et al. (2016).
BHP	Betriebs-Historik-Panel (Establishment History Panel: Administrative employer-microdata of the IAB), see also Gruhl et al. (2012).
BLS	U.S. Bureau of Labor Statistics
BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
BMU	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (German Federal Ministry of the Environment, Nature Conservation and Nuclear Safety)
BMWI	Bundesministerium für Wirtschaft und Energie (German Federal Ministry for Economic Affairs and Energy)
Cedefop	European Centre for the Development of Vocational Training
Destatis	Statistisches Bundesamt (Federal Statistical Office of Germany)
DOC	United States Department of Commerce
DOL	United States Department of Labor
EC	European Commission
EEG	Erneuerbare-Energien-Gesetz (German Renewable Energy Sources Act)
EGSS	Environmental Goods and Services Sector
EU	European Union
Eurostat	Statistical Office of the European Union
FAO	Food and Agriculture Organization of the United Nations
FDZ	Forschungsdatenzentrum (Research Data Center of the BA at the IAB)
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GOJI	Greenness-of-Jobs Index
IAB	Institut für Arbeitsmarktforschung der Bundesagentur für Arbeit (Institute for Employment Research of the German Federal Employment Agency)
IFAD	International Fund for Agricultural Development of the United Nations
IMF	International Monetary Fund
KldB2010	Klassifikation der Berufe, Ausgabe 2010 (German Classification of Occupations, Edition 2010), see also BA (2015a)
OECD	Organisation for Economic Co-operation and Development
RE	Renewable Energy
RNE	Rat für Nachhaltige Entwicklung (German Council for Sustainable Development)
SCBD	Secretariat of the Convention on Biological Diversity (SCBD)
SDGs	Sustainable Development Goals of the United Nations' Agenda 2030
SIAB	Sample of Integrated Labor Market Biographies, see also Antoni et al. (2006).
UBA	Umweltbundesamt (German Federal Environmental Agency)
UCLG	United Cities and Local Governments
UN	United Nations
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNICEF	United Nations International Children's Emergency Fund
WFP	World Food Programme
WHO	World Health Organization
WZ 2008	Klassifikation der Wirtschaftszweige, Ausgabe 2008 (German Classification of Economic Activities, Edition 2008), see also Destatis (2008)

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Abstract

Along the debate about necessary actions for environmental and climate protection, there is an ongoing discussion whether this transition towards environmental sustainability is linked to negative or positive labor market outcomes. So far, however, most studies on the relationship between environmental sustainability and the labor market have used either aggregated statistical data or only survey data. For in-depth analyses, there is a lack of appropriate microdata. This doctoral thesis presents different approaches to fill this gap by introducing new methods to identify green jobs or the greenness of jobs in administrative microdata. Based on innovative data sources, I contribute new insights on the associations between environmental protection and direct labor market outcomes. Besides a comprehensive literature review and the conceptual framework, the thesis presents four empirical studies, examining sector-specific wage differentials in renewable energy value chains, the role of innovation and agglomeration for employment growth in the environmental sector, the measurement of the greenness and greening of jobs, and the labor market outcomes linked to the greenness and greening of jobs. The studies are based on German administrative employment data at micro-level, survey data of the IAB Establishment panel and text-mining results. The empirical strategies applied prove their usefulness to identify and analyze the associations between environmental sustainability and the labor market.

1 Introduction

1.1 Motivation

Today's global community is facing a number of serious environmental problems, such as anthropogenic climate change (Stern 2008; IPCC 2014; Dunlap/Brulle 2015; IPCC 2018), regional food and water crises (FAO et al. 2018; UNICEF et al. 2018; FAO et al. 2017; Wheeler/Braun 2013), loss of biodiversity and shortages of natural resources (SCBD 2014). To mitigate these problems, national and international institutions have launched manifold initiatives and programs with more or less binding goals.

In recent decades, most of these approaches have been discussed together under the common normative concept of *"sustainability"* or, to be more precise, *"environmental sustainability"*. Several practical approaches have been developed to implement the principles of sustainability in the economic context. The most prominent examples are the concepts of the green economy, the green growth, and the circular economy. At the same time growth-critical concepts such as the degrowth paradigm have emerged. The approaches differ, in some cases quite considerably, with regard to their values and agendas, but they share the common vision of establishing a low-carbon economy that is environment-friendly and conserves the natural resources for future generations.

One of the most prominent aspects of these transitions towards environmental sustainability and a "greener" economy is their current and future impact on employment and occupations. For example, the International Labor Organization (ILO) estimates that the transition to a greener economy affects about 1.5 billion people, i.e., half of the global workforce (ILO 2012). So-called "green jobs" play a crucial role in this debate. They are expected to help solving current environmental problems and mitigate climate change while – depending on the precise definition of green jobs – increasing international competitiveness and creating decent jobs. Current research also addresses these phenomena (e.g., Consoli et al. 2016; Gagliardi et al. 2016; Cecere/Mazzanti 2017; Horbach/Jacob 2018; Vona et al. 2018; Bowen/Kuralbayeva 2018). Yet, the underlying subject is not new at all: since the 1970s many papers have been published about the relationship between environmental protection and the labor market (e.g., Paelinck 1976; Sprenger/Britschkat 1979; Meißner 1979; Kabelitz 1980).

Despite decades of work on this research topic, there are still major gaps with regard to the relationships between environmental sustainability and the labor market. There is an ongoing scientific debate about whether environmental protection, especially when supported by statutory regulation, is linked to negative or positive labor market outcomes in terms of employment and wages.

Closely linked to this question is the methodological question of how environmental protection activities and related actors or occupational changes can be identified in administrative labor market data. A particular challenge is that the relevant actors in the "environmental goods and services sector" (EGSS) or—even more broadly—the "green economy" cannot be identified directly in statistical classifications. Due to their cross-sectional nature, they cannot be directly assigned to individual economic activities or occupational classes. For example, ball bearing manufacturers can sell their goods for the construction of both wind turbines and fossil fuel power plants. Or, to give an example in the occupational context, chimney sweeps now perform numerous environmental protection tasks in addition to classic chimney-sweeping and fire-protection tasks. It is even more difficult to measure the level and growth of "greenness" of jobs over time.

1.2 Synopsis / Outline

To tackle these challenges, the thesis contributes new empirical evidence to the discussion about the associations of environmental sustainability and the labor market. As a prerequisite for this, the thesis also explores innovative approaches to identify the transitions towards environmental sustainability in administrative labor market data.

The two key questions of this thesis are: What are the associations between transitions towards environmental sustainability and labor market outcomes and, how can these transitions be identified in administrative labor market data? To answer these questions, I start with a bird's eye view, providing a detailed literature review, followed by four essays addressing exemplary subjects in the context of the associations between environmental sustainability and the labor market. In the first essay, I start with only one but very essential subfield of the EGSS, the renewable energies, focusing on sector-specific wage differentials. The second essay covers the entire EGSS, analyzing the role of innovation and agglomeration for employment growth in the EGSS. The third and fourth essay deal with the economy as a whole and examine the greening of occupations and its relationships to employment and wages. The data sources used vary widely, ranging from administrative labor market data from the German Establishment History Panel and the German Employment History, to survey data from the IAB Establishment Panel and text mining results derived from the occupational expert database BERUFENET. Within these studies, I present three different approaches, all of which facilitate the identification of environment-related establishments and occupations in administrative labor market data: the data-linkage with external firm-level data (chapter 3), the analysis of EGSS-specific survey data (chapter 4), and the development of the text-mining based Greenness-of-Jobs Index (GOJI) (chapters 5 and 6).

The four chapters can be outlined as follows:

The hidden winners of renewable energy promotion: insights into sector-specific wage differentials

In the context of Germany's energy turnaround efforts, this chapter examines differences between renewable energy establishments and their sector peers in terms of their employment structures and wage differentials. The chapter is based on an article that was written together with Manfred Antoni and Florian Lehmer, in which my co-authors and I answer the following research questions: do wages differ between renewable energy (RE) establishments and others? If so, what are the determinants of these wage differentials and how do they differ between sectors? Do these wage differentials merely reflect differences in establishment characteristics or do they reflect other external influences, such as the promotion of RE sources? To tackle these questions, we developed a novel data set by linking company-level information from the German Renewable Energy Federation with administrative establishment-level data from the Institute for Employment Research. The descriptive evidence shows significant differences between renewable energy establishments and their sector peers with regard to wages and several other characteristics. Our estimates provide evidence that the wage differential between manufacturers and energy providers is mainly explained by human capital and other establishment-level characteristics. However, we find a persistent "renewable energy wage premium" of more than ten percent in construction/installation activities and architectural/engineering services. We interpret this premium as a positive indirect effect of the promotion of renewable energies that benefits employees in renewable energy establishments within these two sectors.

The role of innovation and agglomeration for employment growth in the environmental sector

The environmental sector is supposed to yield a dual benefit: its goods and services are intended to tackle environmental challenges while its establishments should create new jobs. However, it is still unclear in empirical terms whether that really is the case. Neoclassical approaches predict rather negative employment effects due to increasing costs for environmental protection activities. On the other hand, several scholars such as Porter/Van der Linde (1995) stress the potentials for establishments to improve their competitiveness—and thus their economic performance in general—due to innovation induced by environmental regulation.

In this chapter, based on an article published together with Jens Horbach, we investigate the extent to which employment growth in establishments with green products and services is higher compared to other establishments. Furthermore, we analyze the main factors determining labor demand in this field. The analysis is based on linked employment and regional data for Germany. The descriptive results show that the environmental sector is characterized by disproportionately high employment growth. The application of a generalized linear mixed model reveals that especially innovation and industry agglomeration foster employment growth in establishments in the environmental sector. Establishments without green products and services show a smaller increase in employment, even if they are also innovative.

The Greenness-of-Jobs Index (GOJI): measuring the greening of jobs by a text mining based index and employment statistics data

The transition towards a greener, less carbon-intensive economy is supposed to lead to a greening of jobs, i.e., to an increasing percentage of environmentally friendly requirements within occupations and to a rising demand for labor in these occupations.

Thus far, to what extent the greening of occupations is occurring and how it is distributed over occupational aggregates, sectors and regions remain open questions. To measure the greening of jobs, the paper introduces the new task-based *Greenness-of-Jobs Index* (*GOJI*) and provides first descriptive statistics. I derive the GOJI by performing text-mining algorithms on yearly data from 2011 to 2016 of BERUFENET, an occupational database provided by the German Federal Employment Agency. Using employment statistics data, the descriptive results show a notable greening of jobs, which varies greatly between occupational aggregates, sectors and regions.

The greening of jobs and its labor market impacts: first evidence from a text-mining based index and employment register data

In the last years, the percentage of environmentally friendly requirements within occupations has increased considerably. In many countries, the ongoing strive towards environmental sustainability is supposed to lead to a rising demand for labor in these green or greening occupations. But is there really an increasing demand for these occupations? It is not clear yet, whether the greenness and greening of occupations affects employment and wages within these occupations. To fill this gap, the chapter analyzes the level and growth of the greenness of jobs and its relationship with employment and wage growth. The key element of this analysis is the new task-based GOJI, presented in the previous chapter. The econometric analysis is based on employment register data from 2011 to 2016. The estimation results reveal that the overall level of greenness of occupations is positively correlated with employment growth. Furthermore, the increase of greenness is related to a slight increase in wage growth.

The remainder of the thesis is organized as follows: Chapter 2 introduces the overall topic of "Environmental sustainability and the labor market" including a detailed literature overview. Chapters 3 to 5 comprise the four essays introduced above with different perspectives on the general subject: while chapter 3 examines sector-specific wage differentials in the context of renewable energy value chains, chapter 4 addresses the entire field of the environmental goods and services sector (EGSS) and analyzes the role of innovation and agglomeration for employment growth in this sector. Chapters 5 and 6 cover the economy as a whole. Chapter 5 introduces the GOJI, a new index to measure the greenness of jobs. Chapter 6 analyzes the relationships between the level and growth of the GOJI and labor market outcomes. Chapter 7 summarizes the main findings of this thesis, shows interrelationships between them and discusses possible policy implications.

2 Labor market relations of environmental sustainability—basic concepts and identification

This chapter aims to provide an overview of the conceptual framework of the dissertation and to place the specific research topics of the subsequent chapters in the overall context. The main questions addressed in this chapter are: What are the basic concepts that should be taken into account when analyzing the relationship between environmental sustainability and the labor market? What approaches are currently used to measure green jobs? Consequently, this chapter does not deal with all aspects of indirect labor market effects and net employment effects. This very important topic goes beyond the scope of my dissertation. There is already a great deal of literature on this subject. See Jacob et al. (2015) for a comprehensive literature review.

The chapter begins with an introduction to the main guiding principle of sustainability and the political framework of sustainable development. The second subsection presents major green economic paradigms aimed at environmental sustainability. An overview of the environmental challenges as well as key drivers of environmental sustainability is provided in the third subsection, while the fourth subsection discusses literature about (direct) labor market effects of environmental sustainability. The fifth subsection reviews approaches to identify and measure impacts of environmental sustainability on the labor market. The sixth and final subsection concludes with a schematic illustration connecting the conceptual framework with the empirical studies presented in the subsequent chapters.

2.1 Sustainability and sustainable development

2.1.1 Origin and definition

The notions of *sustainability* and *sustainable development* have become widely popular since their introduction in the so called "Brundtland Report" (Brundtland Commission 1987). In the light of the discussion surrounding the limits of growth and resources (e.g., Meadows et al. 1972), the Brundtland Commission defines sustainable development as "… development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland Commission 1987: 46). Hence, the normative basis of sustainability is the striving for justice for present and future generations (von Hauff/Kleine 2009). Whereas *sustainability* is the normative foundation, *sustainable development* deals with the strategies and policy measures necessary to achieve the desired state of sustainability.

The term "sustainability" comes from the Latin term "sustinere" (sus: up; tenere: to hold). According to current dictionaries, the primary meaning of "to sustain" is "to support", "to bear" or "to endure".[1] The underlying concept of sustainability is not new: it has long been used in the field of forestry. For instance, the early German adjective for sustainable, "nachhaltend", was already used in the context of forestry about three hundred years ago by von Carlowitz (1713: 105-106; see also Grober 2010).[2] The general idea of sustainability in forestry is that there should be a balance between deforestation and

[1] See also http://www.dictionary.com/browse/sustain (last accessed on Oct 31, 2018).

[2] *„Wird derhalben die größte Kunst/Wissenschaft/Fleiß und Einrichtung hiesiger Lande darinnen beruhen/ wie eine sothane Conservation und Anbau des Holtzes anzustellen / daß es eine continuierliche beständige und* ***nachhaltende*** *Nutzung gebe / weiln es eine unentberliche Sache ist / ohne welche das Land in seinem Esse nicht bleiben mag"* (Carlowitz, 1713: 105-106; marked in bold by the author).

reforestation, or, to put it simply, no more trees may be felled than have been newly planted in the same period (Grober 2010). An important achievement of the Brundtland Report was to transfer the principle of sustainable forestry sustainability to general topics of global development. (Brundtland Commission 1987).

The Brundtland Report paved the way for the UN Conference on Environment and Development in Rio de Janeiro 1992. This conference is considered historic, as it was the first time that several agreements for a global environment and development partnership were adopted under the guiding principle of sustainability. The definition of sustainable development used in the Brundtland report comprises two essential concepts of generational justice. “It [sustainable development] contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.”(Brundtland Commission 1987: 46). Both concepts are clearly anthropocentric (von Hauff/Kleine 2009). The first concept is known as intragenerational justice, i.e., striving for a more equal distribution of material and immaterial resources and development opportunities within and between nations (Glotzbach/Baumgärtner 2012; Baumgärtner/Quaas 2010; Barry 1997; Brundtland Commission 1987). The second concept is referred to as intergenerational *justice*, i.e., conserving natural and/or human-made capital to facilitate the fulfilment of needs of future generations (Solow 1974; Hartwick 1977, 1978a, 1978b; Solow 1986).

2.1.2 The three dimensions of sustainability

Pillars vs. dimensions

Since the Brundtland Report was published, the scope of sustainable development has become more and more differentiated. Whereas the initial report focused mostly on sustainability in general (Brundtland Commission 1987), the follow-up documents often refer to three or more dimensions of sustainability. The most commonly used distinction in terms of the dimensions of sustainability is that based on the three-pillar principle comprising *environmental*, *economic* and *social sustainability*. (e.g., Enquete-Kommission 1998; Barbier 1987). Some authors criticize the term “pillar” as evoking a too rigid image of topics that cannot relate to each other. This might be a reason why the word “pillar” is replaced by “dimension” in several publications (e.g., Krajnc/Glavič 2005; Labuschagne et al 2005; Singh et al 2012). In the remainder of this dissertation I use the notion of “dimensions of sustainability”, because I would like to emphasize the potential overlaps within the concept of sustainability.

Equal priorities vs. primacy of environmental sustainability

In contrast to the basic concept of three dimensions with equal priority, the ecologically dominated concept distinctly emphasizes the environmental dimension of sustainability. Proponents of this approach argue that ecosystems are the basis of life and economic activity and thus play an overriding role. In this sense, economic and social sustainability are based on environmental sustainability and must be subordinated in cases of conflicting interests (von Hauff/Kleine 2009).

Excursus: Ecological, economic and social capital in the context of sustainability

I follow the approach of von Hauff/Kleine (2009) and use the capital-based distinction to explain the three dimensions of sustainability. The following sections shed some light on these three dimensions and also examine their correlations with labor and employment. But prior to that, I present a short excursus on the relationship between sustainability and capital, which is an important distinction when defining the dimensions of sustainability.

Hediger (2000) introduces a welfare function that integrates "principles of basic human needs ('critical economic capital'), integrity of the ecosystem ('critical ecological capital') and the socio-cultural system ('critical social capital')" and describes the restrictions of the social opportunity space in which sustainable development can be achieved. He uses the adjective "critical" as the minimum level of cohesion beyond which the economic, ecological or social system is at risk of collapsing.

In the context of sustainability, Hediger (2000: 485) defines social welfare U "as an increasing function of aggregate income Y, macroeconomic stability M, social capital S, and ecological capital Q (footnote: U_Y and U_{YY} etc. denote the first-order and second-order derivatives of U with respect to Y, etc.)":

Socio-ecological-economic value function according to Hediger (2000):

$$U = U(Y, M, S, Q) \text{ with } U_Y, U_M, U_S, U_Q > 0, U_{YY}, U_{MM}, U_{SS}, U_{QQ} \leq 0 \quad (2.1)$$

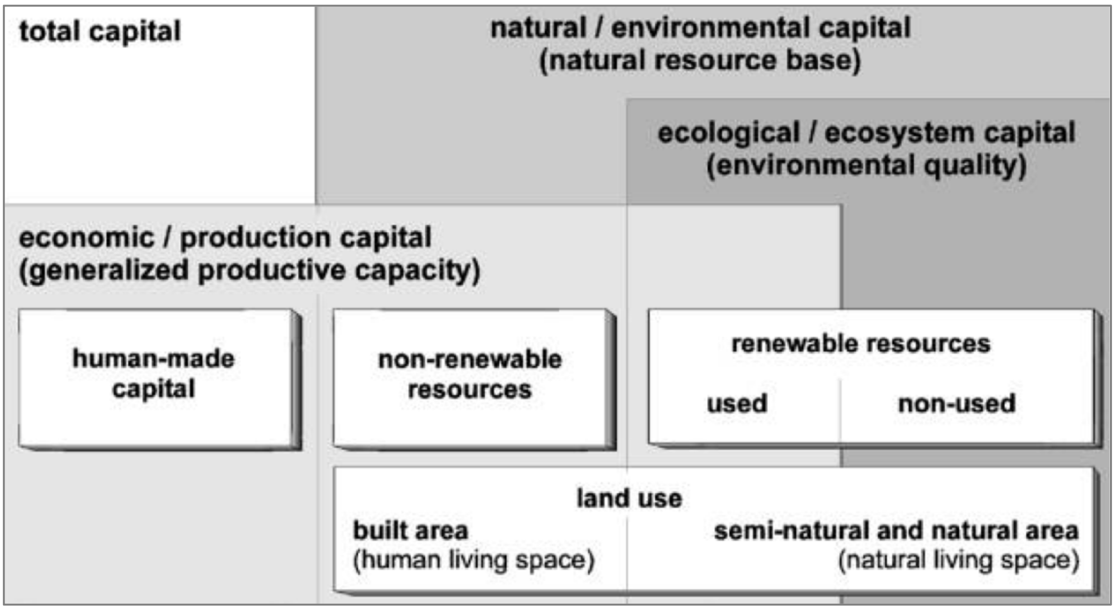
According to the sustainability-related literature (Hediger 2000; von Hauff/Kleine 2009), *social capital* comprises health, literacy, life expectancy, cultural and social integrity, and social cohesion. These features are in line with current publications from political science, which call for a social capital approach that aims to satisfy basic needs, to promote social integration and to facilitate the further development of society (von Hauff/Kleine 2009, Empacher/Wehling 2002).

Ecological capital—or ecosystem capital—comprises "the total of renewable resource stocks (both used and non-used in economic production), semi-natural and natural land areas, as well as ecological factors, such as nutrient cycles, climatic conditions, and the resilience of ecosystems. This is the part of natural capital which determines the overall quality of the ecosystem." (Hediger 2000: 483). This notion is closely related to natural capital (or environmental capital) which the author defines as "the natural resource base of a geographic area. It consists of the ecological capital and stocks of non-renewable resources" (Hediger 2000: 483). As Figure 2-1 shows, Hediger (1999: 1124) also includes the land use of built area (human living space) as an element of natural / environmental capital.

Furthermore, Hediger (2000: 483) defines economic capital as "as an economy's generalized productive capacity; that is, the potential to generate income. It consists of manufactured capital (machines and buildings), immaterial assets (knowledge and knowhow, social organization, institutions, and the state of technology), and natural resources (including non-renewable resources, renewable resources, and land) that are harvested or developed for use in economic transformation processes. Correspondingly, economic capital does not include ecological assets that are not directly used, but that are essential for the functioning of the ecosystem."

In the following figure, Hediger (1999: 1124) illustrates the aggregates of economic and environmental capital:

Figure 2-1: Aggregates of economic and environmental capital



Source: Hediger (1999: 1124; Part of Figure 1)

Environmental sustainability

According to von Hauff/Kleine (2009), *ecological sustainability* aims to preserve the ecological system, or the ecological capital stock, as the basis of human life.

The authors use the notion of ecological sustainability and consequently refer to the definition of ecological capital as formulated by Hediger (1999). In the literature, *environmental sustainability* and *ecological sustainability* are mostly treated as synonyms in the literature. Transferring the approaches of Hediger (1999, 2000) and Hauff/Kleine (2009) to the field of environmental capital and environmental sustainability, yields the following definition of *environmental sustainability, which* I use for the remainder of this work:

Environmental sustainability aims to preserve the natural resource base of a geographic area, including the ecological capital and stocks of non-renewable resources and the land use of built area (human living space) (von Hauff/Kleine 2009; Hediger 1999, 2000: 483, 1124).

2.1.3 Weak vs. strong sustainability

To define sustainability properly, another important distinction has to be drawn: the distinction between weak and strong sustainability. In the academic fields of neoclassical environmental economics and ecological economics, there is a long-standing controversy about weak versus strong sustainability.

The concept of "weak sustainability" assumes that non-renewable natural capital and human-made capital is fully substitutable. In the sense of this definition, an economy fulfils the requirements of (weak) sustainability as long as it replaces the non-renewable resources it has consumed with man-made capital, such as buildings, roads, etc. (von Hauff/Kleine 2009; Neumayer 2003). This paradigm is mainly based on the neoclassical growth theory, particularly on the works of Solow (1974, 1986, 1993) and Hartwick (1977, 1978a, 1978b). The concept of "strong sustainability", on the other hand, assumes that the types of capital are complimentary to each other. Accordingly, an economy fulfils the requirements of (strong) sustainability if each type of capital increases or does not decrease, respectively. The focus here is in particular on (non-renewable) ecological capital (von Hauff/Kleine 2009; Neumayer 2003). Neumayer therefore also refers to weak sustainability as a "substitutability paradigm" (2003: 1) and strong sustainability as a "non-substitutability paradigm" (Neumayer, reference as before).

The neoclassical, utility-oriented concept of weak sustainability was significantly shaped at the Symposium on the Economics of Exhaustible Resources (e.g., Heal 1974; Dasgupta/Heal 1974). In this context, the social welfare function was transferred to exhaustible resources. Therefore, theories of weak sustainability are mainly based on the social welfare function as introduced by Bergson (1938) and further developed by Samuelson (1947). In its basic form the social welfare function represents welfare W (to be maximized) as the sum of all individual benefits U_j, weighted by γ_j:

Max! $W = \sum_{j=1}^{m} \gamma_j * U_j$

Transferred to the case of the consumption of exhaustible resources and intergenerational justice, von Hauff/Kleine (2009) summarize the resulting model as follows:

$$W = \sum_{t=0}^{T} e^{-\rho \times t} * C_t$$

where W is welfare, C_t is the consumption of generation t and $\sum_{t=0}^{T} e^{-\rho \times t}$ is the discounting term for the weighting of time-shifted benefits. In this context, consumption is treated as the utility of a generation:

$U = U(C_t(f(K, R))$

where U is utility, and consumption C_t is the function of (human-made) capital K and (natural) resources R.

One of the main decisive questions between the concepts of weak and strong sustainability is, as to how substitutable different types of capital (e.g., human-made capital) and natural resources are. In the context of weak sustainability, Dasgupta/Heal (1974) state the following equation to estimate the optimal level of consumption from the total discounted benefit for all generations:

$$Max!\, W \ \sum_{t=0}^{T} e^{-\rho \times t} * \left(K_t^{\alpha} * R_t^{\beta} - \dot{K}_t\right);\ \alpha, \beta \ \in [0\%, 100\%];\ \alpha + \beta = 100\%$$

$$\left(K_t^{\alpha} * R_t^{\beta} - \dot{K}_t\right) = \ C_t \ ,$$

where $\sum_{t=0}^{T} e^{-\rho \times t}$ is the discounting term and is the C_t represents the consumption possibilities of generation t, which consist of (human made) capital K and natural ressources R, reduced by stock reduction $\dot{K}$.

The equation is based on a standard Cobb-Douglas production function which assumes a full substitutability with a fixed substitution relationship and is thus a special case of a CES (Constant Elasticity of Substitution) production function, which was initally introduced by (Solow 1956). This assumption of the extent to which (human-made) capital and natural resources are substitutable is one of the main differences between the concepts of weak and strong sustainability.

Georgescu-Roegen (1971, 1986) critizes Solow's concept of full substitutability as "viewing the economic process not as a thermodynamic transformation, but as a mechanical system. Indeed, in a mechanical system absolutely nothing happens besides changes of place, which is not the essence of economic life" (Georgescu-Roegen 1986: 11). Solow himself stated, "… it takes economics as well as the entropy law" (Solow 1974:11) to look at the economic process. However, Georgescu-Roegen (1986) argues that Solow does not apply this insight in his works, because he bases essential parts of his work on the view that production factors such as labor and reproducible capital can fully substitute natural resources (Solow 1974). Referring to the laws of thermodynamics, Georgescu-Roegen (1986: 12) answers, "capital cannot be reproduced without an additional supply of natural resources." Applying thermodynamics principles to resource economics rather corresponds to the principles of strong sustainability (e.g., Berry et al. 1978; Bryant 1982; Young 1991; Daly 1992; Binswanger 1993; Sollner 1997; Krysiak 2006). One possible limitation of the entropy concept is the strong assumption of the world as an "isolated system". For example, one could argue that technologies of solar energy might enable the world population to go beyond the limits of the earth as a closed system.

Von Hauff/Kleine (2009) explain this difference by the elasticity σ of substitution between human-made capital and natural resources: weak sustainability assumes an elasticity of substitution $\sigma = 1$, whereas strong sustainability questions the substitutability of human-made capital and natural capital in principle and assumes an elasticity of substitution $\sigma = 0$. In the case of $\sigma = 1$, Hartwick (1977) uses a Cobb-Douglas production function to show that declining natural resources can be substituted if there is a sufficiently rapid accumulation of human-made capital and if the partial production elasticity of human-made capital in relation to natural capital is stronger. However, cases have been documented, in which the elasticity of substitution is $\sigma < 1$ (e.g., Markandya/Pedroso-Galinato 2006) or where the model of full substitution fails in real life (e.g., the example of phosphate mining on Nauru Island, documented by Gowdy/Mc Daniel 1999). The proponents of strong sustainability favor the concept of complementarity instead of substitutability. Daly underpins the concept of complementarity with some illustrative examples: "The complementarity of manmade and natural capital is made obvious at a concrete and commonsense level by asking: what good is a saw-mill without a forest; a fishing boat without populations of fish; a refinery without petroleum deposits; an irrigated farm without an aquifer or river?"(Daly 1995: 51).

The concept of "weak" sustainability is rejected by the supporters of "strong" sustainability—especially from the ecological economics community. They refer to natural scientific laws and point out that natural capital is not fully replaceable by human-made capital and thus cannot be completely represented and controlled by a price. Representatives of strong sustainability advocate a complementary relationship between natural and physical capital (e.g., Pearce/Atkinson 1993; Gowdy/McDaniel 1999; Rennings/Wiggering 1997; Ayres et al. 2001; Costanza et al. 2016). On the other hand, the concept of strong sustainability is criticized for being too dualistic and for mixing the concepts of substitutability and complementarity (Beckerman 1995). Another critique is the fuzzy definition of capital, because in some models production capital and labor are mixed, which restricts the analytical precision.

The discussion concerning weak and strong sustainability is still ongoing. For example, this differentiation has been used to compare green-economy concepts in terms of their impact on strong and weak sustainability (Loiseau et al. 2016). Nevertheless, some alternative approaches try to combine or balance the two controversial concepts of weak and strong sustainability (e.g., Toman 1994; Hediger 1999; see also von Hauff/Kleine 2009: 32-40).

Meadows et al. (1972), presents the limits of growth due to the limitations of natural resources and thus challenges the substitutability paradigm of weak sustainability. However, Stiglitz states three factors that Meadows et al. do not properly take into account: "technical change, the substitution of man-made factors of production (capital) for natural resources, and returns to scale" (Stiglitz 1974: 123). Stiglitz concludes that these factors enable future generations to have at least the same level of utility as current generations.[3] The role of technological change can be related to the theory expounded by

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[3] This view does not necessarily contradict the approval of economic approaches concerning climate policy. At least Stiglitz writes in a recent article (2016: 45): *"Imposing a carbon price, reflecting the social cost of emissions, would significantly stimulate investment. To ensure a level playing field, we might have to*

Grossman/Helpman (1994), who introduce a model of long-term growth which is based on endogenous technological progress. In line with Romer (1990), they develop a formal model that presents industrial innovation as the engine of endogenous growth, which is seen as one approach to combine economic growth with environmental sustainability (Bovenberg/Smulders 1995; Smulders 1995; Pittel 2002; Smulders/De Nooij 2003).

2.1.4 Sustainable development – a multi-level framework for the political implementation of sustainability

Since the 1990s, the notion of "sustainable development" has covered the policy making and implementation processes of sustainability principles. Sustainable development has evolved into a multi-level framework for the policy implementation of sustainability. From a German perspective, one can mainly differentiate between sustainable development processes at international, European, national and regional level.

International level (the global framework)

As a consequence of the report entitled "Our Common Future" by the Brundtland Commission (1987) and the United Nations Conference on Environment and Development ("Earth Summit") in Rio de Janeiro in 1992, the UN General Assembly established the United Nations Commission on Sustainable Development (CSD) in 1992. The aim of this commission was to implement principles of sustainability worldwide. Twenty years later, it was replaced by a high-level political forum in 2013, which developed and prepared the so called "2030 Agenda for Sustainable Development" (hereafter the "2030 Agenda"). The main aim of the Agenda is to provide everyone with ecologically compatible, socially just and economically fair living conditions by 2030. The agenda was adopted by the United Nations General Assembly in 2015 as the follow-up to the Millennium Development Goals (UNSD 2008). In contrast to its predecessors, the global sustainability agenda applies equally to industrialized and developing countries. The 2030 Agenda comprises 17 Sustainable Development Goals (SDGs), operationalized in 169 specific targets (UN 2015). As a further operationalization, the UN defined 232 indicators that are linked to the SDGs and targets and are continuously refined (UN 2017, 2018). Table 2-1 provides an overview of the 17 SDGs.

Table 2-1: The Sustainable Development Goals (SDGs) of the United Nations

SDG 1:	End poverty in all its forms everywhere
SDG 2:	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
SDG 3:	Ensure healthy lives and promote well-being for all at all ages
SDG 4:	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
SDG 5:	Achieve gender equality and empower all women and girls
SDG 6:	Ensure availability and sustainable management of water and sanitation for all

impose cross-border adjustments. A carbon tax would simultaneously raise substantial revenues needed to finance the public investments described elsewhere in this paper."

SDG 7:	Ensure access to affordable, reliable, sustainable and modern energy for all
SDG 8:	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
SDG 9:	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
SDG 10:	Reduce inequality within and among countries
SDG 11:	Make cities and human settlements inclusive, safe, resilient and sustainable
SDG 12:	Ensure sustainable consumption and production patterns
SDG 13:	Take urgent action to combat climate change and its impacts*
SDG 14:	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
SDG 15:	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
SDG 16:	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
SDG 17:	Strengthen the means of implementation and revitalize the global partnership for sustainable development

Source: UN (2015, 2018)

The broad range is both a strength and a weakness of this approach. On the one hand, it covers all three pillars of sustainability, but on the other hand the interaction between goals introduces a complexity that is difficult to handle. Nilsson et al. 2016 provide an example of this, pointing out that "…using coal to improve energy access (goal 7) in Asian nations, say, would accelerate climate change and acidify the oceans (undermining goals 13 and 14), as well as exacerbating other problems such as damage to health from air pollution (disrupting goal 3)" (Nilsson et al. 2016: 320). The authors recommend mapping the interactions between the SDGs by rating these relationships to make them visible for policy-making decisions.

European level

In the context of the Treaty of Amsterdam in 1997, sustainable development was included for the first time as an overarching objective of European Union policy. In the following years, it was integrated into EU policy, inter alia through the EU Sustainable Development Strategy (EC 2001) and the Europe 2020 Strategy (EC 2010).

In 2016 the European Commission released a communication (EC 2016a) describing the implementation of the SDGs in the target system of the European Union, the EU 2020 strategy and the 10 commission priorities for 2015-2019. Eurostat (2016a) subsequently took up this communication and published an implementation concept to integrate the SDGs into the Sustainable Development monitoring process of the European Union and to link them with existing targets set out in the Europe 2020 strategy. Since 2017, Eurostat has published an annual EU SDG Monitoring Report (e.g., Eurostat 2016b, 2018a/b). Furthermore, the SDGs are also covered in the monitoring report regarding the Europe 2020 strategy (e.g., Eurostat 2018c).

National level – The case of Germany

The German government first adopted a national sustainability strategy in 2002, which was updated several times in the following years. The largest adjustment was made in 2016/2017, when the government aligned the German sustainable development strategy with the SDGs of the UN Agenda 2030 (German Federal Government 2017). Consequently, the indicator set for monitoring sustainable development in Germany was revised, too (Destatis 2017). Every country has to report on a regular basis about the state of the SDG implementation at national level. For example, Germany reported in 2016 and will report again in 2021 (RNE 2017). The German Council for Sustainable Development (Rat für Nachhaltige Entwicklung, RNE) is an advisory board of the German government and plays an important role in the processes of developing, discussing and evaluating the German sustainable development strategy. The RNE was established in 2001. Its 15 members are appointed by the German chancellor for three years, whereby a reappointment is possible (RNE 2018).

Regional level

Since the beginning of the discussion about sustainable development, the regional level has played a major role, because the implementation of real sustainable behavior depends mainly on the actions at local level. Initiated at the Rio conference in 1972 the bottom-up concept of local agenda 21, there was a global movement of municipalities that took up the initiative and set up local agendas 21. (Lafferty/Eckerberg 2013).

Agenda 2030, with its global framework of SDGs, also emphasizes the importance of the local level. However, the challenge of operationalizing standardized global goals at the local level seems to demand more central impulses. There are several international and national efforts to help local actors translate SDGs into their local unit (Rudd et al. 2018; UCLG 2014; UN Habitat 2016; Nrg4SD et al. 2018; Bertelsmann Stiftung et al. 2018).

2.2 "Green" economic paradigms aimed at environmental sustainability

2.2.1 The green economy and green growth paradigms

In 2008 the concept of "green economy" was introduced at the international level as a potential solution for improving the environmental sustainability of the global economy. The first official step was taken in October 2008 when the United Nations Environment Programme (UNEP) launched the Green Economy Initiative. The aim of this initiative was to foster investments in environmental goods and services as well as to transform conventional, "non-green" sectors into more environment-friendly business outputs and processes (UNEP 2008). Based on this initiative the UNEP published a common working definition of green economy in 2010, defining it: Green economy is defined as "…a system of economic activities related to the production, distribution and consumption of goods and services that result in improved human well-being over the long term, while not exposing future generations to significant environmental risks or ecological scarcities…" (UNEP 2010). This working definition was discussed further at the Rio+20 conference in 2012, in fact it was even the main conference subject. In one of the preparatory documents, the UNEP defines green economy as an economy "… that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. (…) The key aim for a transition to a green economy is to enable economic growth and investment while increasing environmental quality and social inclusiveness" (UNEP 2011: 16). This definition and many other similar concepts of green economy also include the three common dimensions of sustainability, i.e., environmental sustainability ("reducing environmental risks and ecological scarcities […] increasing environmental quality"), social sustainability ("improved human well-being and social equity […], increasing [...] social inclusiveness") and economic sustainability ("enable economic growth and investment"). A comparison of the working definition and the final definition stated by the UNEP shows clearly how the green economy concept has developed over time: the dimension of social sustainability is now an essential component of the United Nations' green economy concept. This holistic view reflects the three pillars of sustainability, but the green economy paradigm might be criticized for its objectives being too demanding for many countries to really start an ambitious greening process. This may be the reason why another concept has gained popularity in the context of environmental and economic policy in recent years: the green growth paradigm (OECD 2011). According to the OECD, green growth means "fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies. To do this it must catalyse investment and innovation which will underpin sustained growth and give rise to new economic opportunities" (OECD 2011: 9).

The World Bank published its own definition of green growth, which is similar but focuses on resource efficiency, the minimization of environmental impacts and the responsibility for avoiding natural hazards: "…growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts and resilient in that it accounts for natural hazards…" (World Bank 2012).

Initially, the green growth paradigm was introduced in 2005 as a concept to help fast growing economies in Asia to achieve sustainable development (UNESCAP 2005; OECD 2011; UNEP 2011; World Bank 2012; UNESCAP 2012; Kasztelan 2017). In contrast to the concept of a green economy, the green growth paradigm focuses on the relationship between economic growth and environmental protection. It deals less with the social implications of economic activities. Unlike the concept of sustainable development, the green growth paradigm postulates the reconciliation of environmental protection and economic growth. The concept of sustainable development leaves this issue open or—in the spirit of the report "Limits to Growth"—is even skeptical about growth. Despite the pragmatic and limited focus of the green growth concept, its implementation continues to face major challenges, for instance the countervailing incentives of low prices for carbon-based energy and the ongoing debate about fairness between developing and developed countries (Martinelli/Midttun 2012; Jänicke 2012; Kasztelan 2017). The initiatives towards a Green Economy and Green Growth are also taking place at national level. For example, in Germany in 2012 the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) together with the Federation of German Industries (BDI) presented their concept for a Green Economy in Germany (BMU/BDI 2012).

2.2.2 The circular economy paradigm

The concept of the circular economy is part of the European Union's sustainability strategy (EC 2015) and can be regarded as an essential element of the green economy. A report by the Ellen MacArthur Foundation (2015: 5) defines a circular economy as an economy "that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (see also Ghisellini et al. 2016 and Lieder/Rashid 2016 for extensive literature reviews). Horbach et al. (2015) present a comprehensive overview of relevant studies with a focus on employment in a circular economy. The main difference to the green growth concept is, that the circular economy focuses on "growth within". According to a study presented to the European Commission (Ellen MacArthur Foundation et al. 2015: 14) the circular economy is linked to growth within, "… because it focuses on getting much more value from the existing stock of products and materials. Growth within could be an important source of additional consumer utility and growth for Europe. This circular economy would provide multiple value creation mechanisms decoupled from the consumption of finite resources. The concept rests on three principles: preserve and enhance natural capital, optimise yields from resources in use, and foster system effectiveness (minimise negative externalities)."

The circular economy also has strong links with sustainable development. For example, its actions are closely related to some of the United Nations' Sustainable Development Goals (SDGs). Schroeder et al. (2018) show that circular economy actions contribute to the SDGs of "Clean Water and Sanitation" (SDG 6), "Affordable and Clean Energy" (SDG 7), "Decent Work and Economic Growth" (SDG 8), "Responsible Consumption and Production" (SDG 12) and "Life on Land" (SDG 15).

2.2.3 Growth-critical perspectives: the degrowth paradigm and related concepts

The green economy and green growth concepts are generally regarded as important milestones in the shift towards sustainable development. However, there is also a whole body of literature that criticizes these concepts. One of the most common arguments against these approaches is that they implicitly (green economy) or explicitly (green growth) assume steady economic growth to be the prerequisite for lasting prosperity.

Many critical statements doubt that sustainability necessarily needs growth or that growth is even irreconcilable with sustainable development. In this context, especially the ecological limits and harmful effects of growth have often been stressed (see e.g., Ferguson 2015). This critique is in line with the growth-skeptical positions of ecological economists. Growth-critical paradigms have been increasingly discussed in recent years by this group as well as by sociologists, political scientists and political activists.

The critiques of growth emerged in particular during two periods of crisis: the 1970s and 2007-2010. Against the background of the economic crisis in the 1970s, Meadows et al. (1974) published their report “Limits to growth”. Using computer simulation results, the authors present future scenarios given infinite economic and population growth and finite non-renewable natural resources. Using the “business as usual” scenario Meadows et al. conclude that if “the present growth trends in world population, industrialisation, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity” (Meadows et al. 1972:23). However, the authors point out that it is not yet too late to change the mode of economic activities and behaviors and thus to avoid this negative scenario. In the scientific community, this work was appreciated by ecological economists and led to the foundations of the global discussion surrounding sustainable development (see above). However, the report was also criticized by some scientists as being methodologically inadequate (Simmons 1973; Vermeulen/De Jongh 1976). Yet, thirty years after the publication of the “Limits to growth” report analyses show that so far, its “business as usual” scenario is still relatively in line with the current world development, despite the fact that the positive effect of innovation and technological change have been partly underestimated (Turner 2008, 2012; Bardi 2011).

In the light of a report to the Club of Rome, another related notion emerged: “décroissance” (French for degrowth), which appeared in several French publications (e.g., Gorz 1977). Although used in political movements, particularly in France, Italy and Spain since those early years, it received less public attention during the 1980s and 1990s. At the beginning of the twenty-first century, however, the French term “décroissance” and its English equivalent “degrowth” were taken up again in two newspaper articles by Latouche (2003, 2004). The new public and scientific discussion about degrowth and related concepts has increased since 2007, the year in which the global financial crisis began. The resulting national economic crises in 2007-2010 significantly intensified the discussion of growth-critical approaches. One of the outcomes of this debate was an increasing strand of literature postulating new or updated concepts of “prosperity without growth” (Jackson 2009), “degrowth” (Kallis et al. 2012; Victor 2012; Demaria et al. 2013; Muraca 2013; D’Alisa et al. 2014), “post-growth” (Paech 2013; Schulz/Bailey 2014; Jackson 2009), “economy for the common good” (Felber 2015) or “a-growth” (Van den Bergh 2011).

What all these ideas have in common is that they reject and abandon the narrow focus on GDP growth as the predominant indicator of prosperity and development. They also share the conviction that the earth's ecological system has hard limits that must be respected by human activities. Hence, a common claim of all of these concepts is a transformation of the world's societies into structures that are less or not at all dependent on (permanent) economic growth. An in-depth analysis of the differences of every single concept would go beyond the scope of this chapter. Hence, I refer to Ferguson (2018), who provides a comprehensive overview of the various growth-critical approaches.

Many of these publications refer to the work of Daly (1997), who introduced a model of sustainable development "beyond growth" as early as 1997. Another aspect that the different concepts have in common is their doubt about the positive environmental effects of technological change. Binswanger (2001), for example, points out that many potential resource- or energy-efficient technologies (e.g., LED bulbs) lose their potential for overall energy saving. The reason for this is the so-called rebound effect, i.e., one percent of energy saving leads to a real energy saving of much less than one percent and sometimes even leads to higher energy consumption. However, *Schwartzman (2012) criticizes the categorical rejection of economic growth propounded in some degrowth approaches. Rather, he argues in favor of a more detailed examination of the quality of growth:* "What growth is sustainable in the context of biodiversity preservation and human health, and which is not?" (Schwartzman 2012: 119).

2.3 Key levers for a transition towards environmental sustainability

The main global environmental problems are climate change, loss of biodiversity, increasing land consumption, exhaustion of natural resources and environmental pollution. Most of the processes that cause these problems can be found in the areas of energy, mobility, building and waste. Of course, due to various regional circumstances and different regional natural sources, manifold environmental problems exist at local level, too. In all of these fields – both at global and local level – there are also many approaches or at least potentials for tackling these problems On the one hand, new goods and services have been developed that are intended to protect the environment directly or indirectly, usually referred to as eco-innovation. On the other hand, many public bodies use environmental regulation to encourage individuals and organizations to work towards environmental sustainability. Last but not least, another strong driver of sustainability is green consumption among private and public consumers.

The three environmental approaches of eco-innovation, environmental regulation and green consumption are presented in the following subsections.

2.3.1 Eco-innovation: innovation for environmental sustainability

Many recent studies have described innovation as an important factor for employment growth (e.g., Buerger et al. 2012; Capello/Lenzi 2013). The Oslo Manual (OECD/Eurostat 2005: 46) defines innovation as "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" and differentiates between four types of innovation: product innovations, process innovations, marketing innovations and organizational innovations.

Besides these standard types of innovation, the notion of eco-innovation has emerged in recent years, which is particularly relevant for the environmental sector. Kemp/Pearson (2008) define eco-innovation as follows:

"Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp/Pearson 2008: 7).

In order to analyze the employment effects of eco-innovation it is necessary to distinguish between process and product innovations. The employment effects of eco-process innovations may be negative because of the implementation of end-of-pipe technologies (e.g., additional air emission filters) leading to higher costs. On the other hand, these end-of-pipe measures may require additional employees. The introduction of process-integrated, resource- and energy-saving measures may improve a firm's profitability and competitiveness, which may in turn lead to an increase in the workforce size, but might equally have labor-saving effects. The empirical findings obtained by Horbach and Rennings (2013) revealed positive employment effects of eco-process innovations. In the present paper, the analysis focuses on eco-product innovations since we analyze the development of the environmental sector. In fact, the employment effects of environmental product innovations are also theoretically unclear. Product innovations may induce new demand for the firm by creating completely new markets or by substituting competitors' products, thereby leading to positive employment effects at the firm level. The macroeconomic employment effects remain undetermined as they also depend on the labor intensity of the substituted products. Furthermore, the launch of a new product may result in a monopolistic position accompanied by a reduction of output. In that case, negative employment effects may be observed (Hall et al. 2006; Horbach/Rennings 2013). Empirical studies focusing on general innovations generally find that product innovations have positive effects on labor demand (see, for instance, Smolny 2002, Piva/Vivarelli 2005, Zimmermann 2009). Similar results are observed for the UK (Van Reenen 1997), for France (Greenan/Guellec 2000) and in a study for France, Great Britain, Germany and Spain based on harmonized data from the Community Innovation Panel (CIS) (Harrison et al. 2008). Due to a lack of suitable data, only few studies have analyzed the employment effects of eco-innovations. Most of these studies also show positive effects of eco-innovations on employment (Bijman/Nijkamp 1988, Pfeiffer/Rennings 2001, Rennings/Zwick 2002). Horbach (2010) detects a positive and significant influence of eco-product innovations on employment. The positive effects of eco-innovation appear to be greater than those of other non-environmental innovation fields.[4]

Licht/Peters (2014) use the Community Innovation Survey (CIS) of 2009 to analyze employment effects of product and process innovations for different European countries and for Germany. The authors find that both environmental and non-environmental product innovations are correlated with employment growth, but that non-environmental product innovations are still more likely to increase employment. According to their estimation results, the displacement effect of process innovations seems to be quite small. The paper by Gagliardi et al. (2014) also analyzes the link between eco-innovation and job creation at the company level for Italian companies matched with patent records for the period from 2001 to 2008. The results show a strong positive impact of eco-innovation on the creation of long-term jobs. The effects are substantially larger than those of other innovations.

2.3.2 Environmental regulation

Environmental law, as a separate body of law, is a relatively new phenomenon. After some initial activities in the 1950s, there has been a strong increase in environmental regulation at national and international level since the 1960/70s. This development was mainly caused by resource and environmental crises, e.g., due to the "great smog" in London in 1952, which led to the first Clean Air Act being passed in the UK in 1956 (Garner/Offord 1957; Ashby/Anderson 1981; Giussani 1994; Brimblecombe 2006). In recent years environmental regulation has increasingly become a matter of international policy, especially because of the rise of global environmental problems such as climate change, the increasing pollution of the world's oceans, and the global loss of biodiversity.

According to static models of the economy, environmental regulations (e.g., the mandatory installation of fine dust filters in industrial plants) lead to a loss of competitiveness or, at best, do not have positive impacts (e.g., Jaffe/Palmer 1997).

Contrary to this position, Porter/Van der Linde (1995) point out that environmental regulations may promote innovation and thus improve competitiveness—as long as the regulations are well designed. Acemoglu et al. (2012, 2016) also stress the high importance of directed technical change. According to them, a combination of both environmental regulation (e.g., by means of carbon taxes) and temporary research subsidies may lead to climate protection and sustainable long-run growth. Ekins (2010) also calls for more stringent policies to foster eco-innovations for environmental sustainability.

[4] According to Horbach (2008), there is also a relationship in the other direction, i.e., from employees (human resources) to eco-innovation. He shows that the improvement of knowledge capital (here: technological performance) through research and development is an important driver for eco-innovation.

2.3.3 Green consumption—change in consumption behaviors

Another important driver of transition towards a more environmentally sustainable economy is consumers' changing awareness and behavior with regard to the ecological, social and health impacts of the products and services they consume (Lorek/Spangenberg 2014). In this context it is necessary to differentiate between private and public consumption. Private consumption takes place in households and businesses and is thus a domain governed by individual decisions, whereas public consumption is usually embedded in public tendering rules and partly influenced by politically defined priorities (e.g., Preuss 2009; Brammer/Walker 2011; Zhu et al. 2013; EC 2016b, 2017; UNEP 2017).

The impact of private consumption has been especially important in domains such as food (e.g., Seyfang 2006), energy (e.g., Munksgaard et al. 2000), construction (e.g., Eichholtz 2010) and mobility/tourism (e.g., Barr/Prillwitz 2012, 2014). Especially the field of public procurement is supposed to have a high leverage effect to foster sustainable transitions, though it has often not been used enough so far (e.g., Chiappinelli/ Zipperer 2017; Cheng et al. 2018). Examples of green public procurement are green buildings (e.g., Sparrevik et al. 2018) and mobility (e.g., Leurent/Windisch 2011). Two of the main reasons for these expectations are the direct influence of governmental bodies on their own economic decisions and the fact that the tenders often have a high value. This may in turn help the companies winning the tenders to improve their economies of scale and to lower their prices for the respective sustainable products and services. Green public procurement also has the potential to foster eco-innovation (e.g., Edler/Georghiou 2007; Baron 2016). For example, in 2014 the European Union published an EU directive (EU 2014a, 2014b) demanding that the governments of the EU member countries reform their public procurement legislation in such a way as to include innovation components in public procurement processes by 2016. Czarnitzki et al. (2018) analyze the effects of this policy in Germany. They find that innovation-directed public procurement impacts on turnover from new products and services, with the effects being mainly associated with incremental innovations rather than completely new products or services on the market. These results also point to the potential of public procurement for fostering eco-innovation and economic growth.

2.4 The labor market dimensions of sustainability

Some of the scientific work on sustainable development has already raised the question regarding the importance of sustainability principles for the labor market (e.g., Blazejczak 2013; Lubk 2016). So far, however, no uniform definitions of sustainability factors on the labor market have been put forward. Given the three common dimensions of sustainability and the reciprocity between these dimensions and the labor market I suggest the following differentiation:

a) Environmental sustainability and the labor market

The labor market as a subject of structural change due to environmentally sustainable policies

Transition actions aimed at environmental sustainability, such as environmental regulation or "green" business trends, may have a major impact on the labor market. For example, the promotion of renewable energies may have direct positive effects on some parts of the labor market (e.g., photovoltaic installers) and indirect effects in other sectors. On the other hand, exiting from a non-sustainable technology, such as the lignite industry, may lead to direct negative employment effects due to job displacements in this sector and, again, to indirect effects in other sectors.

A strategy that strives to reconcile environmentally sustainable development and positive labor market transitions is thus regarded as sustainable labor market development. In this context, instruments of passive and active labor market policy can also be used, e.g., the payment of financial benefits during the retraining or job-search period, retraining of unemployed coal workers, etc.

The labor market as a potential facilitator of or obstacle to the transition towards environmental sustainability

In the context of environmental sustainability, however, the labor market can be regarded either as an enabling factor or as an obstacle for the transition towards a more environmentally sustainable economy. For example, occupational labor markets may provide establishments with employees possessing environment-related knowledge and skills. In the public sphere, such efforts aimed at environmental sustainability are often discussed using contemporary buzzwords such as "green jobs" or "green economy". In this respect, instruments of active labor market policy can also be used, e.g., to support vocational training or retraining in occupations with a large proportion of activities relevant to environmental protection.

b) Social sustainability and the labor market

The labor market as a subject of structural change due to socially sustainable policies

In many aspects, the dimension of social sustainability is very closely connected to the labor market. Striving for social sustainability may lead to direct and indirect effects on labor demand or supply. For example, improvements in gender equality consequently entails an increase in the female labor supply. This development may also lead to an indirect labor demand effect, for example a rising demand for child care and household support services.

The labor market as a potential facilitator of or obstacle to the transition towards social sustainability.

Employers, public employment services and other labor market stakeholders can proactively foster the dimensions of social sustainability. In the example of an increased share of female workers and the indirect effect of more demand for child care, the labor market stakeholders could raise the number of training places for early childhood education, improve the working and wage conditions of kindergarten staff or improve the access conditions for those interested in training.

c) Economic sustainability and the labor market

The labor market as a subject of structural change due to economically sustainable policies

Similar to social sustainability, the dimension of economic sustainability is closely related to the labor market. Some basic indicators such as the gross domestic product (GDP) and the inflation rate are directly linked with the labor market at the macroeconomic level. Other indicators, such as the gross domestic expenditure on research and development (R&D) as a percentage of GDP", also have connections with concrete labor demand: an increase in the percentage of R&D usually goes hand in hand with a growing demand for highly qualified workers. However, in times of a shortage of skilled workers, this can also temporarily intensify the labor market situation for this group.

The labor market as a potential facilitator of or obstacle to the transition towards economic sustainability.

In this context, too, labor market institutions may act proactively. For instance, the capacities for universities and other institutions of higher education may be expanded, PhD programs may be promoted, and research-specific basic skills, e.g., skills in science, technology, engineering and math (STEM), may be fostered in schools.

In the remainder of this dissertation, I focus on the interrelationships between environmental sustainability and the labor market.

2.5 The relationships between environmental sustainability and the labor market

2.5.1 Definitions of green jobs

In both science and public statistics, the topic of green jobs has been discussed widely in recent years. However, there is still no common definition and measurement concept but, instead, several coexisting approaches. The different concepts can be differentiated by paradigms based on output, processes and occupations.

Output-based approach: identification by goods and services

The most common approaches used so far to define and measure green jobs are related to the goods and services provided by firms or – at an aggregated level – by sectors. Up to now, only a few theoretical papers have delivered a scientific definition of green jobs. Hence, in accordance with empirical studies on green jobs (e.g., Deschenes 2013; Peters 2014; Vona et al. 2015; Consoli et al. 2016) I also refer to the common statistical definitions. According to the international System of Environmental-Economic

Accounting (SEEA), the environmental goods and services sector (EGSS) “consists of a heterogeneous set of enterprises which produce environmental goods and services. Historically, the production of environmental goods and services focused on the demand for basic services, such as wastewater treatment and the collection of solid waste. However, with the drive towards cleaner and more resource-efficient processes, products and materials, the activities of the sector have expanded to also include resource management activities.” (UN et al. 2017: 25 in connection with UN et al. 2014) This conception is in line with the EGSS as defined by Eurostat (2016a: 8): The EGSS “comprises all entities in their capacity as ‘environmental producers’, i.e., undertaking the economic activities that result in products for environmental protection and resource management. Producers in the EGSS may or may not be specialised in the production of environmental goods and services, and may produce them as principal or secondary activities or produce these products for own use.” Generally based on the SEEA definition of environmental goods and services, the definition of employment in environmental activities used by the International Labour Organization (ILO) emphasizes the difference between employment in the production of environmental outputs and employment in environmental processes (ILO 2013a, 2013b, 2013c).

Focusing on EGSS, it must be taken into account that there are considerable differences between end-of-pipe technologies and clean technologies. Whereas end-of-pipe technologies are mostly regulation-driven, clean technologies are often more market-driven (e.g., as a source of cost savings) and triggered by general or environmental management systems (Frondel et al. 2007).

The multi-purpose problem

As already mentioned in the Eurostat definition, the main problem of the output-oriented approach is that many firms do not produce or deliver solely environmental goods and services. One general drawback of an output-related concept is the two sides of the “multi-product” and “multi-purpose” problem: many establishments do not produce or deliver only environmental goods and services, but follow a multi-product strategy, i.e., they produce environment-friendly goods and services, e.g., food based on organic ingredients, but also other goods and services from non-environment-friendly sources. A similar problem concerns multi-purpose products and services: there are many cases where products or services can be used both for environment-friendly purposes and for environmentally neutral or even harmful purposes. Pumps that can be installed both in biogas plants and in coal-fired power plants are one example.

It is also difficult to identify the environmental share of employment, as many employees are not only engaged in environment-related tasks but also perform work for non-environmental goods and services (in the case of multi-purpose firms). Moreover, the environmental impact of products and services may differ.

There is a huge difference between the climate impact of a zero-emission e-car and a large SUV with a cleaner hybrid drive but still high fuel consumption. Nevertheless, both help to reduce air pollution and are thus regarded as environmental goods and services.

Despite these drawbacks, most statistical publications so far identify green jobs based on environmental goods and services (see also DOL/BLS 2013b; DOC 2010; OECD/Cedefop 2014). The majority of research papers also use output-oriented identification strategies. For example, Lehr et al. (2012) and Hillebrand et al. (2006) focus on firms related to renewable energies. Becker/Shadbegian (2009) analyze a broader group of firms, namely manufacturers of environmental products, and measure employment in terms of total employment.

Papers such as Horbach et al. (2009), Horbach (2010), Horbach/Rennings (2013), Horbach (2014a) and Horbach/Jacob (2018) analyze employment in the entire environmental goods and services sector. They identify green employment by equating the turnover in the field of green goods and services with the share of employees involved in the production of green goods and services. This approach helps to tackle the issue of multi-purpose firms, but still neglects a large part of integrated environmental protection.

Two chapters in this thesis also use the output-based approach: chapter 3 (published as Antoni et al. 2015) uses the membership data of renewable energy business associations to identify firms that are active in renewable-energy value chains. They regard all workers in those firms as renewable-energy workers. Chapter 4 (published as Horbach/Janser 2016) analyzes employment in the entire EGSS. Based on survey questions about EGSS and the related percentage of turnover enable, it identifies establishments with environmental goods and services. For the descriptive analysis of chapter 4, the related percentage of environmental employment is calculated by equating the turnover in the field of environmental goods and services with the percentage of employees involved in the production of these goods and services.

Adding the process perspective

Using a process-based approach provides a wider view than this limited goods and services perspective. Process-based perspectives focus on integrated environmental protection and the application of clean technologies and other environmentally friendly practices in business processes within firms. This approach is not an alternative approach but rather an additional dimension sometimes included in definitions of green jobs. For example, the Bureau of Labor Statistics of the U.S. Department of Labor (DOL/BLS 2013a) developed an extended definition of green jobs. Their definition involves the basic distinction between output and process. Whereas the output-related approach covers the green goods and services, the process approach “identifies establishments that use environmentally friendly production processes and practices” (Sommers 2013:5). Deschenes (2013), too, uses a mixed approach for his overview about green jobs. Based on the SEEA definition of environmental goods and services, the definition of employment in environmental activities used by the International Labour Organization

(ILO) also emphasizes the difference between employment in the production of environmental outputs and employment in environmental processes (ILO 2013a, 2013b, 2013c, 2015). The ILO introduces an even tighter definition of green jobs by adding a decent work dimension to the environmental dimension (2013a, 2013b, 2013c, 2015). In the sense of the ILO definition, green jobs include only employment in environmental activities that fulfill the conditions of decent work[5]. From a holistic perspective on sustainability, linking the two areas of environmental protection and decent jobs may be desirable. However, the complex issues of defining and measuring "decent work" make it even more difficult to identify green jobs according to the ILO definition. Each of the following chapters—at least in the descriptive part—also deals with the working conditions of the green jobs analyzed, thereby contributing to the discussion surrounding green jobs in the sense of the ILO definition. However, this thesis does not claim to cover all aspects of "decent jobs", because this would go beyond the scope of this dissertation. The in-depth analysis of the interrelationships between green jobs and the characteristic of "decent work" remains a worthwhile issue for future research.

Task-based approaches: identification of green jobs by occupational tasks

Both the output perspective of the environmental goods and services approach and the process perspective of integrated environmental protection have the shortcoming of being based on a firm-level perspective. In terms of the green transitions at worker level, firms remain a "black box". The task-based approach provides a way to look into this black box by analyzing the occupational tasks that are carried out within the firm.

Peters (2014), Consoli et al. (2016) and Vona et al. (2015) were the first to apply the task-based approach to identify the greenness of jobs. They work with US-American data from the occupational database O*NET. Acemoglu/Autor (2011: 1045) define a task as "a unit of work activity that produces output (goods and services)." Tasks have to be clearly distinguished from skills. According to Acemoglu/Autor (2011: 1045), a skill is "a worker's endowment of capabilities for performing various tasks. Workers apply their skill endowments to tasks in exchange for wages, and skills applied to tasks produce output." Hence, both worker skills and job tasks can change over time and may be reallocated if skills and/or tasks change within the working context. In chapter 5, I use a task-based approach to identify the greenness of jobs in Germany. It is important to note that this paper focuses on the demand side of labor and thus on tasks rather than skills.

Dierdorff et al. (2009: 4), who work with US-American O*NET data, refer to the greening of occupations as "the extent to which green economy activities and technologies increase the demand for existing occupations, shape the work and worker requirements needed for

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[5] The ILO uses a framework for measuring decent work which includes ten elements: *"(i) employment opportunities; (ii) adequate earnings and productive work; (iii) decent working time; (iv) combining work, family and personal life; (v) work that should be abolished; (vi) stability and security of work; (vii) equal opportunity and treatment in employment; (viii) safe work environment; (ix) social security; and (x) social dialogue, employers' and workers' representation."* (ILO 2013d: 12).

occupational performance, or generate unique work and worker requirements." They distinguish between the following types of greening occupations: (1) Green Increased Demand Occupations: the greening of the economy causes increasing demand for existing occupations without significant changes in occupational requirements, (2) Green Enhanced Skills Occupations: the greening of the economy leads to significant changes in the occupational requirements of existing occupations – and may or may not lead to increasing labor demand, and (3) Green New and Emerging Occupations: the greening of the economy triggers the need for new occupations. Both Green Enhanced Skills Occupations and Green New and Emerging Occupations can be identified by analyzing occupational contents, such as job requirements. The European Centre for the Development of Vocational Training has adopted this concept to a large extent (Cedefop 2012).

Similarly to the multi-purpose firms mentioned above, multi-purpose occupations are also a challenge for occupational concepts: most occupations do not include only green tasks. Instead, they comprise a certain share of tasks with environmental protection requirements as well as non-green tasks. Only a few scientific papers analyze in detail the extent of the greenness of jobs (e.g., Peters 2014; Consoli et al. 2016; Vona et al. 2015; 2017), and almost all the studies on the greenness of jobs look at the US labor market. The focus and main contribution of Chapter 5 is to demonstrate a text mining approach to identify Green Enhanced Skills Occupations in Germany, to measure – for the first time – the related changes in occupational requirements over time and to analyze their impact on employment growth. Chapter 5 shows that a greening of jobs is taking place in Germany, i.e., both the share of environmentally friendly requirements within occupations (greening of occupations) and the labor demand in these occupations (greening of employment) are growing.

This section has introduced the different approaches for identifying green jobs, namely output-, process- and occupation-based paradigms. The thesis in hand shows examples of all of these perspectives: chapters 3 and 4 present an output-oriented identification of green jobs, with chapter 3 addressing one specific branch of the EGSS and chapter 4 examining the entire EGSS. The analyses presented in chapters 5 and 6 cover all jobs with environment-related tasks and use an occupation-based approach which also includes elements of process-based approaches to identify green tasks, (including tasks of EGSS jobs as well as tasks in environment-related processes of non-EGSS jobs).

2.5.2 Environmental regulation, eco-innovation and the demand for labor

From a theoretical perspective, the labor market impacts of the trend towards a green(er) economy may be explained by the interplay between the drivers of a greening economy (e.g., environmental regulation, transition towards sustainable consumption patterns), innovation processes (e.g., eco-innovations, technological and structural change, social transitions) and economic outcomes (e.g., economic competitiveness, labor demand and wages). As already mentioned above, Porter/Van der Linde (1995) and also Acemoglu et al. (2012, 2016) stress that environmental regulations may promote innovation and thus improve competitiveness—and consequently may lead to an increase in employment. This is in contrast to scientific papers that present a more static model of the economy where regulations inherently lead to a loss of competitiveness or which at least do not find these positive impacts (e.g., Jaffe/Palmer 1997). Another reason for possible low employment effects—at least for technology-related green jobs—is presented by Peters (2014). He notes that the number of jobs created on account of green energy should be rather small because energy technologies are generally capital-intensive. According to Deschenes (2013), it is difficult to draw a definitive conclusion on the employment potential of green policies. He calls for more careful and detailed empirical studies to learn more about the labor market impacts of green jobs. The measurement approaches presented in this thesis contribute to this research strand.

Considering labor demand in general, several papers (e.g., Neisser 1942; Appelbaum/Schettkat 1995; Möller 2001; Combes et al. 2004; Blien/Sanner 2014) emphasize the important role of demand elasticities in the production function: based on the studies mentioned above, Blien/Ludewig (2017) show that technological progress leads to an increase in employment when product demand is elastic. However, it is accompanied by a decline in employment if product demand is inelastic. So far, no data on demand elasticity are available to support the econometric analysis of research questions in the context of green jobs with demand elasticities. As soon as detailed data on demand elasticities become available this might be a promising starting point for future research. Nevertheless, the decisive role of demand elasticities has already been useful for interpreting empirical results. For example, Horbach et al. (2009) used the concept of demand elasticities to explain the partial decline in the environmental goods and services sector. Using data from the IAB Establishment Panel, they show a strong drop in employment in the environmental sub-sectors dominated by end-of-pipe technologies, which are at a stage in their product life cycle that is characterized by low elasticity. On the other hand, their study also reveals positive employment trends and expectations for cleaner technologies, which – at least at the time of the study – were characterized by high demand elasticity. According to their findings a similar result should be expected for the econometric analysis at the end of this paper. Smulders et al. (2014) also demonstrate how green growth can be integrated into dynamic general equilibrium models. They find that green growth is feasible if there is a good substitution, a clean backstop technology, a low proportion of natural resources in the gross domestic product or green-directed technical change.

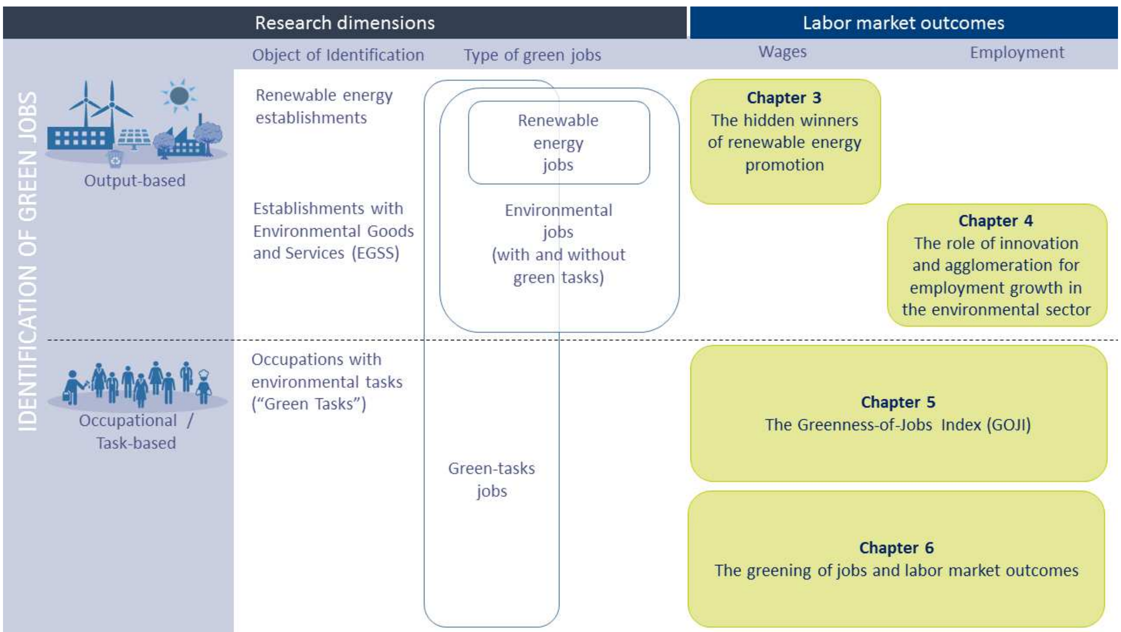
Another important theoretical thread is the task-based approach and the literature on employment polarization and technological change (see Autor et al. 2003; Autor 2013; Autor/Dorn al 2013; Goos et al. 2014; Autor 2015), i.e., the growing employment shares in the highest and lowest paid occupations due to the shift in labor demand towards non-routine tasks. Especially computerization seems to result in a substitution of repetitive, routine tasks which are mainly performed in medium-skilled occupations, whereas non-routine cognitive tasks predominantly occurring in high-skilled occupations are complemented by computerization (Acemoglu/Autor 2011; Autor et al. 2003; Autor 2013; Autor/Dorn 2013). Consequently, occupations with a large share of routine tasks are at greater risk of being replaced by computer algorithms or robots (Acemoglu/Restrepo 2018; Blien/Ludewig 2017; Dauth et al. 2017; Dengler/Matthes 2018a/b).

In general, eco-innovation appears to be closely linked with the creation of green jobs. For example, Cecere/Mazzanti (2017) investigate the relationship between green jobs and eco-innovations in European small and medium-sized enterprises and reveal that green innovation is highly relevant for the formation of green jobs. They report that the decision to hire for green jobs is especially driven by the interaction term between an eco-management system and product/service innovations. Observing the time period between 2001 and 2008, Gagliardi et al. (2016) also find that the emergence of eco-innovation has contributed considerably to long-run job creation. This positive influence of eco-innovation is shown for both product innovation (Horbach 2010) and process innovation (Horbach/Rennings 2013). Horbach (2010) finds that the positive effect of eco-product innovation is even greater than other non-eco-innovation fields. Licht/Peters (2014) confirm that both environmental and non-environmental product innovations are correlated with employment growth, but that non-eco product innovations are more likely to increase employment.

2.6 The green jobs framework

To conclude this introductory chapter, Figure 1 below gives an overview of main research dimensions of the conceptual framework. It maps the framework and its interrelationships with the empirical studies presented in the subsequent chapters.

Figure 2-2: The framework: research dimensions and labor market outcomes



Source: Own illustration.

3 The hidden winners of renewable energy promotion: insights into sector-specific wage differentials

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Abstract

In light of Germany´s energy system transformation, this paper examines differences in employment structures and wage differentials between renewable energy establishments and their sector peers. To do so, we have developed a novel data set by linking company-level information from the German Renewable Energy Federation with administrative establishment-level data from the Institute for Employment Research. Descriptive evidence shows significant differences in wages and several other characteristics between renewable energy establishments and their sector peers. Our estimates give evidence that human capital and other establishment-level characteristics mostly explain the wage differential among manufacturers and energy providers. However, we find a persistent "renewable energy wage premium" of more than ten percent in construction/installation activities and architectural/engineering services. We interpret this premium as a positive indirect effect of the promotion of renewable energies for the benefit of employees in renewable energy establishments within these two sectors.

JEL Classification: J31, Q42, Q52, Q58, C81

Keywords: Renewable Energy, Employment, Green Jobs, Wages, Human Capital, Record Linkage

3.1 Introduction

Public promotion has played – and still plays – an important role in stimulating supply and demand in the renewable energy (RE) market. With regard to the large allocation of feed-in tariffs and subsidies for the development of RE sources, there is a broad public interest in the economic impact of these promotion activities. Whereas the quantitative development of the RE supply is monitored on a broad level (for example, see IEA/IRENA 2015), there is little data concerning the actors within the RE product

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markets. For the evaluation of quantitative employment effects of RE products and services almost only macroeconomic data are available, which can merely provide rough estimates (Lambert and Silva 2012). There is even less evidence regarding the quality of jobs in this sector. An important question is whether workers within RE value chains also benefit from the promotion of RE sources in terms of wages. To fill this gap, we tackle the following research questions: Is there a difference in wages between RE establishments and others? If so, what are the determinants for this wage differential and how do they differ among sectors? Do those wage differentials merely reflect differences in establishment characteristics or do they reflect other external influences, such as the promotion of RE sources?

Due to Germany's role as one of the RE pioneers, the insights into RE establishment characteristics, RE wage differentials and potential indirect effects of RE promotion are also highly relevant at the international level. For example, more than 65 states have introduced feed-in tariff systems, often based on or developed from Germany's feed-in tariff model (IEA/IRENA 2015). Therefore, some of the phenomena presented below may also be observable in other regions of the world.

In the following paragraphs, we provide some background information about RE development in Germany, which might directly or indirectly influence RE employment. More details can be found in the relevant literature, e.g., Bruns et al. (2011).

The global struggle to mitigate climate change has led to a growing and dynamic RE market. Germany in particular has seen a boom of renewables supported by fixed feed-in tariffs and many further instruments of public promotion. Within the European Union (EU), especially in Germany, the promotion of RE sources has quite a long history. Initial research funding activities started in the 1970s, while joint efforts to foster RE on a larger scale began in the 1990s (IEA/IRENA 2015; Bruns et al. 2011). According to the IEA/IRENA Global Renewable Energy Policies and Measures Database (IEA/IRENA 2015), there were seventeen European and six German RE promotion policies and measures active in the year 2009[7], e.g., the European Directive on the Taxation of Energy Products and Electricity, Germany's feed-in tariff system and the German Market Incentive Program. Bruns et al. (2011: 57 et seq.) note that the different stages of Germany's feed-in tariff system have been "*key policy measures"* in the development of the RE market. In light of the Fukushima nuclear catastrophe in 2011, Germany's federal government decided to accelerate the transition towards a sustainable, nuclear-free and low-carbon energy system. One of the key targets of the German energy transition efforts, which are most relevant for the work in hand, is the expansion of the share of RE of total energy consumption. In this context, RE not only covers the electricity supply but also

[7] An overview of over 40 RE promotion activities in Germany since 1985 is available at the IEA/IRENA Global Renewable Energy Policies and Measures Database: www.iea.org/policiesandmeasures/renewableenergy, Advanced Search > Submenu 'Country' > Choose 'Germany' (last accessed on 31 Oct, 2018).

the heat and fuel supplies. The increase of the RE share in Germany's gross final energy consumption is shown in *Figure 3-1* in the *Appendix.*

In conjunction with an increase in exports of RE products and services, there has been a substantial growth in turnover and gross employment (Lehr et al. 2015; O'Sullivan et al. 2014; Lehr et al. 2012; Blazejczak et al. 2011; Lehr et al. 2011a). Several studies observe similar positive developments in other countries and regions, for example, in the USA (Haerer/Pratson 2015; Sommers 2013), Canada (Böhringer et al. 2012), China and India (Poschen et al. 2012; Arora et al. 2010) and Europe (Ragwitz et al. 2009; Blanco/ Rodrigues 2009). However, total RE employment decreased in Germany in 2013 for the first time, particularly because of the crisis of the solar technology market (O'Sullivan et al. 2014). Parallel to the RE development in general, the public debate about the quality of the RE jobs has intensified. The height of wages is here one of the most controversial dimensions of RE job quality. There is, to our knowledge, no comparative analysis of RE wages available so far. As mentioned above, the paper in hand contributes to fill this research gap.

The remainder of the paper is organized as follows: the next section gives insights into the methods applied, including the theoretical background, our data and sample selection as well as our estimation approach. Section three presents and discusses our results and ends with a consideration of several possible political impacts. Section four concludes and summarizes both our findings and their political impacts.

3.2 Methods

3.2.1 Theoretical background and hypotheses

In the following subsection, we identify the commonly acknowledged determinants of wages at the establishment-level[8]. We distinguish between determinants of wages in terms of human capital characteristics and other structural characteristics. Furthermore, we connect these wage determinants with literature about the specific situation of RE establishments.

There is a considerable body of literature offering overviews of wage determinants, e.g., Akerman et al. (2013), Lane et al. (2007), and Willis (1987). According to the neoclassical theory of human capital, the stock of competencies and knowledge of an employee influences wages strongly (Mincer 1974; Becker 1994). In RE establishments, medium skilled workers cover the highest share of the labor force, whereas high skilled workers also represent a relatively high share (ILO/EC 2011; BMU 2012). Those studies also show that the skill level of the staff depends on the specific technology of RE (e.g., solar

[8] We mostly use the term 'establishment' because our data consider production sites and single plants (see section 3.2.2 for more details). We use the term 'company' when we discuss the entire legal entity, which may consist of several establishments. The focus on the establishment-level allows us to analyze effects closer to the production process. Finally, there is also the term 'firm', which is often used in the literature but is less specific. We only use firm when it is explicitly used in the literature.

energy: high skill level; biomass: low skill level) and the function within the value chain (e.g., research and development: high skill level; production in partially automated processes: medium skill level). Furthermore, these studies observe a high amount of training activities in RE-related companies. Connecting the neoclassical theory of human capital with the empirical findings of above average skills in RE establishments, we expect RE establishments to pay higher wages than non-RE establishments.

The shortage of skilled labor is another driver of higher wages (see Horbach 2014b; Bennett/McGuinness 2009). Partial skill shortages exist in some RE segments, whereas the degree of the shortage depends on the specific RE technology and the business life cycle (IRENA 2013; ILO/EC 2011). Based on the IAB establishment panel, approximately twelve percent of establishments in the technology field of "Climate protection, renewable energies, energy saving" reported in 2012 that they had a lack of personnel compared to approximately seven percent of all establishments (Horbach 2014b). This should also lead to higher wages in RE establishments compared to non-RE establishments.

Women on average still earn less than men, as is amply documented in the gender wage gap literature (e.g., Hirsch et al. 2010; Ransom/Oaxaca 2010). The relatively low share of women in RE companies (ILO/EC 2011: 24 percent; Staiß et al. 2006: 17 percent) thus might be another reason for higher wages in this field compared to non-RE companies.

The lower wage per hour in part-time employment is often connected to the gender pay gap but is also observed for men (e.g., Gornick/Jacobs 1996). The ILO/EC (2011) reports a higher share of full-time workers in RE companies, which should also contribute to above average wages for RE employees.

According to findings of Seike (2010) and others, younger employees earn less, on average, than comparable older workers. In German RE businesses, both the share of young workers (<25 years) and the share of older workers (>55 years) is slightly below the average (Staiß et al. 2006). That suggests that the overall effects of age of employees on the RE wage differential is unclear.

There is a broad range of works, e.g., from Eberts/Stone (1985) and Carpenter et al. (2015) showing that higher wages are paid to compensate for working conditions that are particularly demanding or risky ("compensating wage differential"). As RE companies tend to have less hazardous working conditions than comparable non-RE companies (ILO/EC 2011), there might be a reason for lower wages from this perspective. However, because RE companies are on average younger than others (see literature on firm age below) the risk of failure is higher and that can in turn lead to higher wages.

Considering the combination of human capital-related wage determinants and the characteristics of RE companies, it seems that wages paid by RE companies should tend to be higher than in non-RE companies.

In addition to the human capital characteristics shown above, several other important and well-documented structural establishment characteristics determine wages. Several papers identify a “firm size wage premium” (e.g., Heyman, 2007 Oi/Idson 1999; Brown/Medoff 1989). Staiß et al. (2006) state that establishments engaged in RE product markets are mostly small- or medium-sized. Therefore, RE establishments would be expected to pay less than comparable establishments; however, the average establishment size may have changed in recent years due to the rapid growth in the field of RE products and services.

Another important determinant of wages is firm age, which is to some extent related to firm size (Heyman 2007) and worker characteristics (Brown/Medoff 2003). Brixy et al. (2007) show that wages are lower in newly founded firms than in comparable firms. As the use of RE on a larger scale is relatively new, the firms engaged in RE related products and services are relatively young (ILO/EU 2011: 27). With respect to the firm age wage gap, those firms may pay less than non-RE companies do.

The location of the establishment also plays a role in wage levels (e.g., Topel 1994). Establishments in urban areas pay an “urban wage premium” (Lehmer/Möller 2010; Yankow 2006). The regional and local distribution of RE-related activities is widely spread and depends on the type of RE and on the specific part of the value chain (Ulrich et al. 2012). It is therefore not possible to derive a specific hypothesis for RE companies overall based on the regional wage differential.

Furthermore, Abowd et al. (2012) and several other studies show that there are significant differences between industries that cannot fully be explained by worker and company or establishment characteristics (e.g., Genre et al. 2011; Gibbons/Katz 1992; Krueger/Summers 1988). Because most RE companies are part of industries where employers usually pay high or medium wages (Staiß et al. 2006), RE employers should pay more than the average.

The export share of RE establishments is another wage determinant that varies based on RE type, but essentially all RE fields have a substantial export share (ILO/EC 2011; BMU 2012; Staiß et al. 2006). In accordance with the labor market literature (e.g., Hauptmann/Schmerer 2013; Schank et al. 2010), this would contribute to higher wages in RE establishments. As in some of the cases above, there are also studies stating that the export wage premium vanishes after controlling for worker characteristics (e.g., Breau/Rigby 2006).

The rent-sharing theory and related empirical studies show that increasing profits can lead to increasing wages (e.g., Abowd et al. 2012; Budd/Slaughter 2004; Arai 2003). The profitability of RE companies differs widely among RE types, the business life cycle and the position within the value chain (Staiß et al. 2006). Several RE companies have become profitable in recent years, but on the other hand, the production of solar panels in Germany is currently at a stage of crisis and high losses. Facing this heterogeneous situation, a hypothesis valid for all RE companies cannot be derived in terms of rent-sharing wage differentials.

Finally, product market regulations also affect wages significantly (e.g., Abowd et al. 2012; Feldman 2012). The RE product markets in Germany are regulated, especially because of the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz, EEG). The EEG provides the framework for Germany's feed-in tariff system and strongly influences the demand for new RE installations. Recently the demand for renewable energies has vastly increased, leading to a boom in the product markets of RE products and services. Therefore, wages in these industries may be higher on average. However, as the EEG was reformed several times over the last few years by withdrawing some of the favorable conditions for some RE types (particularly solar energy and onshore wind energy), wages should stop increasing or even decrease.

Considering and weighting all of these potential wage determinants, we state the following main hypotheses for our study:

Hypothesis 1: On average, wages paid in RE establishments are higher than wages paid in other establishments.

Hypothesis 2: Personal and other organizational characteristics explain the RE wage differential to a greater extent than the fact that the establishment is an RE establishment.

3.2.2 Data and sample selection

For our empirical analyses, we use a subset of a novel data set from the Institute for Employment Research (IAB).[9] These data enable us to differentiate between establishments that are involved with producing or distributing RE and establishments that are not but that are active within the same sectors. Because the RE value chain entails a variety of products and services, we cannot simply identify involvement by a single characteristic, such as an industry code or by a high share of certain occupations in a given establishment.[10] We use membership in the German Renewable Energy Federation (Bundesverband Erneuerbare Energie e.V., BEE) as a proxy for a company's involvement in this value chain. The BEE is the umbrella organization of currently 25 German associations in the area of wind energy, solar energy, biomass, water power and geothermal energy. The data on RE companies stem from membership lists provided by

[9] Due to data protection requirements, these data are not yet available to the scientific community.

[10] In terms of industry codes, only two sub-sectors (in a 5-digit classification) allow us to identify parts of the RE 'solar energy' technology directly: 'manufacture of solar cells and solar modules' (26111) and 'manufacture of solar heat collectors' (28211) (WZ 2008, see Destatis 2008). Obviously, these two sectors do not cover the entire value chain of solar power generation. We see a similar situation in the occupational classification: there are only a few specific RE-occupations listed, e.g., 'Specialists in renewable energy technology (26242)' (BA 2014).

the BEE in 2009.[11] These lists are composed of the name, legal form, company address and an indicator for the association with which the company is affiliated. Therefore, we can also examine the differences between companies involved in the production or provision of the different types of RE represented by the BEE.

Because the membership list only provides identifying variables and the association indicator, we add data that offer information about the structure of the companies' workforce and wages for our empirical analyses. In Germany, there is no research data set at the company level that allows to link above identifiers with actual micro-data. Our solution is to use administrative establishment-level data instead of company-level data.

The Establishment History Panel (BHP)[12] contains longitudinal data at the establishment-level since 1975 for West Germany and since 1992 for East Germany. These data offer yearly information about establishments' workforces, earnings distributions, sectors and locations. Both employees liable for social security contributions and those who are marginally employed are reported in total numbers and are differentiated by gender, age, occupational status, qualification and nationality. The BHP also contains quantiles of age groups and wages, both for all employees and for full-time employees only. For each year, establishments are included when they register at least one dependent employee at the reference date of June 30th. Because the BHP is derived from mandatory employer notifications to the German social security system, the data are highly accurate and reliable.

Bringing the company-level information in the BEE membership list and the establishment-level data of the BHP together is not a trivial task. The membership list does not provide a unique company identifier, and even if it did, such an identifier would not be compatible to the establishment-level data. The BHP, on the other hand, only offers an establishment identifier. We tackle this challenge by exploiting the fact that companies must apply for a unique establishment number when they register an establishment for the first time. These numbers are mandatory, as they are necessary for all social security notifications from employers regarding their dependent employees. When companies apply for such a number at a central unit of the German Federal Employment Agency (Bundesagentur für Arbeit, BA), the company name is registered as the first part of the name of the establishment, because establishments as dependent sub-units usually do not have individual names.

We use record linkage techniques (see Herzog et al. 2007) to identify establishments that belong to BEE member companies. With these techniques, we are able to match the names and legal forms of BEE members with the corresponding establishment-level

[11] We gratefully acknowledge that the BEE has provided us with this membership list free of charge. Beyond that, there is no financial or contractual relationship between the authors and the BEE or any of the associations or companies that are covered by these data.

[12] See Gruhl et al. (2012) for more details about the BHP. Access to the BHP is provided by the Research Data Center (FDZ) of the German Federal Employment Agency at the IAB (see http://fdz.iab.de).

information. In preparing the actual linkage, we submit these non-unique and error-prone identifiers in both data sources to comprehensive preprocessing. This step includes, for instance, parsing the information at hand into relevant elements and standardizing the spelling of the resulting parts. For the actual record linkage, we compare the corresponding variables from both data sources and classified record pairs as links or non-links. We then use the data on establishments classified as links in the empirical analysis.[13]

We define establishments identified by this procedure as being actively involved in value chains of RE production. However, some companies named in the BEE membership list obviously are not part of the RE value chain. We assume that these banks, caterers, insurance companies and temporary work agencies became members of one of the associations in the BEE because they maintain important business relationships with actual RE companies. To avoid any spurious influence of these non-RE companies on our results we exclude them from the data based on their industry codes. One might argue that employees of temporary work agencies that are hired to RE companies are actually part of the RE value chain. However, we still have to exclude these workers because, for one thing, the membership of an agency in a RE association gives no indication on whether or to what extent its workers are actually hired to RE companies. For another thing, wages in German temporary work agencies are mostly determined by collective agreements within the temporary work sector rather than by wage setting in their client companies (e.g., Jahn/Pozzoli 2013).

The data linkage and the removal of establishments from irrelevant sectors leave us with our full sample of 3,215 RE establishments with more than 360,000 employees (see *Table 3-1*). As our estimation approach relies on a comparison with non-RE establishments, we need to identify sectors that contain the most relevant RE establishments. While doing so, we observe that RE establishments are spread over several different sectors (using the Classification of Economic Activities, issue 2008 (WZ 2008) of the German Federal Statistical Office, see also Destatis 2008). To identify the most relevant RE sectors, we select those sectors that comprise more than 100 RE establishments in our sample. *Table 3-2* shows that the most relevant RE sectors are *Manufacturing*; *Electricity*; *Construction*; *Trade*; *Transport* and *Professional, scientific and technical activities (WZ 2008, 1-digit codes: C, D, F, G, H, M).* These six sectors cover 2,906 RE establishments (about 90 percent of the full sample) and 342,557 employees (95 percent of the full sample).

However, for the empirical analysis of wage differentials we are still facing the challenge that heterogeneity between establishments within a sector can still be very high at this aggregated 1-digit level. For instance, the manufacturing sector contains establishments which produce computers, electronic components or electric motors but also

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[13] Manfred Antoni conducted the record linkage as a member of the German Record Linkage Center (GRLC), which was funded by the German Research Foundation (DFG) at the time. The record linkage also benefitted from methods described by Schäffler (2014).

establishments where the main focus lies in processing and preserving of fish or fruits and vegetables. In order to avoid comparing apples (e.g., RE establishments producing electric motors) and oranges (e.g., non-RE establishments preserving fruits), we narrow the focus of our analysis to the most detailed and feasible level of aggregation, i.e., the 3-digit level of the WZ 2008. At this level of aggregation, we select sixteen sectors with at least 50 RE establishments each. These sectors comprise 1,752 RE establishments with 182,386 RE employees (see Table 3-3).

Due to space limits we are not able to discuss the results of our econometric analysis for all of these sixteen sectors in detail. We rather present the key estimation results for all of them in our results section and discuss only four paradigmatical 3-digit sectors. These four 3-digit sectors are selected from different areas according to the number of RE establishments per sector. We focus on *Manufacturing*, *Electricity*, *Construction and Professional, scientific and technical activities*.[14]

As exemplary for Manufacturing we choose *Manufacture of electronic components and boards* (sector 261).[15] Furthermore, we select *Electric power generation, transmission and distribution* (sector 351) for Electricity, *Electrical, plumbing and other construction installation activities* (sector 432) for Construction and *Architectural and engineering activities and related technical consultancy* (sector 711 for Professional, scientific and technical activities. Altogether, these four sectors comprise 583 RE establishments with more than 75,000 employees.

We are confident that these four sectors paradigmatically reflect relevant areas of the renewable energy value-chain. *Table 3-3* shows the development of the number of RE observations over the process of data preparation at the company, establishment and employee levels. Although it is not in the focus of our analyses, *Table 3-3* includes the observation numbers differentiated for the energy types wind, solar and others. This shows that our sample selection does not influence the energy type composition to a large extent. However, presenting detailed results for a meaningful part of the renewable energy value-chain does not necessarily mean that these results are representative for the whole field of RE. Therefore, section 3.2 also presents and discusses the results for the full sample (3,215 establishments) and sector-specific results at different levels of aggregation. Important areas of the machinery sector are included in this discussion as well as the sectors trade and transport.

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[14] Due to the word limit, we will not discuss the sectors *Trade (G.)* and *Transport (H.)* in detail. This seems appropriate since *Trade* and *Transport* do not necessarily belong to the most RE intensive sectors (Helmrich et al. 2014; Lehr et al. 2015). However, *Trade* and *Transport* are still very relevant sectors with large numbers of RE establishments and RE employees in our sample. Consequently, we present in Table 3-7 the core econometric results for sectors of *Trade* and *Transport*, too.

[15] *Table 3-3* shows that other 3-digit sectors within Manufacturing have the same or nearly the same number of RE establishments. We select the sector Manufacture of electronic components and boards for detailed analysis and discussion because of its higher RE employment.

Table 3-1: Number of renewable energy observations in 2009

	Companies		Establishments		Employees	
	Number	**Share**	**Number**	**Share**	**Number**	**Share**
Entries in BEE membership list	2,760	100.00%	N/A	N/A	N/A	N/A
Wind	7	28.37%	N/A	N/A	N/A	N/A
Solar	1,153	41.78%	N/A	N/A	N/A	N/A
Rest	824	29.86%	N/A	N/A	N/A	N/A
Full sample	1,232	100.00%	3,215	100.00%	361,303	100.00
Wind	291	23.62%	557	17.33%	50,710	14.04%
Solar	532	43.18%	1,226	38.13%	223,436	61.84%
Rest	409	33.20%	1,432	44.54%	87,157	24.12%
Selection of four sectors	415	100.00%	583	100.00%	75,363	100.00
Wind	105	25.30%	141	24.19%	9,609	12.75%
Solar	206	49.64%	265	45.45%	50,891	67.53%
Rest	104	25.06%	177	30.36%	14,863	19.72%

Note: Full sample denotes the sample after record linkage and after removing non-relevant sectors as discussed above. Source: BEE membership list, Establishment History Panel of the Institute for Employment Research, own calculations.

Table 3-2: Full-sample of RE establishments and RE employees in 2009 by economic sectors, WZ 2008 (1-digit level)

Economic sector, WZ 2008 (1-digit code)		**Number of RE establishments**	**Number of RE employees**
C	Manufacturing	768	216,762
D	Electricity, gas, steam and air conditioning supply	187	26,429
E	Water supply; sewerage, waste management and remediation activities	31	2,172
F	Construction	332	13,179
G	Wholesale & retail trade; repair of motor vehicles & motorcycles	1,020	30,370
H	Transportation and storage	115	3,735
J	Information and communication	49	2,184
K	Financial and insurance activities	62	1,748
M	Professional, scientific and technical activities	484	52,082
N	Administrative and support service activities	62	3,644
S	Other service activities	38	1,349
	Remaining sectors	67	7,649
	Total	**3,215**	**361,303**

Note: Sectors with less than 20 establishments are subsumed in the category "Remaining sectors" due to privacy guidelines. This category comprises the following sectors: A. Agriculture, forestry and fishing; B. Mining and quarrying; I. Accommodation and food service activities; L. Real estate activities; O. Public administration and defense; compulsory social security; P. Education; Q. Human health and social work activities; R. Arts, entertainment and recreation; T. Activities of households as employers; undifferentiated goods and services producing activities of households for own use.
Source: BEE membership list, Establishment History Panel of the Institute for Employment Research, own calculations.

Table 3-3: Extract from full-sample of RE establishments and RE employees in 2009 by economic sectors, WZ 2008 (3-digit level)

Economic Sector **WZ 2008 (3-digit code; subheadings: 1-digit code)**		**Number of RE establishments**	**Number of RE employees**
C	Manufacturing		
261	Manufacture of electronic components and boards	58	36,229
271	Manufacture of electric motors, generators, transformers, electricity distribution and control apparatus	58	27,795
281	Manufacture of general-purpose machinery	51	28,892
282	Manufacture of other general-purpose machinery	57	3,254
D	Electricity, gas, steam and air conditioning supply		
351	Electric power generation, transmission and distribution	141	24,456
F	Construction		
432	Electrical, plumbing and other construction installation activities	190	6,613
G	Wholesale and retail trade, repair of motor vehicles and motorcycles		
461	Wholesale on a fee or contract basis	195	5,494
462	Wholesale of agricultural raw materials and live animals	132	3,250
467	Other specialized wholesale	187	9,810
469	Non-specialized wholesale trade	51	1,440
471	Retail sale in non-specialized stores	131	2,593
475	Retail sale of other household equipment in specialized stores	96	2,042
H	Transportation and storage		
522	Support activities for transportation	64	2,389
M	Professional, scientific and technical activities		
692	Accounting, bookkeeping and auditing activities; tax consultancy	75	16,575
711	Architectural and engineering activities and related technical consultancy	194	8,065
712	Technical testing and analysis	72	3,489
	Total	1,752	182,386

Notes: The table contains all sectors at the 3-digit level with more than 50 RE establishments.
Source: BEE membership list, Establishment History Panel of the Institute for Employment Research, own calculations.

3.2.3 Estimation of the wage differential

Our dependent variable is w_{et} for RE establishments (and W_{et} for non-RE establishments), i.e., the median wage of establishments *e*, given at a specific time *t*. In our basic model, wages are determined by three different parameters:

ϕ / Φ : Establishment-level determinants of wages in terms of human capital/personnel structure

ψ / Ψ : Establishment-level determinants of wages in terms of other establishment characteristics

τ / T : Residual variable for all unobservable determinants (at the establishment-level and others)

Formally, this is

(1) $$w_{et} = \phi + \psi + \tau$$

for RE establishments, and

(2) $$W_{et} = \Phi + \Psi + \mathrm{T}$$

for non-RE establishments.

Hence, the wage differential is

(3) $$w_{et} - W_{et} = \Delta w_{et}.$$

A straightforward way to explain raw wage differentials between two groups is to employ the Blinder (1973)-Oaxaca (1973) decomposition technique. The decomposition is based on the wage regressions

(4) $$\ln w_{et} = x'_{et}\beta + \varepsilon_{et} \quad \text{and} \quad \ln W_{et} = X'_{et}\mathrm{B} + \mathrm{E}_{et}$$

for RE establishments and the reference group of non-RE establishments, respectively. Here, $\ln w_{et}$ and $\ln W_{et}$ represent the logarithm of gross daily median wages for full time employees within establishment e in year t, x_{et} (X_{et}) are vectors of establishment-level control variables, and β (B) are vectors that contain the corresponding coefficients. The residuals, ε_{et} (E_{et}), are assumed to be uncorrelated with all other right-hand side variables. We include a rich set of control variables: linear and squared terms of log establishment size and age, median age of employees within the establishment, a dummy for being located in the eastern part of Germany, four variables capturing the type of the region, twelve variables measuring the shares of specific characteristics of workers within an establishment (*Share of female employees, Share of German employees,* and the other shares being subsumed in the categories *Qualification, Working time* and *Occupational status*) and eleven variables capturing the *Share of occupational categories* as presented in *Table 3-4*. At the aggregated level of analysis we further include a detailed set of dummy-regressors controlling for industry effects (at a 5 digit level). These variables capture most of the determinants discussed above. However, the lack of data prevents us from analyzing the effects of regulation, rent sharing, export orientation and compensating wage factors directly. However, we carefully take these important factors into account in our discussion of the sector-specific results.

The contributions of the various right-hand side variables to the mean wage difference $\overline{w} - \overline{W}$ between the RE establishments and non-RE establishments is obtained by feeding the regression results into the Blinder- Oaxaca decomposition

(5) $$\overline{w} - \overline{W} = \overline{X}(\hat{\beta} - \hat{B}) + (\overline{x} - \overline{X})\hat{B} + (\overline{x} - \overline{X})(\hat{\beta} - \hat{B})$$

The three expressions on the right hand side of the equation represent the coefficient, characteristic and interaction effects, respectively. The coefficient effects measures the wage difference due to differential remuneration of the characteristics of RE establishments and non-RE establishments, the characteristic effects measures the wage difference due to differences in observed endowments, and the interaction effects measure the wage difference resulting for RE establishments if endowment differences were remunerated with the coefficient differences. An extension of the decomposition to the contributions of individual regressors or regressor groups (as e.g., dummy variable sets) is possible by applying the above formula to individual regressors.

The estimation approach employs this Blinder-Oaxaca decomposition for the year 2009 at both the aggregate and sector-specific levels. This tells us the extent to which the wage differential can be explained by differences in characteristics being observed in our data. The unexplained gap reflects all of the factors that cannot be observed in our data. This includes the effects of regulation and other factors like rent sharing, export orientation or compensating wage factors. In section 3.2, we carefully take this into account when discussing the sector-specific results.

3.3 Results and discussion

3.3.1 Characteristics of RE and non-RE establishments

Table 3-4 shows some basic characteristics of RE and non-RE establishments in the four sectors during the year 2009. We observe that RE establishments pay distinctly higher wages than non-RE establishments: the average gross daily median wages for full-time employees within the establishment is approximately 102 Euros for RE establishments and approximately 74 Euros for non-RE establishments.[16] This large wage premium indicates that there might be substantial differences in the characteristics of both groups. With respect to *Establishment size*, one difference is obvious: the average number of employees is 129 in RE establishments and only 11 in non-RE establishments. We interpret this as a first hint that RE establishments and non-RE establishments are hardly comparable at an aggregated level and should therefore be analyzed at the sector level instead.[17] One could assume that the high median wages paid by RE establishments are

[16] The table shows that this result holds for other percentiles of the wage distribution within the establishment and also for specific employment groups like the highly-skilled employees.

[17] However, there are still establishment size differentials within sectors, as we show in section 3.3.2. We therefore control for different establishment size distributions (see 3.5.1 Appendix A.1.2).

related to establishment size wage premia, at least to some extent. Further differences that may partly explain the observed wage premium are a higher *Share of fulltime employees* in RE establishments (79 percent vs. 74 percent), a lower *Share of marginally employed workers* (10 percent vs. 16 percent) and a lower *Share of female employees* (28 percent vs. 32 percent). Regarding the skill composition and qualification levels within establishments, the picture is mixed: on the one hand, the *Share of qualified workers* (and also the *Share of skilled workers*)[18] is somewhat lower in RE establishments (45 percent vs. 52 percent), but on the other hand, the *Share of highly skilled workers* is distinctly higher (19 percent vs. 10 percent). The latter is also true for the *Share of white-collar employees*. Turning to the occupational structure one observes marked differences for the *Share of skilled manual occupations* (23 percent in RE establishments vs. 38 percent in non-RE establishments) and the *Share of engineers*; the latter being distinctly higher in RE establishments (15 percent vs. 10 percent). Management professions also play a more important role for RE establishments (6 percent vs. 2 percent). Next, Table 3-4 entails information about the age structure: there is almost no difference between employees of RE establishments and those of the control group. For instance, the median age is 40.3 years compared with 40.6 years for non-RE employees. A further aspect concerns the distribution of establishments over regions and region types. Ulrich et al. (2012) note that there are regional concentrations in specific fields of the RE sector. Our results underline this evidence. We find that RE establishments are strongly represented in core cities and in the northern and eastern part of Germany (the latter is not documented in the table due to space restrictions).[19]

As noted above, we argue that RE establishments and non-RE establishments should be compared at a more disaggregated 3-digit sector level. Interestingly, although the four sectors differ in several respects and sometimes substantially, the described differences between RE establishments and non-RE establishments at the aggregate level persist within sectors. As a prominent exception, we observe that the wage premium is reversed in *Electric power generation, transmission and distribution*. Here, the median gross daily wages for full time employees are 111 Euros for RE establishments on average but approximately 120 Euros for non-RE establishments. Regarding other characteristics, it is evident that the *Share of female employees* is higher in RE establishments than in non-RE establishments, which is different from other sectors and the aggregate. Further

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[18] *Qualified workers:* employees in an establishment with either an upper secondary school leaving certificate as their highest school qualification or a vocational qualification; *Skilled workers*: employees with the value ‘Skilled worker’ (value 2) in the B1 code (B1 code contains values of occupational status; e.g., employee in vocational training (0), unskilled worker (1), skilled worker (2), master craftsman (3), white-collar employee(4)) (Gruhl et al. 2012)

[19] The described differences in characteristics are very similar in the full sample (see Table 3-8 in the Appendix). Larger deviations concern the regional distribution (RE establishments are more evenly distributed over region types) and the occupational structure. For instance, the share of skilled manual occupations is distinctly lower and the same for both RE and non-RE establishments. This is not surprising because the full sample also includes services sectors with lower levels of qualification.

differences with respect to the aggregate are, for instance, a comparable *Share of qualified employees* in RE and non-RE establishments within *Electrical, plumbing and other construction installation activities* and that the median age is even slightly higher in RE establishments of this sector.

In sum: the descriptive evidence shows for the aggregate and for each sector separately, marked differences in observed characteristics between RE establishments and non-RE establishments. But do these differences explain the observed wage differential?

Table 3-4: Average characteristics of RE establishments and non-RE establishments in the year 2009 (four selected sectors at 3-digit level)

WZ 2008, 3-digit code			261		351		432		711	
	Four selected sectors (Total)		Manufacture of electronic components and boards		Electric power generation, transmission and distribution		Electrical, plumbing and other construction installation activities		Architectural and engineering activities and related techn. consultancy	
Variables	**non-RE**	**RE**	**non-RE**	**RE**	**non-RE**	**RE**	**non-RE**	**RE**	**non-RE**	**RE**
Wage (gross average daily wage) quartile P25 for all full-time employees (fte)	64.55	85.48	71.75	84.21	108.32	96.72	59.21	75.49	70.03	87.48
Wage quartile Med for all fte	73.89	101.87	84.88	105.53	119.95	111.33	66.85	87.77	82.01	107.71
Wage quartile P75 for all fte	82.94	118.69	102.20	132.76	131.73	127.64	73.68	99.57	94.36	126.70
Wage quart. P25 highly qualified fte	98.72	118.21	115.97	128.14	144.29	123.27	94.35	118.33	95.31	111.82
Wage quart. Med highly qualified fte	107.61	132.84	129.59	144.41	154.21	137.34	100.29	130.64	104.61	127.41
Wage quart. P75 highly qualified fte	115.94	144.46	141.14	157.21	159.44	148.32	105.80	140.49	113.73	139.92
Number of employees	10.5	129.3	55.8	624.6	54.7	173.4	8.3	34.8	8.7	41.6
Share of full-time employees	73.8	79.4	76.8	86.2	83.0	85.7	73.0	75.8	74.3	76.3
Share of marginal part-time workers	15.5	10.3	14.2	5.9	6.8	5.9	15.1	10.9	16.9	14.0
Share of female employees	32.2	27.8	39.5	27.5	22.3	27.6	21.9	20.3	50.9	35.2
Share of qualified employees	52.1	44.9	47.2	34.3	66.8	50.3	58.5	58.6	39.7	30.8
Share of highly qualified employees	9.7	19.0	12.7	19.1	12.7	20.8	1.5	6.1	23.9	30.4
Share of German employees	95.2	95.8	94.4	96.2	98.1	96.2	94.4	96.3	96.3	94.9
Share of trainees/apprentices	5.0	3.8	2.1	3.2	2.2	2.2	7.1	7.5	1.7	1.5
Share of skilled workers	28.6	19.4	16.9	15.2	27.1	18.6	42.4	37.2	5.0	3.8
Share of unskilled employees	12.0	8.1	19.9	14.8	8.5	6.0	16.6	12.3	3.8	3.5
Share of master crafts- and foremen	2.2	1.9	1.2	0.6	5.1	3.0	2.8	3.0	0.8	0.4
Share of white-collar employees	33.1	51.4	40.7	56.6	43.1	59.6	13.4	24.9	66.8	69.9

Share of employees in midi part-time employment	4.4	5.3	5.6	3.3	7.0	5.3	3.6	4.8	5.4	6.4
Share of unskilled manual occupations	9.0	8.1	20.9	15.1	8.3	8.4	12.6	8.9	2.3	5.0
Share of unskilled services	4.2	4.4	6.7	4.6	6.0	4.3	3.2	4.4	5.7	4.5
Share of unskilled commercial and admin. occupations	5.3	5.1	3.4	3.1	3.5	6.2	4.6	3.8	6.6	6.0
Share of skilled manual occupations	37.5	23.0	21.1	13.4	31.2	18.1	57.6	49.2	3.3	3.7
Share of skilled services	0.7	0.7	0.4	0.2	1.4	0.9	0.2	0.2	1.4	1.2
Share of skilled commercial and admin. occupations	18.5	23.1	19.9	24.7	23.5	26.6	16.1	17.1	22.1	25.9
Share of technicians	11.0	11.4	11.1	12.6	9.4	10.1	2.4	9.4	26.4	13.8
Share of semiprofessions	0.1	1.0	0.2	0.1	0.5	0.6	0.0	0.1	0.2	2.5
Share of engineers	10.1	14.5	8.8	15.0	6.1	12.8	0.7	2.9	27.1	27.0
Share of professions	0.2	1.0	0.4	1.0	0.5	1.8	0.1	0.1	0.4	1.2
Share of managers	1.9	6.3	5.2	7.8	6.8	9.3	1.1	2.3	2.7	7.6
Age quartile P25 of the total of emp.	33.6	32.9	35.4	31.2	37.8	35.2	32.0	32.0	36.1	32.8
Age quartile Med of the total of emp.	40.6	40.3	42.4	39.0	44.1	41.8	39.6	40.2	41.9	39.8
Age quartile P75 of the total of emp.	47.6	47.2	49.2	46.5	49.7	47.7	47.2	47.9	48.0	46.4
Core cities	28.7	36.7	24.2	36.2	18.6	33.3	24.4	28.4	37.3	47.4
Urbanized districts	38.2	34.5	46.7	31.0	35.5	26.2	39.0	40.0	36.4	36.1
Rural districts with features of concentration	17.4	16.6	16.1	20.7	23.4	22.7	19.0	16.8	14.2	10.8
Rural districts – sparsely populated	15.7	12.2	12.9	12.1	22.5	17.7	17.5	14.7	12.1	5.7
Total number of establishments	114,489	583	1,827	58	3,285	141	69,846	190	39,531	194

Source: BEE membership list, Establishment History Panel of the Institute for Employment Research, own calculations.

Table 3-5: Decomposition of log gross average daily wages for four selected sectors at the sample means for the year 2009 (comparison group: non-RE establishments)

WZ 2008, 3-digit code			261		351		432		711	
	Four selected sectors (Total)		Manufacture of electronic components and boards		Electric power generation, transmission and distribution		Electrical, plumbing and other construction installation activities		Architectural and engineering activities and related techn. consultancy	
	Coefficients	s.e.	Coefficients	s.e.	Coefficients	s.e.	Coefficients	s.e.	Coefficients	s.e.
Prediction RE establishments	4.556***	0.016	4.597***	0.047	4.656***	0.031	4.414***	0.027	4.609***	0.030
Prediction non-RE establishments	4.202***	0.001	4.340***	0.011	4.682***	0.009	4.131***	0.002	4.279***	0.003
Predicted difference	0.354***	0.016	0.257***	0.048	-0.026	0.032	0.282***	0.027	0.330***	0.030
ENDOWMENT EFFECTS										
Establishment size	0.098***	0.006	0.087***	0.014	0.023**	0.011	0.099***	0.008	0.136***	0.011
Establishment age	-0.006***	0.001	0.005	0.006	-0.001	0.002	0.006*	0.003	-0.004***	0.001
Region	-0.008*	0.004	-0.033*	0.018	-0.040***	0.011	0.001	0.009	0.002	0.005
Region type	0.005***	0.001	0.007	0.005	0.017***	0.006	0.003	0.002	0.010***	0.003
Median age	-0.000	0.000	-0.010	0.006	-0.008**	0.004	0.001	0.001	-0.004***	0.001
Working time	-0.000	0.001	-0.003	0.014	0.014	0.012	0.001	0.001	-0.000	0.002
Share of female employees	0.020***	0.004	0.064***	0.013	-0.020**	0.009	0.006	0.005	0.070***	0.007
Education	0.014***	0.002	0.007	0.008	0.003	0.016	0.011***	0.003	0.008***	0.003
Nationality	0.001*	0.001	-0.002	0.002	0.001	0.003	0.004***	0.001	-0.001*	0.001
Occupational status	-0.006**	0.002	0.038**	0.019	0.006	0.016	-0.029***	0.005	0.003	0.004
Occupational composition	0.027***	0.004	0.061***	0.016	-0.034**	0.014	0.035***	0.005	-0.002	0.007
Industry	0.116***	0.007								
Total	**0.260*** **	**0.012**	**0.221*** **	**0.040**	**-0.040**	**0.029**	**0.139*** **	**0.018**	**0.219*** **	**0.020**

WZ 2008, 3-digit code				261		351		432		711	
	Four selected sectors (Total)		**Manufacture of electronic components and boards**		**Electric power generation, transmission and distribution**		**Electrical, plumbing and other construction installation activities**		**Architectural and engineering activities and related techn. consultancy**	
	Coefficients	**s.e.**	**Coefficients**	**s.e.**	**Coefficients**	**s.e.**	**Coefficients**	**s.e.**	**Coefficients**	**s.e.**
COEFFICIENT EFFECTS										
Establishment size	-0.143***	0.039	-0.432***	0.120	-0.189**	0.082	-0.204***	0.074	-0.165**	0.072
Establishment age	-0.012	0.034	-0.048	0.056	0.078	0.065	-0.098	0.063	0.058	0.052
Region	0.004	0.008	0.032**	0.014	0.029*	0.016	-0.008	0.012	-0.008	0.015
Region type	-0.006	0.019	-0.094***	0.034	-0.082	0.066	0.062**	0.029	-0.027	0.030
Median age	0.190**	0.092	-0.054	0.311	-0.315	0.270	0.297***	0.104	0.335*	0.171
Working time	-0.041	0.246	-0.139	0.946	-0.353	0.587	-0.327	0.344	-0.133	0.464
Share of female employees	0.018	0.037	0.028	0.078	0.005	0.038	0.067	0.053	-0.025	0.108
Education	-0.011	0.029	0.070	0.060	-0.313***	0.094	0.032	0.051	0.022	0.057
Nationality	-0.235	0.179	-0.842	0.515	0.101	0.446	-0.692***	0.192	-0.296	0.218
Occupational status	0.201	0.166	-1.220**	0.544	0.373	0.389	0.192	0.183	0.491	0.394
Occupational composition	0.122	0.163	-0.314	0.637	0.701	0.561	0.421**	0.195	0.568**	0.276
Industry	0.219***	0.071								
Constant	-0.138	0.342	3.161**	1.344	-0.072	0.857	0.390	0.430	-0.665	0.415
Total	**0.166*** **	**0.027**	**0.148** **	**0.067**	**-0.036**	**0.033**	**0.132*** **	**0.039**	**0.157** **	**0.062**
INTERACTION EFFECTS										
Establishment size	-0.026	0.018	-0.180***	0.058	-0.018	0.012	-0.060**	0.028	-0.050	0.033
Establishment age	0.001	0.004	0.010	0.010	-0.002	0.008	-0.007	0.005	-0.009	0.010
Region	0.001	0.001	0.017	0.012	0.023*	0.014	0.000	0.001	0.000	0.001
Region type	-0.000	0.002	0.004	0.014	0.015	0.012	-0.005	0.004	0.006	0.009

WZ 2008, 3-digit code			261		351		432		711	
	Four selected sectors (Total)		**Manufacture of electronic components and boards**		**Electric power generation, transmission and distribution**		**Electrical, plumbing and other construction installation activities**		**Architectural and engineering activities and related techn. consultancy**	
	Coefficients	**s.e.**	**Coefficients**	**s.e.**	**Coefficients**	**s.e.**	**Coefficients**	**s.e.**	**Coefficients**	**s.e.**
Median age	-0.001	0.002	0.004	0.025	0.016	0.015	0.005	0.005	-0.017*	0.010
Working time	0.012	0.012	0.221***	0.075	-0.022	0.016	0.028**	0.012	0.004	0.014
Share of female employees	-0.002	0.005	-0.009	0.024	0.001	0.009	-0.005	0.005	0.008	0.033
Education	0.003	0.010	-0.056**	0.026	0.033	0.028	-0.009	0.019	0.008	0.012
Nationality	-0.002	0.002	-0.016	0.011	-0.002	0.008	-0.014**	0.006	0.004	0.004
Occupational status	0.038*	0.021	-0.159**	0.068	0.011	0.028	0.048**	0.021	-0.002	0.014
Occupational composition	0.013	0.021	0.053*	0.032	-0.005	0.038	0.030	0.024	0.003	0.019
Industry	-0.110***	0.016								
Total	**-0.072*** **	**0.022**	**-0.112***	**0.066**	**0.050**	**0.033**	**0.011**	**0.036**	**-0.046**	**0.050**

Notes: Standard errors in parentheses. Significance levels are reported at 1% (***), 5% (**) and 10% (*) levels.
Source: BEE membership list, Establishment History Panel of the Institute for Employment Research, own calculations.

3.3.2 Determinants of wage differentials between RE and non-RE establishments

The left panel of Table 3-5 contains the predicted gross median daily wages for all full-time employees of RE and non-RE establishments, the predicted positive wage advantage of 35 log points for RE establishments, and the Blinder-Oaxaca decomposition results. The table shows that the endowment effect is generally positive (26 log points) and statistically significant at the 1 percent level. Hence, the wage premium of RE establishments over non-RE establishments can actually be explained largely by the favorable characteristics of RE establishments. In particular, establishment size (10 log points) and industry effects (12 log points) contribute to higher wages for RE establishments. To a lesser extent, further wage enhancing effects are driven by the under-representation of female workers (2 log points), by qualification effects (1 log point) and by the occupational composition (3 log points). Negative effects can be observed for establishment age, region and the aggregated occupational status variables, but all are below 1 log point.

Turning to the coefficient effects, which measures the wage difference due to divergent remuneration of endowments of RE and non-RE establishments, it becomes clear that this also adds to higher wages for RE establishments (17 log points). It should be noted that pay differentials might be due to unobserved heterogeneity between member and non-RE establishments. Specifically, at this aggregated level of analysis, it is therefore not surprising that the unexplained gap is so large. Regarding the statistically significant single regressor effects, the negative establishment size effect (-14 log points) is overcompensated by the positive effects of the median age within the establishment and the industry controls. The latter is a further hint that the sector matters when analyzing the wage premium.

The single interaction effects are statistically not significant at the five percent level; one exception is again the industry effect (-11 log points). Altogether, the interaction effects sum to a total of -7 log points and therefore reduce the observed wage gap.

Turning to the *Manufacture of electronic components and boards* sector, particularly establishment size, occupational composition and *Share of female employees* explain a crucial part of the raw wage premium is 26 log points in this sector. The latter stems from the clear over-representation of male employees in RE establishments within this sector (see Table 3-4).

Altogether, the endowment effects sum to 22 log points, while both coefficients and interaction effects are smaller (+15 log points and -11 log points, respectively) and are statistically significant at the 5 and 10 percent level only. In sum, the results for this sector show that our regressors are able to explain the observed raw wage premium to a large extent, indicating that unobserved heterogeneity plays a minor role. Possible reasons are that this industry is facing a strong international competition and continuously falling product prices. Because of this difficult market situation, the wage driving factors of export orientation and compensating wage factors probably have only a little or no effect in the current situation. Furthermore, the high costs for research and development in this sector can also reduce productivity (see Soltmann et al. 2015 on productivity impacts of green inventions). Consequently, this may lead to a smaller scope for rent sharing in terms of an additional increase in wages. Finally, structural changes seem to take place due to technological change and the maturity of product life cycles. For example, photovoltaic-panels with silicon-based solar cells have reached a life cycle stage of semi-automated mass production[20]. Related tasks have thus become increasingly subject to routinization in the sense of Autor et al. (2003) and are therefore more "offshorable", which puts wages under pressure (Blinder/Krueger 2013; Autor 2013)[21]. On the contrary, the wind energy sector is, to some extent, in a different stage of the product life cycle. Intensified by the specific production processes, the production of wind power stations continues to show a high degree of complex non-routine manual tasks. Wind energy related manufacturing establishments partly report a shortage of workers possessing those skills. Therefore, the business cycle stage of the specific RE technology (wind, solar, biomass etc.) could influence the demand for labor and thus the wage level. A further central sector of the RE value chain is *Electric power generation, transmission and distribution*. In contrast to the other observed sectors, we find no wage premium in favor of RE establishments. This result is somewhat unexpected. One might expect that these establishments would profit most from the financial promotion of renewable energies and share possible financial surpluses with their employees, but this is not the case. Due to the long-term financial burden of investing in RE plants and the steadily changing support framework, most RE suppliers might be unable to share this benefit with their workers. A possible explanation is that within these capital-intensive[22] businesses only the investors profit financially – if there is a surplus to be shared at all.

Whereas the small negative RE wage differential of *Electric power generation, transmission and distribution* is statistically not significant, some single regressor effects have an influence, for instance, the endowment effects for *Establishment size* and *Region type* (both +2 log points), *Region* (-4 log points), *Share of female employees* (-2 log points) or *Occupational composition* (-3 log points). The same is true for the total of endowment, coefficient and interaction effects. The result of non-differing wages between RE establishments and non-RE establishments is worth mentioning in the face of the distinct differences in characteristics, as described above, and should be examined in future work. Other arguments, such as export orientation and compensating wage factors, are less

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[20] For example, Schmalensee et al. (2015, p 26) report a current development in the solar industry: *'Advanced factories can produce thin-film modules in a highly streamlined and automated fashion'*.

[21] In almost every occupational field, there is a higher share of non-routine tasks in RE establishments than in non-RE establishments (Helmrich et al., 2014). This fact could explain part of the unexplained rest of the positive wage differential of many RE sectors. Nevertheless, in parts of the value chain of RE where (semi-) automated processes increase, routinization may also increase.

[22] In this context, the increasing difficulties in raising capital for RE projects (Cárdenas Rodríguez et al. 2015) may also lead to higher costs and lower profits.

important in the sector *Electric power generation, transmission and distribution*. In this sector, there is a strong focus on the domestic market and thus a lower export orientation than in other sectors. Furthermore, most of the energy providers show a relatively high firm age (e.g., municipal utilities), which reduces the risk of unemployment and thus reduces the relevance of wage compensation.

The wage premia in both remaining sectors—*Electrical, plumbing and other construction installation activities* and *Architectural and engineering activities and related technical consultancy*—are 28 and 33 log points, respectively. For the latter, two-thirds of the raw wage premium can be explained by observed characteristics (again, establishment size and gender effects are important). However, the unexplained wage premium remains high. The same is true for *Electrical, plumbing and other construction installation activities*, where 50 percent of the gap remains unexplained. We interpret the wage premium as a possible indirect effect of the promotion of RE in favor of employees within the *Electrical, plumbing and other construction installation activities* and *Architectural and engineering activities and related technical consultancy* sectors.

There are several possible explanations as to why employees in these two sectors benefit more from the promotion of RE than employees in the two other sectors: First, since the German domestic demand for RE products has grown strongly within the last several years, the demand for planning, project management, installation and operation activities in the field of RE has strongly increased as well. Second, the two sectors benefited from the falling global product prices, whereas the high-tech manufacturing sector suffered because of this development. Those first two developments allow employers to apply rent sharing in order to involve and motivate their employees. Third, in both RE wage premium sectors, non-routine manual tasks and abstract, non-routine cognitive tasks seem to be prevalent. According to the task-based literature, these tasks are less offshorable and wages are under less pressure than in jobs with a higher degree of routinization (Blinder/Krueger 2013; Autor 2013; Autor et al. 2003). Fourth, another wage-related advantage of *Construction installation activities* and *Architectural and engineering activities* is their relatively low capital-intensity. On the contrary, the other two sectors (energy suppliers and high-tech manufacturers) are facing costly investments in terms of new RE plants or research and development, respectively. Fifth, a shortage of skilled labor might be another relevant driver for the wage premium. For two reasons we are confident that this is not the case here: the variables controlling for *Qualification, Occupational status* and *Occupational composition* may cover a substantial degree of this phenomenon. Furthermore, there are no hints for the shortage of skilled labor being more prevalent in the *Construction installation activities* and *Architectural/engineering services* sectors than in the *High-tech manufacturers* and E*nergy provider* sectors. Sixth, one could hypothesize that RE establishments use temporary agency work more often than non-RE establishments and therefore are able to pay higher wages to their core workforce. According to Lehr et al. (2011b, 2015), the share of temporary agency workers in RE establishments is relatively high (2007: 7.4 percent / 2012: 9.8 percent) and differs between RE types (2007: e.g., Wind 11.3 percent, photovoltaics 7.3 percent). In contrast, the German Labor Placement Statistics shows a much lower share of temporary agency workers within the total work force (2007: 2.1 percent / 2012: 2.6 percent, BA 2015b). However, in a survey question regarding motivation for using temporary agency work, only 7.2 percent of the RE establishments answer that the reason is the different wage structure (Lehr et al. 2015). According to their answers, these RE establishments rather take advantage of the flexibility offered by temporary agency work. Because of the limitations of our data, we cannot address this issue in more detail. Seventh, export orientation seems not to apply for both planning and installation because most of these establishments are more engaged in domestic markets. Eighth, compensating wage factors could probably be more influential, but there seems to be no specific difference in risk-taking, for instance, whether a roofer covers a roof with tiles or with photovoltaic modules. Finally, it may also be worthwhile to analyze the effects of membership in specific industry associations. Because we use the membership of the RE association in Germany as a proxy for being a RE establishment, we are aware that this might cause selectivity concerning our treatment group. Eichner/Pethig (2015) provide a comprehensive overview of related literature and add their own findings to the topic of lobbying for renewable energy promotion. However, there is no information included about some kind of "green lobbying employment/wage impact". We argue that, since many companies (RE and non-RE alike) are members of industry associations, membership in such an association and its potential benefits do not seem to be RE-specific. Furthermore, there is no indication for the German RE association being more effective or successful than other industry associations.

In sum, the sector-specific Blinder-Oaxaca decomposition of wages has shown that RE establishments in one sector differ from RE establishments in other sectors. Moreover, in two of the four sectors (*Construction installation activities* and *Architectural and engineering services*), the observed wage differences cannot be fully explained by the differences in characteristics between RE establishments and non-RE establishments. Interpreting these results and discussing possible explanations and sector-specific differentials, we conclude that there is a positive indirect effect of the promotion of RE in *Construction installation activities* and *Architectural and engineering services*.

But how representative are these results for other sectors and for other levels of aggregation? We argue that our focus on 583 establishments of four paradigmatical RE sectors avoids comparing apples and oranges. However, this narrow focus could raise the question whether the selected sample is representative for the whole economic field of RE. Moreover, the paper has so far shed no light on whether the effects differ between different technologies like wind, solar and others. If the selection into four paradigmatical sectors favors specific technologies one could question the general validity of the documented results. To address these issues, this subsection firstly uses the full sample as described above.

Table 3-6: Decomposition of log gross average daily wages for the full sample at sample means (comparison group: non-RE establishments) by RE type for the year 2009

	Full sample (Total)		Renewable energy type: Wind		Solar		Others	
	Coefficients	s.e.	Coefficients	s.e.	Coefficients	s.e.	Coefficients	s.e.
Prediction RE establishments	4.557***	0.007	4.595***	0.017	4.528***	0.013	4.568***	0.009
Prediction non-RE establishments	4.031***	0.000	4.031***	0.000	4.031***	0.000	4.031***	0.000
Predicted difference	0.527***	0.007	0.564***	0.017	0.497***	0.013	0.537***	0.009
ENDOWMENT EFFECTS								
Establishment size	0.109***	0.003	0.090***	0.007	0.107***	0.004	0.118***	0.004
Establishment age	0.005***	0.001	-0.007***	0.002	0.004***	0.001	0.011***	0.001
Region	0.003**	0.002	-0.007*	0.004	0.001	0.003	0.010***	0.002
Region type	-0.001	0.000	0.004***	0.001	0.002***	0.001	-0.005***	0.001
Median age	0.000**	0.000	-0.000	0.000	-0.000	0.000	0.000***	0.000
Working time	0.033***	0.001	0.033***	0.002	0.034***	0.002	0.033***	0.001
Share of female employees	0.079***	0.001	0.071***	0.004	0.072***	0.002	0.088***	0.002
Education	0.040***	0.001	0.052***	0.004	0.034***	0.002	0.041***	0.002
Nationality	0.006***	0.000	0.004***	0.001	0.005***	0.000	0.008***	0.000
Occupational status	-0.008***	0.001	-0.003	0.003	-0.010***	0.002	-0.008***	0.002
Occupational composition	0.046***	0.002	0.069***	0.004	0.050***	0.003	0.034***	0.003
Industry	0.093***	0.002	0.105***	0.005	0.085***	0.003	0.095***	0.003
Total	0.407***	0.005	0.412***	0.013	0.384***	0.009	0.424***	0.007
COEFFICIENT EFFECTS								
Establishment size	-0.236***	0.015	-0.233***	0.037	-0.224***	0.023	-0.246***	0.025
Establishment age	-0.049***	0.013	-0.069**	0.031	-0.007	0.020	-0.076***	0.017
Region	0.006*	0.004	0.024***	0.007	0.005	0.005	0.008	0.006
Region type	-0.013	0.008	0.016	0.021	0.006	0.012	-0.041***	0.012
Median age	0.226***	0.041	0.226**	0.109	0.219***	0.062	0.167***	0.064
Working time	0.012	0.138	-0.225	0.263	0.115	0.221	-0.028	0.209
Share of female employees	-0.070***	0.022	-0.069	0.045	-0.024	0.036	-0.081**	0.037
Education	0.000	0.013	-0.026	0.030	-0.001	0.018	-0.002	0.026
Nationality	-0.120	0.107	-0.064	0.206	-0.296***	0.102	0.079	0.203
Occupational status	-0.176	0.118	-0.347*	0.205	-0.405**	0.163	0.139	0.204
Occupational composition	-0.183	0.114	0.105	0.228	-0.178	0.157	-0.188	0.162
Industry	-0.228**	0.109	-0.211	0.153	0.142*	0.083	-0.259***	0.079
Constant	0.984***	0.217	1.173***	0.344	0.722***	0.260	0.750**	0.342
Total	0.153***	0.022	0.300***	0.043	0.075	0.055	0.223***	0.045
INTERACTION EFFECTS								
Establishment size	-0.061***	0.006	-0.049***	0.012	-0.046***	0.011	-0.079***	0.009
Establishment age	-0.002**	0.001	0.008**	0.003	-0.001	0.001	-0.008***	0.002
Region	-0.000	0.000	0.004	0.002	-0.000	0.000	-0.002	0.001
Region type	-0.000	0.000	-0.002	0.003	0.000	0.001	-0.003*	0.002
Median age	0.002***	0.001	-0.003	0.002	-0.001	0.001	0.005**	0.002
Working time	0.036	0.024	0.050	0.051	0.077**	0.032	-0.024	0.039

Share of female employees	0.031***	0.010	0.027	0.018	0.010	0.014	0.040**	0.018
Education	-0.005	0.005	-0.010	0.011	-0.012*	0.007	0.002	0.011
Nationality	-0.004	0.004	-0.002	0.005	-0.008***	0.003	0.004	0.009
Occupational status	-0.009	0.023	-0.036	0.053	-0.050	0.031	0.039	0.035
Occupational composition	0.007	0.029	-0.102***	0.038	0.005	0.052	-0.012	0.044
Industry	-0.027	0.020	-0.034	0.040	0.065***	0.025	-0.073***	0.023
Total	-0.033	0.021	-0.148***	0.043	0.039	0.053	-0.110**	0.044

Notes: Standard errors in parentheses. Significance levels are reported at 1% (***), 5% (**) and 10% (*) levels.
Source: BEE membership list, Establishment History Panel of the Institute for Employment Research, own calculations.

We now compare 3,215 RE establishments with almost 1.7 million non-RE establishments. Repeating the decompositions for this full sample we observe a raw wage gap of more than 50 log points (see *Table 3-6*). This large gap is not surprising since the reference group now contains establishments from many low-pay sectors. Indeed, the table shows that industry effects and establishment effects add most to explain the raw wage differential. Altogether, more than three-quarters of the gap are due to differences in observed characteristics. About 12 log points of the raw wage premium remains unexplained. This result for the full sample is nearly identical to the result for the selected four sectors, hence corroborating the meaningfulness of our selection.

Secondly, we show differences in wages by RE technology. The right-hand panel of *Table 3-6* reveals minor differentials between wind, solar and the third category containing all other RE technologies (biofuels, biomass, hydropower and geothermal energy): The raw wage gap ranges between 50 log points for solar and 56 log points for wind technology. For all technologies, about three quarters of the gap are captured by endowments effect. We are therefore confident that the sample restriction to the four paradigmatical sectors does not constrain the validity of our results.

Table 3-7: Decomposition of log gross average daily wages for selected sectors at the sample means (comparison group: non-RE establishments) for the year 2009; selection criterion: sectors with the highest number of RE establishments

		Prediction RE establishments		Prediction non-RE establishments		Predicted difference		Explained		Unexplained	
		Coeff.	**s.e.**	**Coeff.**	**s.e.**	**Coeff.**	**s.e.**	**Coeff.**	**s.e.**	**Coeff.**	**s.e.**
Economic sector, WZ 2008 (1-digit code)											
C	Manufacturing	4.582***	0.013	4.171***	0.001	0.411***	0.013	0.343***	0.011	0.068***	0.009
D	Electricity, gas, steam and air conditioning supply	4.661***	0.027	4.627***	0.008	0.034	0.028	0.052**	0.023	-0.018	0.026
F	Construction	4.449***	0.020	4.142***	0.001	0.307***	0.020	0.154***	0.012	0.153***	0.018
G	Wholesale and retail trade, repair of motor vehicles and motorcycles	4.494***	0.010	4.039***	0.001	0.455***	0.010	0.351***	0.009	0.105***	0.009

H	Transportation and storage	4.543***	0.034	3.993***	0.002	0.550***	0.034	0.466***	0.028	0.084***	0.026
M	Professional, scientific and technical activities	4.703***	0.019	4.176***	0.002	0.527***	0.019	0.378***	0.015	0.149***	0.017
	Total	4.560***	0.007	4.105***	0.001	0.455***	0.007	0.345***	0.005	0.110***	0.006
Economic sector, WZ 2008 (3-digit code; subheadings: 1-digit code)											
C	*Manufacturing*										
261	Manufacture of electronic components and boards	4.597***	0.047	4.340***	0.011	0.257***	0.048	0.221***	0.040	0.036	0.029
271	Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	4.756***	0.044	4.334***	0.009	0.423***	0.045	0.287***	0.042	0.136***	0.032
281	Manufacture of general-purpose machinery	4.719***	0.042	4.449***	0.008	0.270***	0.043	0.233***	0.037	0.037	0.028
282	Manufacture of other general-purpose machinery	4.579***	0.041	4.422***	0.005	0.157***	0.042	0.142***	0.035	0.014	0.029
D	*Electricity, gas, steam and air conditioning supply*										
351	Electric power generation, transmission and distribution	4.656***	0.031	4.682***	0.009	-0.026	0.032	-0.037	0.028	0.011	0.032
F	*Construction*										
432	Electrical, plumbing and other construction installation activities	4.414***	0.027	4.131***	0.002	0.282***	0.027	0.140***	0.018	0.142***	0.025
G	*Wholesale and retail trade, repair of motor vehicles and motorcycles*										
461	Wholesale on a fee or contract basis	4.654***	0.028	4.215***	0.003	0.439***	0.028	0.342***	0.024	0.097***	0.023
462	Wholesale of agricultural raw materials and live animals	4.489***	0.017	4.139***	0.008	0.350***	0.019	0.231***	0.018	0.119***	0.022
467	Other specialized wholesale	4.542***	0.020	4.322***	0.003	0.220***	0.021	0.127***	0.015	0.092***	0.016
469	Non-specialized wholesale trade	4.482***	0.053	4.262***	0.008	0.220***	0.053	0.129***	0.037	0.091**	0.043
471	Retail sale in non-specialized stores	4.481***	0.016	4.072***	0.003	0.409***	0.016	0.101***	0.021	0.308***	0.025
475	Retail sale of other household equipment in specialized stores	4.415***	0.025	4.027***	0.003	0.389***	0.025	0.227***	0.019	0.162***	0.026
H	*Transportation and storage*										

522	Support activities for transportation	4.558***	0.038	4.171***	0.003	0.388***	0.038	0.251***	0.025	0.137***	0.025
M	*Professional, scientific and technical activities*										
692	Accounting, bookkeeping and auditing activities; tax consultancy	4.815***	0.038	4.142***	0.003	0.673***	0.038	0.349***	0.033	0.324***	0.040
711	Architectural and engineering activities and related technical consultancy	4.609***	0.030	4.279***	0.003	0.330***	0.030	0.220***	0.020	0.110***	0.025
712	Technical testing and analysis	4.817***	0.036	4.476***	0.008	0.341***	0.037	0.266***	0.034	0.075**	0.030
	Total	4.579***	0.008	4.182***	0.001	0.396***	0.008	0.279***	0.007	0.118***	0.007

Notes: Standard errors in parentheses. Significance levels are reported at 1% (***), 5% (**) and 10% (*) levels. For observation numbers of RE establishments, please see *Tables 3-2* and 3-*3*. The observation numbers for the control group of non-RE establishments within sectors range between 4,000 and 357,000 at the 1-digit level and 1,800 and 69,800 at the 3-digit level (all numbers are available on request from the authors). Source: BEE membership list, Establishment History Panel of the Institute for Employment Research, own calculations

Thirdly, we present and discuss results at different levels of aggregation. The upper panel of *Table 3-7* shows the results for the main RE areas as described in section 2.2. Also at this level of aggregation, one observes distinct unexplained wage differentials in *Construction* and *Professional, scientific and technical activities* (both 15 log points), a lower but statistically significant unexplained wage premium in *Manufacturing* (7 log points) and non-significant unexplained wage differentials in *Electricity* (-2 log points). The sectors *Trade* and *Transportation* exhibit an unexplained wage differential of 11 log points and 8 log points respectively. The unexplained wage premium for these six sectors together (2,906 RE establishments) is 11 log points and hence as high as for the full sample (12 log points, 3,215 RE establishments) and the aggregate of the four selected sectors (9 log points, 583 establishments) as presented above.

The lower panel of Table 3-7 provides additional information at the 3-digit level. It is evident that the results for *Manufacture of general-purpose machinery (281)* are nearly identical to the results for *Manufacture of electronic components and boards (261)*, which are presented above. The results for *Manufacture of other general-purpose machinery* (281) are also very similar since the bulk of the raw wage gap can be explained by different characteristics. An exception is the sector *Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus* where a significant unexplained part (14 log points) remains. This again shows the sector-specific heterogeneity. Our results show that the selected sector *Manufacture of electronic components and boards* is representative for large parts of the whole manufacturing sector. Turning to *Professional, scientific and technical activities*, the unexplained wage premium ranges from 8 log points for *Technical testing and analysis* to 32 log points for *Accounting, bookkeeping and auditing* activities. This large range corroborates the importance of sector-specific differences. The unexplained wage premium of

Architectural and engineering services lies in-between (11 log points), hence confirming its representativity for this RE field.

The unexplained wage premium for the total of the 3-digit sectors presented in Table 3-7 (1,752 RE establishments) is 12 log points, as thus as high as for the full sample (3,215 RE establishments; see Table 3-3 for observation numbers of sectors at 3-digit level).[23]

To sum up, although there are important sector-specific differences, our main results are robust to variations in the sample selection and of the specifications. *Appendix A.1* provides a brief summary of additional robustness analyses. Hence, our results are representative for large parts of the RE value-chain.

Based on the discussion of our results, we propose the following policy implications:

1. The value chains of RE products and services cover a broad range of very different industry branches. Therefore, political decision-makers should bear in mind the entire RE value chain while developing policy instruments. Otherwise they might easily cause unintended impacts on important but less obvious stakeholders.

2. In large parts of the RE value chain establishments have created relatively well-paid jobs with medium and high qualification requirements. Therefore, the promotion of RE technologies might not only support climate and energy policies. It also has the potential to contribute to an improvement of the wage and qualification structure of RE establishments. In consequence, policy makers should be aware that a change of RE-policies can affect both the quantity **and** quality of RE jobs.

3. To make such quality issues visible in energy policy evaluations it would be advisable to supplement them with quality-of-work indicators. In consequence, our results suggest that if an organization tries to estimate net employment effects of RE promotion, they should take into account the value generated by the RE wage premium and other quality aspects.

4. This leads directly to the issue of data availability: it is still challenging to identify RE establishments within administrative or statistical data. Moreover, due to the lack of data, the role of temporary agency work within the RE value chain cannot be analyzed properly. In order to improve evidence-based policy advice, decision-makers should also support initiatives to improve the data availability of RE-specific data.

3.4 Conclusions and Policy Implications

Our goal was to answer the following research questions: Is there a difference in wages between RE establishments and others? If so, what are the determinants for this wage differential and how do they differ among sectors? Do those wage differentials merely reflect differences in establishment characteristics, or do they reflect other external

[23] The same is true for an alternative level of aggregation, the 2-digit level (see Appendix Table 3-10). The sector-specific results at the 2-digit level corroborate the presented results at the more detailed 3-digit level.

influences, such as the promotion of RE sources? For the empirical analyses of these questions, we have selected six RE sectors at 1-digit level and sixteen sectors at 3-digit level. Because the characteristics of sectors differ widely, we have chosen four paradigmatical sectors to analyze and discuss our results in more detail: *manufacture of electronic components and boards*; *electric power generation; transmission and distribution*; *electrical, plumbing and other construction installation activities*; and *architectural and engineering activities and related technical consultancy*. Descriptive analyses of establishments in these four RE sectors have shown significant differences in both establishment characteristics and wage differentials between RE establishments and their sector peers. Our results show that RE establishments pay considerably more than non-RE establishments in most RE sectors. But our analyses have also shown an exemption: RE establishments pay slightly less in the *electric power generation, transmission and distribution* sector.

The results of the Blinder-Oaxaca decomposition provide evidence that the observed differences in human capital and other establishment-level characteristics explain most of the wage differentials, e.g., in the *manufacture of electronic components and boards* and *energy provider* sectors. In several sectors, however, endowment differences between RE establishments and non-RE establishments explain a distinctly lower share of the raw wage premium: As discussed in detail, in the sectors of c*onstruction installation activities* and *architectural/engineering services*, an unexplained wage differential of more than ten log points remains, which we denote as “renewable energy wage premium”. In contrast, the R&D-intensive sector of the *manufacture of electronic components and boards* and the capital-intensive *electric power generation, transmission and distribution* sector do not show this RE wage premium, perhaps due to their capital costs and further structural changes.

Our results, which are corroborated by comprehensive sensitivity analyses, suggest that employees in the sectors with a positive wage differential such as the *construction installation activities* as well as the *architectural and engineering services* are the “hidden winners” of the RE promotion. As the most likely interpretation for this development, we consider the explanation of the wage premium as a positive indirect effect of the public RE promotion.

We propose the following policy implications in terms of promotion activities: first, if policy-makers design or change RE policies, they should bear in mind the entire RE value chain. Second, politicians should be aware that a change of RE policies such as reforms of feed-in tariffs can also affect both the quantity **and** quality of RE jobs. Third, including quality-of-work indicators in energy policy evaluations would be an appropriate measure to consider further important effects of RE development. This directly leads to fourth, a call to support initiatives to improve the data availability of RE-specific data.

3.5 Appendix of chapter 3

3.5.1 Appendix A.1—Sensitivity analyses

Our main results are robust to variations in the sample selection and specifications. This section provides a brief summary of these robustness analyses. For the sake of brevity, only some of these results are presented below, all other results are available upon request.

A.1.1 Alternative sample of RE establishments

When examining our relatively low number of observations for RE establishments in the paradigmatical four sector sample, one might be concerned whether our results are relevant in an economic sense or whether they are only valid for a handful of establishments that have been identified as "renewable" by membership in an industry association. Considering the different sectors, it is obvious that the number of observations of RE establishments is particularly low (approximately 60) in the *manufacture of electronic components and boards* sector. This sector, however, contains the branch "manufacture of solar cells and solar modules" (26111), which is one of the two major exceptions where the classification is informative about RE activities. We use this information in a sensitivity check and classify all of the establishments within this branch as RE establishments. In doing so, we increase the number of establishments from 60 to 135.[24] Repeating the sector-specific Oaxaca-decomposition for the year 2009 with this sample returns a raw wage premium of 15 log points (instead of 26 log points), and the endowment effects sum to 16 log points; the coefficient and interaction effects are irrelevant (+ 1 log points and -2 log points, respectively). Although the raw premium decreases by 11 log percentage points, the results corroborate our view that unobserved heterogeneity plays a minor role in explaining wage level differentials in this sector.

A.1.2 controlling for differences in the establishment-size distribution

When considering the characteristics of the establishments, by far the most striking difference between RE establishments and non-RE establishments is their number of employees, which is on average 129.3 in RE establishments and 10.5 in non-RE establishments (see Table 3-4).

We argued that this difference is a first hint that RE establishments and non-RE establishments are barely comparable at the aggregated level and should therefore be analyzed at the sector level instead; however, large differences remain at the sector level. Although we control for establishment size in our sector-specific analyses, one might argue that this control does not capture all of the relevant heterogeneity. To verify this,

[24] This branch contains 100 establishments in the year 2009, 25 of which belong to the German Renewable Energy Federation and are classified as RE establishments in the main sample. Hence, we added 75 establishments to the treatment group.

we repeat the decompositions with a counterfactual sample where the size of RE establishments is reweighted to mimic the distribution of non-RE establishments.[25]

Doing so, we find that the raw wage differentials in 2009 decrease relative to the unweighted sample by 2-8 log points. The same is true for the endowment effects. The relationship between the explained and unexplained gap, however, remains almost unchanged: in two of the four sectors, the observed wage differences cannot be fully explained by the differences in characteristics.

In addition to taking establishment size differentials into account by creating a counterfactual sample, one could go a step further by choosing a counterfactual approach considering all of the covariates. By taking this approach, we further estimated several variants (one nearest neighbor and kernel) of propensity score matching within each sector. The average treatment effect on the treated turned out to be statistically significant in the *construction installation activities* and *architectural and engineering services* sectors, amounting to 10 log points. This corroborates our finding of a RE wage premium in these sectors. For the two remaining sectors, the average treatment effect on the treated is not significantly different from zero.

A.1.3 Establishment fixed effects regressions

So far, the paper analyzes wage level differences between RE establishment and non-RE establishments in the year 2009. As described in section 3.2.3, the unexplained gap in the decomposition reflects all of the factors that cannot be directly observed in our data. To eliminate at least the time-constant unobserved heterogeneity between RE establishments and non-RE establishments, and to give some information on the time-related development of the gap, we apply establishment-fixed effects regression models that consider the development of remunerations from the year 2007 to 2011 rather than wage levels in 2009. More precisely, we estimate establishment fixed effects regressions – at the aggregated level and within the four sectors – for RE establishments and non-RE establishments separately. We adapt an approach by Lehmer/Ludsteck (2015) and use the estimated coefficients to decompose the wage changes into three factors: first, the adjustment due to all observed time-varying characteristics, such as changes in establishment size, workforce composition and so on; second, the adjustment due to sample composition effects (Composition) and third, the adjustment due to all unobserved time-varying factors (Trend). *Appendix Figure 3-2* contains the aggregate level results and depicts an average real wage increase for full-time employees in RE establishments of 4 log percentage points (indicated by the light grey bar *_Total*). The corresponding increase within non-RE establishments, however, is almost the same, amounting to 3 log percentage points. This means that the raw wage premium remains nearly unchanged

[25] We differentiate between four establishment-size categories: 1-19 employees, 20-99 employees, 100-499 employees, and 500+ employees. Then, we compute the shares of these cells in the treatment and control group and obtain the reweighting factors as the ratios of the shares among non-RE establishments to the respective shares among RE establishments.

during the observation period.[26] Investigating the determinants of wage growth for both groups, it is evident that changes in the workforce composition within the establishments, as captured by the *Other Shares*-category,[27] are mostly responsible for the average real wage growth. However, in this respect there are no differences between RE establishments and the reference of non-RE establishments. Such differences emerge with regard to the *Composition*- and *Trend*-effects. At an aggregated level, it seems that the median wage in non-RE establishments benefits from non-random outmigration from the observation sample, while the opposite is true for RE establishments. The negative trend effect indicates time-variant unobserved heterogeneity that decreases wages predominantly in non-RE establishments. Hence, there is actually an unobserved time-varying component that favors RE establishment-wages relative to no-RE establishment wages.

The sector-specific analyses[28] show slightly higher total wage increases in non-RE establishments than among RE establishments in the sectors *Manufacture of electronic components and boards* and *Electric power generation, transmission and distribution*. In the two remaining sectors—*Electrical, plumbing and other construction installation activities* and *Architectural and engineering activities and related technical consultancy* –the average wage growth for member and non-RE establishments tends to be comparable. Consequently, the raw wage premiums remain constant over the observation period, amounting to approximately 30 log points. Altogether, we observe a pronounced heterogeneity between the sectors.

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[26] This is corroborated by the result of the Blinder-Oaxaca decompositions for each single year in the observation period from 2007 to 2011. The raw wage premium ranges from 32 to 35 log percent. These results are not included in the paper for the sake of brevity but are available from the authors on request.

[27] This category contains the effects of the Share of full-time employees, Share of marginal part-time workers, Share of qualified employees, Share of skilled workers, Share of unskilled employees, Share of master craftsmen and foremen, Share of white-collar employees and Share of employees in midi part-time employment.

[28] These results are not included in the paper for the sake of brevity but are available from the authors on request.

3.5.2 Appendix A.2—Tables

Table 3-8: Extract from full-sample of RE establishments and RE employees in 2009 by economic sectors, WZ 2008 (2-digit level)

Sector, WZ 2008 (2-digit level; subheadings: 1-digit level)		Number of RE establishments	Number of RE employees
C	*Manufacturing*		
20	Manufacture of chemicals and chemical products	62	27,635
23	Manufacture of other non-metallic mineral products	57	5,020
25	Manufacture of fabricated metal products, except machinery and equipment	80	10,091
26	Manufacture of computer, electronic and optical products	98	46,320
27	Manufacture of electrical equipment	112	52,960
28	Manufacture of machinery and equipment n.e.c.	153	41,209
33	Repair and installation of machinery and equipment	60	8,745
D	*Electricity, gas, steam and air conditioning supply*		
35	Electricity, gas, steam and air conditioning supply	187	26,429
F	*Construction*		
43	Specialised construction activities	277	8,839
G	*Wholesale and retail trade, repair of motor vehicles and motorcycles*		
46	Wholesale trade, except of motor vehicles and motorcycles	653	23,349
47	Retail trade, except of motor vehicles and motorcycles	339	6,451
H	*Transportation and storage*		
52	Warehousing and support activities for transportation	103	3,240
M	*Professional, scientific and technical activities*		
69	Legal and accounting activities	85	17,043
70	Activities of head offices; management consultancy activities	84	17,145
71	Architectural and engineering activities; technical testing and analysis	266	11,554
	Total	2,616	306,030

Notes: The table contains all sectors at the 2-digit level with more than 50 RE establishments. N.e.c. = not elsewhere classified. Source: BEE membership list, Establishment History Panel of the Institute for Employment Research, own calculations.

Table 3-9: Average characteristics of RE establishments and non-RE establishments in the year 2009 (full sample / sectors)

			Renewable energy type		
	Full sample		Wind	Solar	Others
Variables	non-RE	RE	RE	RE	RE
Wage (gross average daily wage) quartile P25 for all full-time employees (fte)	56.87	87.13	90.67	85.83	86.87
Wage quartile Med for all fte	64.85	102.03	105.95	100.95	101.44
Wage quartile P75 for all fte	73.81	119.45	124.05	118.17	118.76
Wage quart. P25 highly qualified fte	103.51	127.16	123.02	130.23	126.26
Wage quart. Med highly qualified fte	112.89	140.51	136.48	142.86	140.23
Wage quart. P75 highly qualified fte	121.13	150.69	146.45	153.01	150.55
Number of employees	17.26	112.38	91.04	182.25	60.86
Share of full-time employees	64.22	78.21	81.47	77.84	77.26
Share of marginal part-time workers	21.67	9.73	9.06	9.71	10.02
Share of female employees	52.55	29.48	31.75	31.49	26.87
Share of qualified employees	49.10	56.18	51.40	52.21	61.44
Share of highly qualified employees	5.09	14.42	19.08	13.84	13.10
Share of German employees	92.57	95.80	94.87	95.00	96.84
Share of trainees/apprentices	3.93	3.85	2.65	3.57	4.57
Share of skilled workers	16.99	15.13	13.49	15.79	15.21
Share of unskilled employees	15.34	12.38	10.46	13.70	12.00
Share of master craftsmen and foremen	1.13	1.57	0.89	1.31	2.06
Share of white-collar employees	33.42	50.25	57.77	48.35	48.96
Share of employees in midi part-time employment	8.34	6.54	5.44	6.98	6.58
Share of unskilled manual occupations	7.43	10.50	10.54	11.70	9.47
Share of unskilled services	17.01	11.34	8.49	8.60	14.79
Share of unskilled commercial and admin. occup.	11.95	11.21	8.23	10.44	13.01
Share of skilled manual occupations	14.95	14.05	10.51	16.10	13.68
Share of skilled services	10.68	0.42	0.59	0.51	0.27
Share of skilled commercial and admin. occup.	20.11	26.33	29.31	26.14	25.33
Share of technicians	3.11	8.27	8.79	8.59	7.80
Share of semiprofessions	3.95	0.50	1.72	0.42	0.08
Share of engineers	1.50	7.90	11.04	6.51	7.88
Share of professions	1.18	0.79	1.74	0.69	0.51
Share of managers	3.44	6.87	7.18	8.32	5.52
Age quartile P25 of the total of employees	34.04	33.55	33.60	33.43	33.63
Age quartile Med of the total of employees	40.95	41.32	40.46	40.72	42.17
Age quartile P75 of the total of employees	47.99	48.76	47.14	48.18	49.90
Core cities	29.35	29.49	38.42	32.46	23.46
Urbanized districts	37.73	35.24	30.88	38.74	33.94
Rural districts with features of concentration	17.23	19.72	17.06	15.25	24.58
Rural districts – sparsely populated	15.69	15.55	13.64	13.54	18.02
Total number of establishments	1,697,395	3,215	557	1,226	1,432

Source: Establishment History Panel of the Institute for Employment Research, own calculations.

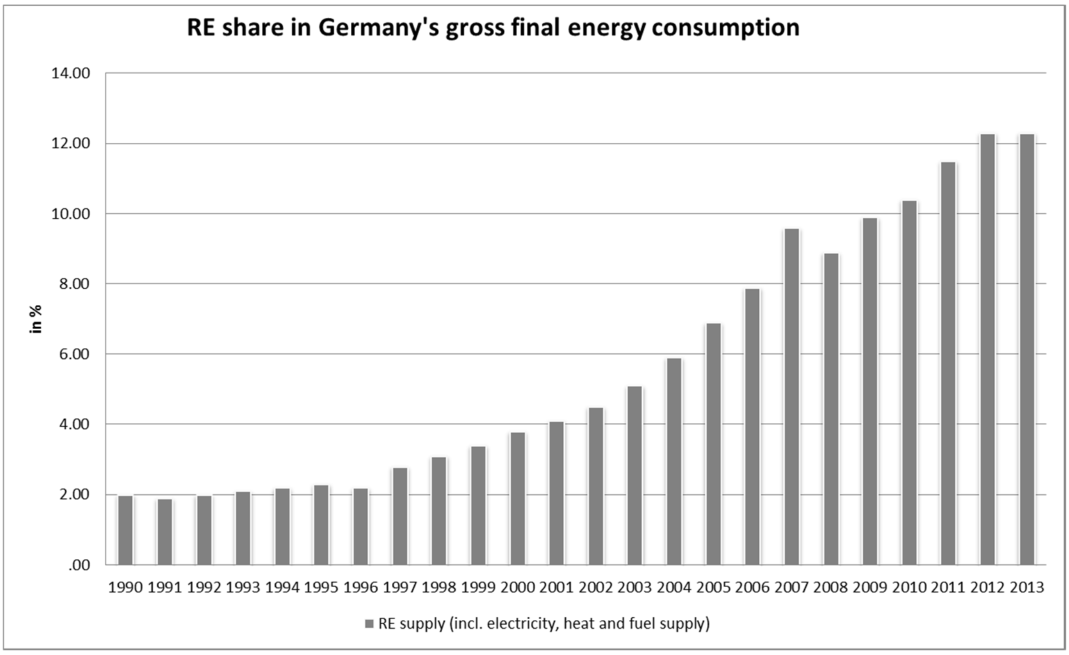
Table 3-10: Decomposition of log gross average daily wages for selected RE sectors at the sample means (comparison group: non-RE establishments) for 2009 (2-digit level); selection criterion: sectors with the highest number of RE establishments

ID	Sectors	Prediction RE establishments		Prediction non-RE establishments		Predicted difference		Explained		Unexplained	
		Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.	Coeff.	s.e.
Economic sectors, WZ 2008 (2-digit code)											
20	Manufacture of chemicals and chemical products	4.698***	0.043	4.449***	0.007	0.249***	0.044	0.226***	0.035	0.023	0.021
23	Manufacture of other non-metallic mineral products	4.533***	0.035	4.259***	0.005	0.274***	0.036	0.169***	0.030	0.105***	0.025
25	Manufacture of fabricated metal products, except machinery and equipment	4.477***	0.032	4.197***	0.002	0.279***	0.032	0.183***	0.023	0.097***	0.022
26	Manufacture of computer, electronic and optical products	4.676***	0.037	4.398***	0.006	0.278***	0.038	0.227***	0.031	0.051**	0.023
27	Manufacture of electrical equipment	4.735***	0.033	4.330***	0.006	0.404***	0.034	0.297***	0.031	0.107***	0.023
28	Manufacture of machinery and equipment n.e.c.	4.649***	0.024	4.435***	0.003	0.215***	0.025	0.184***	0.020	0.031*	0.017
33	Repair and installation of machinery and equipment	4.473***	0.047	4.240***	0.005	0.232***	0.047	0.133***	0.033	0.100***	0.037
35	Electricity, gas, steam and air conditioning supply	4.661***	0.027	4.627***	0.008	0.034	0.028	0.052**	0.023	-0.018	0.026
43	Specialised construction activities	4.420***	0.021	4.124***	0.001	0.296***	0.022	0.144***	0.013	0.152***	0.021
46	Wholesale trade, except of motor vehicles and motorcycles	4.569***	0.013	4.239***	0.002	0.330***	0.013	0.233***	0.010	0.097***	0.011
47	Retail trade, except of motor vehicles and motorcycles	4.365***	0.016	3.948***	0.001	0.416***	0.016	0.257***	0.012	0.159***	0.015
52	Warehousing and support activities for transportation	4.594***	0.030	4.179***	0.003	0.416***	0.030	0.285***	0.025	0.130***	0.022
69	Legal and accounting activities	4.797***	0.037	4.070***	0.002	0.727***	0.037	0.438***	0.029	0.288***	0.033
70	Activities of head offices; management consultancy activities	4.757***	0.054	4.300***	0.005	0.456***	0.054	0.316***	0.048	0.140**	0.056
71	Architectural and engineering activities; technical testing/analysis	4.665***	0.024	4.299***	0.003	0.366***	0.024	0.255***	0.017	0.111***	0.020
	Total	4.571***	0.007	4.126***	0.001	0.444***	0.007	0.326***	0.005	0.118***	0.006

Notes: Standard errors in parentheses. Significance levels are reported at 1% (***), 5% (**) and 10% (*) levels. For observation numbers of RE establishments, please see Table 3-8. The observation numbers for the control group of non-RE establishments within sectors range between 3,500 and 205,000 (all numbers are available on request from the authors). N.e.c. = not elsewhere classified. Source: BEE membership list, Establishment History Panel of the Institute for Employment Research, own calculations.

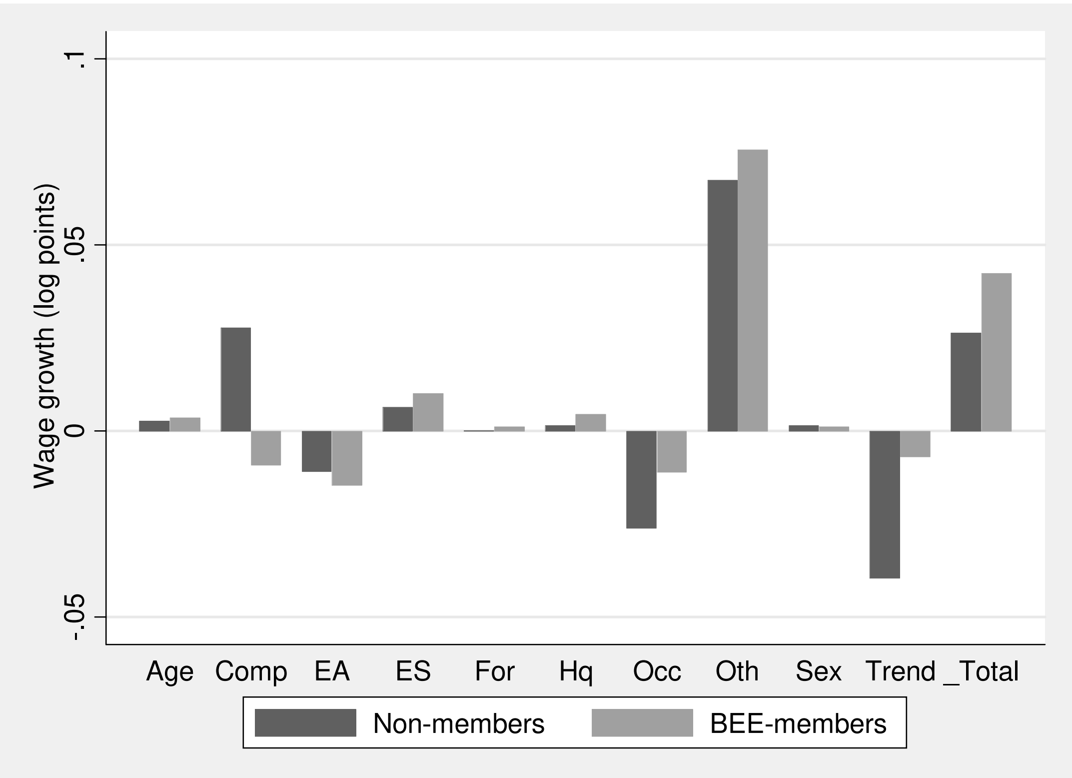
3.5.3 Appendix A.3—Figures

Figure 3-1: RE share in Germany's gross final energy consumption



Source: BMWI (2014)

Figure 3-2: Decomposition of the wage growth of RE establishments and non-RE



Notes: The dark grey bars represent changes in the non-RE establishments' (log) wage growth due to the specific effect (age structure effect, composition effect, establishment size effect, …), and the light grey bars show the corresponding effects for RE establishments. _Total indicates total (real) wage growth from 2007 to 2011.
Source: Establishment History Panel of the Institute for Employment Research, own calculations.

4 The role of innovation and agglomeration for employment growth in the environmental sector

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Abstract

The environmental sector is supposed to yield a dual benefit: its goods and services are intended to tackle environmental challenges and its establishments should create new jobs. However, it is still unclear in empirical terms whether that really is the case. This paper investigates to what extent employment growth in establishments with green products and services is higher compared to other establishments. Furthermore, the main factors determining labor demand in this field are analyzed. We use linked employment and regional data for Germany. The descriptive results show that the environmental sector is characterized by disproportionately high employment growth. The application of a generalized linear mixed model reveals that especially innovation and industry agglomeration foster employment growth in establishments in the environmental sector. Establishments without green products and services show a smaller increase in employment, even if they are also innovative.

JEL classification: J21, O33, Q55, R23

Keywords: Employment, environmental sector, eco-innovation, green jobs, technological change, industrial agglomeration, spatial disparities

4.1 Introduction

The environmental sector is supposed to yield a dual societal benefit. First, its goods and services help to tackle today's global challenges of climate change and environmental pollution. Second, it may create new jobs and could thus help to improve economic well-being. Because of these potential environmental and employment benefits, the environmental sector has received a great deal of political attention in recent years and has become an essential element of many green economy approaches (Allen/Clouth 2012;

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OECD/Cedefop 2014; UNEP 2011). However, depending strongly on regulation and subsidies, the societal benefit of the environmental sector—particularly in terms of employment—is an ongoing matter of discussion. Whereas green products and services are often seen as a driving force for employment growth (e.g., EC 2014, OECD/Cedefop 2014), there are also studies that question the efficiency of those investments and its impacts on productivity and employment growth (e.g., Deschenes 2013; Elliott/Lindley 2014).

In Germany, approximately two million people are employed in the environmental sector (Edler/Blazejczak, 2014; UBA 2014) but this figure does not indicate whether the environmental sector exhibits more dynamic employment growth compared to other sectors of the economy. Furthermore, the determinants of employment growth in the environmental sector have not been examined in detail to date.

This paper contributes to fill this gap. We analyze labor demand in the environmental sector empirically and compare it to other sectors of the German economy. Our research questions are as follows: (1) Do labor demand and employment growth differ between *environmental establishments*[30] and establishments that do not produce environmental goods or services? (2) Which determinants of labor demand foster employment growth and which determinants hinder it in the environmental sector?

In addition to analyzing standard factors of a labor demand function, such as product demand, wages or export orientation, we focus on the role of innovation and agglomeration forces for employment growth in the environmental sector compared to the German economy as a whole. As the environmental sector is not homogeneous, our econometric estimations take differences between environmental technology fields into account. Relatively new environmental technology fields such as renewable energies may be more dynamic compared to already established fields, e.g., filter systems to reduce air or water pollution. Furthermore, we consider barriers to employment growth: high competitive pressure may force firms to lower labor costs, or collective wage agreements accompanied by higher labor costs may decrease labor demand.

For our empirical analysis we combine three data bases: the IAB Establishment Panel, the Establishment History Panel, and statistical data of the Federal Employment Agency (Bundesagentur für Arbeit) at NUTS 3 level to capture the role of agglomeration forces. We estimate different regression models to analyze the development of employment in the environmental sector compared to the rest of the economy. The data bases permit analyses of the short-term (from 2009 to 2012, 2011 to 2012 and 2011 to 2014) and the long-term (from 2002 to 2012) development of employment.

The paper is organized as follows: Section 2 contains a detailed definition of the environmental sector (2.1) and summarizes the determinants of labor demand from a

[30] *Environmental establishments:* Short for “Establishments within the environmental goods and services sector”

theoretical perspective (2.2). The data basis is presented in Section 3.1 followed by a descriptive analysis in Section 3.2. The results of different econometric estimations of our labor demand function are shown in Section 3.3. Section 4 concludes.

4.2 Employment development in the environmental sector: theoretical background and hypotheses

4.2.1 The environmental sector

Generally speaking, the environmental sector (short for "Environmental goods and services sector", EGSS) deals with the supply side of environmental protection and resource management activities. In this paper we use the definition of the System of Environmental-Economic Accounting (SEEA), which defines the EGSS as follows: "*The EGSS consists of producers of all environmental goods and services. Thus, all products that are produced, designed and manufactured for purposes of environmental protection and resource management are within scope of the EGSS.*" (UN et al. 2014: 111).[31]

The SEEA distinguishes between four types of environmental goods and services (UN et al. 2014): environmental specific services (e.g., waste and waste water management and treatment services; energy- and water-saving activities), environmental sole-purpose products and services (e.g., catalytic converters, the installation of renewable energy production technologies), adapted goods (e.g., cars with lower air emissions, recycled paper), and environmental technologies: end-of-pipe technologies, e.g., air pollution filters (Eurostat 2009: 10); cleaner technologies, e.g., technical processes to avoid air pollution (Eurostat 2009: 12). There are considerable differences between end-of-pipe technologies and integrated technologies. Whereas end-of-pipe technologies are mostly regulation-driven, cleaner technologies are often more market-driven (e.g., as a source of cost savings) and triggered by general or environmental management systems (Frondel et al. 2007).

A further relevant definition of green jobs has been developed by the Bureau of Labor Statistics of the U.S. Department of Labor (BLS). Their definition also involves the basic distinction between output and process. Whereas the output-related approach covers the *green goods and services*, the process approach "*… identifies establishments that use environmentally friendly production processes and practices …*" (Sommers 2013: 5).

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[31] In terms of data collection and the organization of data, the SEEA refers to Eurostat's data collection handbook, which provides a more precise definition: '*The environmental goods and services sector consists of a heterogeneous set of producers of technologies, goods and services that:*

- Measure, control, restore, prevent, treat, minimize, research and sensitise environmental damages to air, water and soil as well as problems related to waste, noise, biodiversity and landscapes. This includes 'cleaner' technologies, goods and services that prevent or minimise pollution.

- Measure, control, restore, prevent, minimise, research and sensitise resource depletion. This results mainly in resource-efficient technologies, goods and services that minimise the use of natural resources. These technologies and products (i.e., goods and services) must satisfy the end purpose criterion, i.e., they must have an environmental protection or resource management purpose […] as their prime objective.' (Eurostat 2009: 29)

As we will show below (Section 4.3.1), we focus solely on employment in the production of environmental outputs. Therefore, we do not deliver any conclusions for green jobs on the whole in this paper, but for employment in the environmental sector, or, more precisely, for employment in the production of environmental outputs.[32]

However – even using a standard environmental sector definition – the problem still remains of where exactly the line should be drawn between environmental and non-environmental establishments. For example, many establishments do not produce or deliver only environmental goods and services. They often follow a multi-purpose strategy (e.g., technical facilities like pumps that can be applied both in biogas plants and in coal-fired power plants). It is also difficult to identify the environmental share of employment, as many employees are not only engaged in environmental-related tasks but also perform work for non-environmental goods and services (in the case of multi-purpose firms). Moreover, the environmental impact of products and services may differ. There is a huge difference between the climate impact of a zero-emission e-car and a large SUV with a cleaner hybrid drive but still high fuel consumption. Nevertheless, both help to reduce air pollution and thus are regarded as environmental goods and services.

4.2.2 Determinants of employment growth

We use the notion of employment growth[33] as the increase or decline of employment between two dates. This corresponds to the definition of *standard employment change* as used by Hamermesh et al. (1996) in their *taxonomy of employment dynamics:* the standard employment (E) change measures the difference between the number of jobs available at the end of the period (J_{t+1}) and the jobs available at the beginning of the measurement period (J_t). For our estimations we use the growth rate of employment:

$$\frac{\dot{E}}{E} = \frac{J_{t+1} - J_t}{J_t} * 100$$

The extent of employment growth is determined by various factors. In the following, we briefly present central determinants of employment growth that are widely used in literature:

[32] Based on the SEEA definition of environmental goods and services, the International Labour Organization (ILO) emphasizes in their definition of employment in environmental activities the difference between employment in the production of environmental outputs and employment in environmental processes (ILO 2013a, 2013b, 2013c). Furthermore, the ILO introduces a tighter definition of green jobs by adding a decent work dimension to the environmental dimension (ILO 2012, 2013a, 2013b, 2013c). In the sense of the ILO definition, green jobs include only employment in environmental activities that fulfill the conditions of decent work (decent work indicators according to ILO 2012). Our analysis only captures the environmental dimension of the ILO definition.

[33] The notions of employment growth and employment dynamics are used differently in the literature. According to many authors (e.g., Carlsson et al. 2013, Dauth 2013, Hyatt and Spletzer 2013, Konigsberg et al. 2009), employment dynamics are seen as the growth or decline of employment between two dates, which corresponds to the concept of employment growth. Other authors (e.g., Bauer et al. 2007, Hamermesh et al. 1996, Kölling 2012) define employment dynamics in the sense of labor turnover or worker flows. In the paper in hand, we focus on employment growth.

Many recent studies have described innovation as one of the major factors for employment growth (e.g., Buerger et al. 2012; Capello/Lenzi 2013). The Oslo Manual (OECD/Eurostat 2005: 46) defines innovation as: "… *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 organisation or external relations.*" and differentiates between four types of innovation: product innovations, process innovations, marketing innovations and organizational innovations.

Besides these standard types of innovation and particular relevant for the environmental sector, the notion of eco-innovation has emerged in recent years. Kemp/Pearson (2008) denote eco-innovation as follows:

"*Eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives.*" (Kemp/Pearson 2008: 7).

The analysis of the employment effects of eco-innovation requires a distinction between process and product innovations. The employment effects of eco-process innovations may be negative because of the implementation of end-of-pipe technologies (e.g., additional air emission filters) leading to higher costs. On the other hand, these end-of-pipe measures may require additional employees. The introduction of process-integrated, resource- and energy-saving measures may improve a firm's profitability and competitiveness, which may lead to an increase in the number of employees but the introduction of these measures may also lead to labor saving effects. Horbach/Rennings (2013) empirically detected positive employment effects of eco-process innovations. In the present paper, eco-product innovations are in the focus of the analysis because we analyze the development of the environmental sector. In fact, the employment effects of environmental product innovations are also theoretically unclear. Product innovations may induce new demand for the firm by creating completely new markets or by substituting products of competitors leading to positive employment effects at the firm level. The macroeconomic employment effects remain undetermined as they also depend on the labor intensity of the substituted products. Furthermore, the introduction of a new product may cause a monopolistic position accompanied by a reduction of output. In that case, negative employment effects may be observed (Hall et al. 2006, Horbach/Rennings 2013). Empirical studies focusing on general innovations mostly find positive effects of product innovations on labor demand (see for instance Smolny 2002, Piva/Vivarelli 2005, Zimmermann 2009). Similar results are observed for the UK (Van Reenen 1997), for France (Greenan/Guellec 2000) and in a study for France, Great Britain, Germany and Spain based on harmonized data of the Community Innovation Panel (CIS) (Harrison et al. 2008). Due to the lack of suitable data, there are only few analyses on the employment effects of eco-innovations. In most cases, these studies also show positive effects of eco-innovations on employment (Bijman/Nijkamp 1988; Pfeiffer/Rennings 2001;

Rennings/Zwick 2002). Horbach (2010) detects a positive and significant influence of eco-product innovations on employment. The positive effects of eco-innovation appear to be greater compared to other non-environmental innovation fields.

Licht/Peters (2014) use the Community Innovation Survey (CIS) of 2009 to analyze employment effects of products and process innovations for different European countries and for Germany. The authors find that both environmental and non-environmental product innovations are correlated to employment growth, but that still non-environmental product innovations are more likely to increase employment. Following their estimation results, the displacement effect of process innovations seems to be quite small. The paper of Gagliardi et al. (2014) also analyzes the link between eco-innovation and job creation at the company level for Italian companies matched with patent records for the period from 2001 to 2008. The results show a strong positive impact of eco-innovation on the creation of long-run jobs. The effects are substantially greater compared to the effects of other innovations.

Agglomeration is recognized as a further important factor concerning labor demand (e.g., Alyan 1999; Morrison et al. 2006; Mulligan et al. 2014; Reggiani et al. 2011). Hence, the positive role of eco-innovation for the development of employment may be reinforced by the existence of agglomeration effects.

Agglomeration in the sense of the *New Economic Geography* (e.g., Krugman 1998; Puga 2010) describes mainly the magnitude, causes and consequences of firms located close to each other. Agglomeration economies have been identified across a large range of different fields, including the US carpet production industry in the Georgian city of Dalton (Krugman 1991) and composers of classical music (Borowiecki 2013). According to Duranton/Puga (2004), the causes of agglomeration are a more efficient sharing of the local infrastructure, a better matching between market partners – e.g., between employers and workers – and a better environment for inter-organizational learning. The latter includes the prerequisites for knowledge spillovers. The literature on spillovers (see e.g., Audretsch/Feldman 2004; Feldman 1999; Kaiser 2002) is closely related to innovation and agglomeration. Since knowledge is strongly linked to workers, innovation intensity increases when workers share their knowledge across firms. Although modern information and computer technology makes it possible to collaborate easily across large distances, physical proximity to those network partners is helpful for knowledge spillovers especially for so-called tacit knowledge, which requires face-to-face contacts (Horbach et al., 2013).

Up to now, there are only few articles available concerning the relationship between agglomerations and the environmental sector or eco-innovation. Sensier et al. (2013) show that connections to local governments have positive impacts on the growth of small and medium-sized environmental firms. On the other hand, the growth of these firms benefits from international networks with companies and universities outside the local region. The authors conclude that environmental firms should be both locally and globally oriented in order to be most successful. As reported by Antonioli et al. (2016), local conditions significantly support eco-innovation activities: the more eco-innovative firms are located in a municipality the higher is the probability of eco-innovation adoptions in firms belonging to the same region. This study also finds that firms adopting both environmental and organizational innovations perform economically better. Horbach (2014a) shows that external knowledge sources such as the regional proximity to research centers and universities are more important for eco-innovations compared to other innovations.

According to Hamermesh (1993), the product market, or more specifically product demand, influences labor demand significantly. In addition, high productivity plays a key role in determining labor demand because it helps to improve a firm's (international) competitiveness, thereby leading to increased product demand. The simple neo-classical labor demand function shows that the demand for labor depends on the development of real wages. The "normal" case describes a situation where higher real wages lead to a reduction of labor demand. But the relationship is more complicated: successful firms (which are characterized by positive employment growth) are also more likely to pay higher wages. In econometric analyses, this causes endogeneity problems that have to be considered.

Further labor demand factors that are discussed in the relevant literature are binding wage agreements, union membership (Dittrich/Schirwitz 2011), labor shortage (Horbach 2014b) as barriers to employment development, skills (Addison et al. 2008), firm size (Kölling 2012), occupations and sectors of industry (Cörvers/Dupuy 2010). Finally, conditions of the establishment's organizational environment may also influence labor demand: regional effects (Fuchs/Weyh 2010; Fuchs 2011), regulation (Beise/Rennings, 2005; David/Sinclair-Desgagné 2005), economic development activities (e.g., Kölling 2014), external shocks (e.g., economic crisis, see Bohachova et al. 2011), industry structure (Cörvers/Dupuy 2010; Dauth/Suedekum 2014) and changes in factor markets (e.g., energy prices, see Hamermesh 1980).

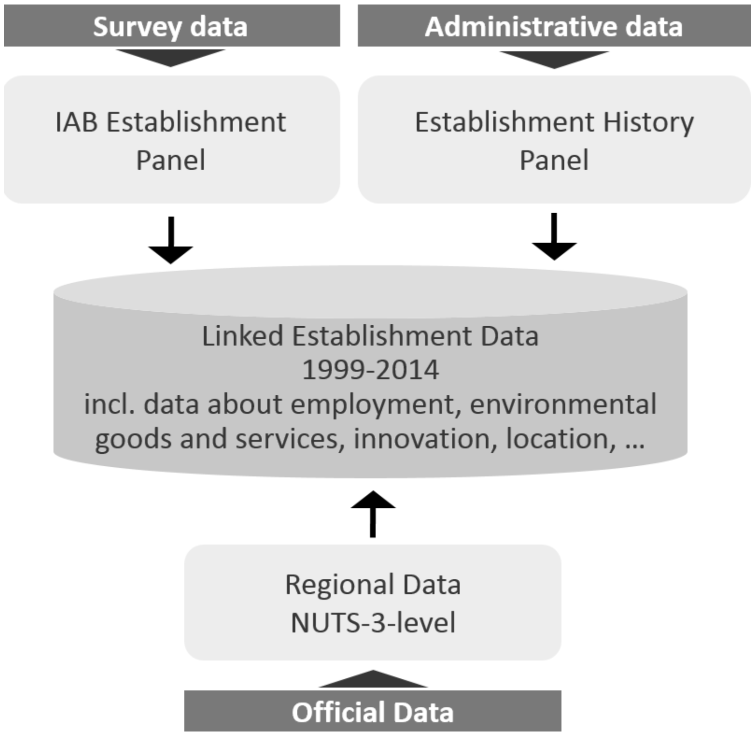
All in all, our theoretical considerations show the important role of high product demand, wages and wage agreements, innovation activities, agglomeration forces and competitive pressure for the development of a firm's employment. The empirical questions of whether environmental establishments exhibit higher employment growth compared to other firms and what factors are crucial for such a development are yet to be answered (see Section 3).

4.3 Empirical analysis of employment growth in the environmental sector

4.3.1 Data

Our empirical analysis combines data from three sources in order to analyze the determinants of employment development: Survey data (IAB Establishment Panel), administrative data (Establishment History Panel (Betriebs-Historik-Panel – BHP)) and official data: regional employment statistics data at NUTS 3 level (*Landkreise* and *kreisfreie Städte*). Figure 4-1 offers an overview of our linked data set:

Figure 4-1: Data sources



Source: Own figure.

The Establishment Panel of the Institute for Employment Research (IAB) was set up in 1993 to obtain a representative picture of German establishments that have at least one employee subject to social security. The annual survey is characterized by response rates of more than 70 percent and covers over 15,000 establishments. It contains both a yearly program of standard questions and additional questions on special topics of current interest. As one of those specific topics, environmental-specific questions were asked in the 1999, 2005 and 2012 waves. Those questions allow us to identify and analyze environmental establishments, their employment development, innovation activities and other organizational characteristics. Furthermore, the establishments are asked to report their share of turnover in the field of environmental goods and services. Based on the answers to this question, we calculate the share of environmental-related employees within our descriptive analysis in Section 3.2. This applies especially for firms producing multi-purpose goods and services as well as for firms producing both environmental and non-environmental goods and services.

For the econometric analysis, the question on the environmental goods and services in the 2012 wave is used to identify the firms belonging to the environmental sector. A firm is assigned to the environmental sector if it offered an environmental good or service in 2011. 15.1 percent (2,413 firms) of all the firms in the sample of the 2012 wave declared that they produce or deliver environmental goods and services. Similar filter questions were introduced in 1999 and 2005. However, products associated with renewable energies and nature conservation were mentioned explicitly only in 2012. Because of these changes, comparisons of the results of 1999/2005 with those of 2012 are limited. A further restraint is due to panel mortality. Owing to the fact that too few of the environmental establishments surveyed in 2012 were included in the previous waves, there are strong limitations when following the environmental establishments surveyed in 2012 within the longitudinal set of the survey panel data. It is therefore not possible to conduct an econometric analysis of employment dynamics based on differences between 1999/2005 and 2012. Nevertheless, we report the descriptive results of the 1999, 2005 and 2012 waves by different environmental technology fields in Section 4.3.2. The use of further waves (here: 2009 and 2010) of the Establishment Panel permits the inclusion of lagged independent variables to reduce endogeneity problems.

Combining the 2009, 2012 and 2014 waves then enables us to calculate the development of employment in the environmental sector from 2009 to 2012, from 2011 to 2012 and from 2011 to 2014. This comparison allows us to check the persistence of the results across different time periods. However, the limitation of this procedure is that it is not known whether a firm already offered environmental goods and services before 2012 because the filter question is only available for 2012. Therefore it may occur that the employment development of firms that did not offer environmental products or services in 2009 is analyzed.

Facing the limitations concerning panel data in terms of the environmental sector from the Establishment Panel, we merged the survey data with administrative data from the German Establishment History Panel (BHP)[34]. The BHP contains longitudinal data at establishment level that are obtained from mandatory employer notifications to the German social security system, which leads to highly accurate and reliable data. All German establishments are included in the annual BHP data set, if they register at least one dependent employee as of the reference date of June 30. The BHP provides data about establishments' workforces, wage distributions, sectors and locations. Regarding our econometric analysis, we used the BHP data for an analysis of the long-term development of employment from 2002 to 2012.

After merging the data sets of the Establishment Panel data and the BHP, we added regional statistical data at NUTS 3 level. Finally, our data file contains data on 15,544 establishments that participated in the 2012 Establishment Panel survey and could be identified within the administrative data of the BHP data. Our analysis of firm-level data gives us the opportunity to isolate the effects of different labor demand factors. Therefore, we can analyze those factors at firm, industry and regional level as well as over time. The

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[34] This study uses the IAB Establishment Panel waves of 2012, 2010, 2009, 2005, 1999 and the Establishment History Panel (BHP) version 7510 (here: years 1993-2010). Data access was provided by the Research Data Centre (FDZ) of the German Federal Employment Agency (BA) at the Institute for Employment Research (IAB). For detailed data documentation see Ellguth et al. (2014); Fischer et al. (2009); Gruhl et al. (2012).

following section provides an overview of the descriptive results based on this linked project data set.

4.3.2 Descriptive analysis

The calculation of employment in the environmental sector is based on the turnover shares for environmental goods and services. These shares are multiplied with the total employment of the firms in 2012. In 2012, the German environmental sector employed 1.47 million persons (Table 4-1). The largest share of these employees – almost two thirds – works in connection with the provision of services, while about one third works in the production of goods.

Table 4-1: Employment in the environmental sector in 2012 – number of employees

Environmental goods/services	Employees 2012	
	Number	Share
Environmental goods	520,516	35.5%
Environmental services	945,165	64.5%
Total	1,465,682	100.0%

Source: IAB Establishment Panel 2012, own calculations, projected results.

Table 4-2 shows the development of the employment shares between the panel waves of 1999, 2005 and 2012. Since the environmental sector comprises a broad range of goods and services, it is necessary to distinguish between different subfields. In 2012, the question on the composition of the different environmental fields was changed significantly such that the results obtained in 1999/2005 are not fully comparable with those obtained in 2012. The results document the considerable importance of the subfield of *climate protection and renewable energies* (2012: 35.2 percent) for employment whereas the shares of subfields such as water or recycling decreased (e.g., recycling from 29.8 percent in 2005 to 19.0 percent in 2012).

Table 4-2: Employment in the environmental sector by different subfields

Subfield	Distribution of employment in %		
	1999	2005	2012
Prevention of water pollution, waste water treatment	18.9	13.0	12.3
Waste management, recycling	27.4	29.8	19.0
Air purification, climate protection	16.3	22.1	-
Air purification	-	-	3.8
Climate protection, renewable energies, energy saving	-	-	35.2
Noise abatement	2.3	2.1	4.5
Environmental remediation, soil conservation	3.7	5.4	1.6
Nature conservation, landscape management	-	-	9.7
Measurement, analysis and control technology	6.6	6.5	3.9
Analytics, consultancy, project planning	4.7	5.4	2.9
Environmental research, development and monitoring	1.5	4.7	2.0

Other environmental fields	18.6	11.0	5.1
Total	100	100	100

Note: In our analysis of environmental subfields we use a mutually exclusive variable. The firms had to choose one environmental subfield as most important in terms of business volume in 2011 (only one answer was permitted).
Source: IAB Establishment Panel 2012, Horbach et al. (2009), own calculations, projected results.

In a further step, we analyze the employment growth from 2009 to 2012. For this reason, we have to identify environmental establishments based on questions from one wave of the IAB Establishment Panel. This enables us to trace these establishments in previous panel waves – if they had participated in those waves. We use the questions asked in 2012 to identify the firms in the environmental sector, as the filter questions in 2012 are not comparable to those asked in 2005 and 1999. Furthermore, it has to be borne in mind that firms may be incorrectly assigned to the environmental sector for the period from 2009 to 2011 if they had not yet provided environmental goods and services prior to 2012. Employment development denotes the growth rate of the total number of employees between 2009 and 2012.

Table 4-3: Employment growth from 2009 to 2012 by different subfields compared to non-environmental establishments

Subfield	**Employment growth 2009 – 2012 in %**
Prevention of water pollution, waste water treatment	2.7
Waste management, recycling	0.6
Air purification	12.0
Climate protection, renewable energies, energy saving	6.2
Noise abatement	6.1
Environmental remediation, soil conservation	16.8
Nature conservation, landscape management	1.2
Measurement, analysis and control technology	9.5
Analytics, consultancy, project planning	16.3
Environmental research, development and monitoring	14.0
Other environmental fields	11.7
Environmental establishments in total	4.7
All establishments	4.1

Source: IAB Establishment Panel 2012, own calculations.

Table 4-3 shows the employment growth from 2009 to 2012 by different subfields of the environmental sector compared to non-environmental establishments. The employment growth from 2009 to 2012 is based on data of those establishments that could be identified in both waves 2009 and 2012 of the IAB Establishment Panel. The calculation of the employment growth from 2009 to 2012 is weighted by the size of the firms. The values of employment growth in subfields are not interpolated, because the standard grossing-up factor of the IAB Establishment Panel does not cover this dimension over time. The results show that employment growth is slightly higher in the environmental sector as a whole (4.7 percent) compared to non-environmental establishments (4.1 percent). Within the environmental sector, pronounced differences between subfields are visible. The subfield of *environmental remediation, soil conservation* shows the highest value (16.8 percent), whereas *waste management, recycling* has the lowest value (0.6 percent). *Climate protection, renewable energies, energy saving*, the subfield with the largest employment share, grew by 6.2 percent, which is stronger than the average of the environmental sector in total (4.7 percent).

Table 4-4:Qualification level of employees and innovativeness in the German environmental sector in 2011

Subfield	**Share of employees with … university education in %**	**Share of employees with … no vocational training in %**	**Share of innovative establish-ments in %**
Prevention of water pollution, waste water treatment	13.4	14.7	47.2
Waste management, recycling	8.9	20.3	53.0
Air purification	8.6	13.1	54.2
Climate protection, renewable energies, energy saving	13.4	11.0	55.2
Noise abatement	13.1	13.9	55.4
Environmental remediation, soil conservation	9.5	9.2	54.5
Nature conservation, landscape management	12.9	17.3	36.6
Measurement, analysis and control technology	16.4	12.2	66.1
Analytics, consultancy, project planning	26.8	6.5	65.3
Environmental research, development and monitoring	38.4	5.8	60.0
Other environmental fields	12.1	14.1	62.7
Environmental establishments in total	13.4	14.0	53.4
All establishments	9.9	24.2	40.4

Source: IAB Establishment Panel 2012.

In the light of this employment growth, we want to know what qualification levels the environmental establishments demand and how the establishments differ in terms of innovation. Table 4-4 provides an overview of these two aspects. Again, we observe significant differences between subfields. Except *nature conservation*, all subfields show larger innovation shares than the overall sample. The subfields with the largest shares of innovative establishments (more than 60 percent) are *measurement, analysis and control technology*, *environmental research, development and monitoring,* and *analytics, consultancy, project planning.* These subfields also show a larger share of employees with a university education and a smaller share of employees with no vocational training. Among other things, the largest subfield, *climate protection, renewable energies, energy saving,* also has an above-average share of innovative establishments (55 percent).

All in all, the environmental sector accounts for a considerable share of employees and a large share of environmental services. Compared with the sample average, the environmental sector has grown more strongly supporting our first main research hypothesis (see Section 1). Except nature conservation, all subfields of the environmental sector show larger innovation shares than the overall sample. However, the environmental sector is not homogeneous. In terms of both employment growth and other environmental sector characteristics there are pronounced differences between its subfields.

4.3.3 Econometric analysis

Our econometric analysis aims at exploring the determinants of employment development in the environmental sector compared to the German economy as a whole therefore answering our second main research question formulated in Section 1. In a first step, we analyze the short-term development of employment from 2009 to 2012. Furthermore, the time periods of 2011 to 2012 and from 2011 to 2014 are considered to reduce problems of endogeneity. Combining the Establishment Panel with the so-called Establishment History Panel enables us to observe the firms belonging to the environmental sector for a longer time period from 2002 to 2012, so we also estimate such a long-term model. Separate models are estimated for all firms including environmentally relevant explanatory variables and for the environmental sector alone.

As the baseline estimation, we use an OLS model with clustered standard errors at NUTS 3 level, because variables at the establishment and the regional level are considered. Furthermore, we apply a two-level mixed-effects linear regression. The two models take into account the problem that the employment growth of firms within a region may be correlated. The mixed-effects model contains both random and fixed effects. We have to consider a two-level model for a series of 402 clusters (402 regional German NUTS 3 units). The model reads as follows (StataCorp 2013):

$$empdev_{ij} = \beta_0 + \beta_1 reg_{ij} + \beta_2 inno_{ij} + \beta_3 pdem_{ij} + \beta_4 wagedev_{ij} + \beta_5 \psi_{ij} + \mu_j + \varepsilon_{ij}$$

for $j = 1; \ldots; 411$ clusters, with cluster j consisting of $i = 1; \ldots; n_j$ observations. The random effect μ_j serves to shift the regression line up or down according to the NUTS 3 unit (StataCorp 2013). Because of the small numbers of cases in many regions, a random intercept model was estimated assuming fixed slopes. The log-likelihood function is approximated by Gauss-Hermite quadrature (Cameron/Trivedi 2009). Following the theoretical analysis in Section 2, we consider vectors of regional variables (reg_{ij}), innovation ($inno_{ij}$), indicators for product demand ($pdem_{ij}$), the development of wages ($wagedev_{ij}$) and further control variables ψ_{ij} such as export shares, state of technical equipment, firm size, firm age, competitive pressure, qualification structure, sector dummies and dummies for the German *Länder* (NUTS 1 units).

To reduce the problem of endogeneity regarding wages, we lagged this variable by one period. In fact, this endogeneity problem may be minor because the possibilities for a single establishment to alter wages are restricted due to the pressure from national and international competitors. Therefore, wages are probably influenced more by developments in specific industries than by single establishments.

As a further robustness check, we estimate a treatment effects model regarding the environmental innovation intensity as treatment variable. The outcome variable is once again the employment development (empdev) from 2009 to 2012. This model helps to answer the question as to whether firms with intensive innovation in the environmental sector demonstrate better employment growth compared to the economy as a whole. The so-called propensity score matching estimator calculates the conditional probability that an observation receives a specific treatment given certain covariates. The unknown potential output without treatment is estimated using an average of the outcomes of similar subjects (StataCorp 2013).

Description of variables

For our econometric analysis, we use the following variables (for a precise definition see Appendix, Table 4-9). *Empdev0912* describes the growth rate of the number of employees from 2009 to 2012, *empdev1112*, *empdev1214* and *empdev0212*, the respective employment developments. The subsection "Products and services for the environmental protection' of the IAB Establishment Panel questionnaire covers information about the type and scope of environmental establishments. This subsection starts with the filter question "*Does your establishment/office provide any products or services related to environmental protection in one of the following sectors?"* (IAB 2016), which allows us to distinguish between "environmental establishment" and "non-environmental establishment". We denote an establishment as an "environmental establishment" if the firm answered that it offers "goods or services for environmental protection". All other firms are defined as "non-environmental establishments".

The dummy variables *ecoinnointens, waterinno, recycinno, airclimateinno* and *natureinno* are given the value one if the firm belongs to the respective environmental field and has implemented a product or process innovation in 2011. In the questionnaire, there are no further details available about the environmental-relatedness of product or process innovations. Therefore, this study uses "environmental innovation" as "innovation in environmental establishments". Unfortunately, we only have data for 2011 concerning the different environmental innovation fields so that it is difficult to cope with possible endogeneity problems of these innovation activities. Furthermore, reliable exogenous instruments for the different innovation fields are not available. Therefore, as a robustness check, we analyze two further short term periods from 2011 to 2012 and from 2011 to 2014 that follow the innovation activities of 2011 (Table 4-6). These results can be better interpreted in the sense of causality rather than mere correlation. The disadvantage of this procedure is on the one hand that the time period of 2011 to 2012 is very short. On the other hand, from 2011 to 2014, the panel mortality is high so that many observations are lost leading to less significant results. *Otherinno* captures firms that are innovative but not active in the environmental sector.

Age describes the age of the firm, the variable has the value one if the firm was founded after 1990, zero otherwise. The state of a firms' capital stock is indicated by *capitalnew*. The value one characterizes a modern capital stock. The dummy variable *competition* denotes high competitive pressure perceived by the firm. The share of employees with a university degree in the firm's entire workforce is captured by *highqual*. The value one for *profitsituation* denotes the firm having a very good or good self-perceived profit situation before the analyzed time period. Besides the profit situation, o*vertime* is a further proxy variable for the product demand. If a firm made use of overtime, this variable is given the value one. The product demand also reflects the influence of environmental policy because German environmental policies such as the German feed-in-tariff system foster the demand for environmental goods and services. However, because of a lack of data, we cannot include further regulation indicators in our model.

Size denotes the number of employees of the establishment in 2002, 2009 or 2011 always related to the base year of the employment development in the different econometric models. Furthermore, dummies for the German *Länder* and sectors were included. *Invest* has the value one if the establishment made investments in 2011. We also include the variables *popdens* and *secshare* at NUTS 3 level. *Popdens* denotes the population density of the respective NUTS 3 unit; *secshare* captures the sector share of the sector to which the firm belongs in the respective NUTS 3 unit, thus signaling localization advantages (or disadvantages).

Table 4-5: Determinants of employment growth from 2009 to 2012

Dependent variable: Empdev0912—Employment growth rate from 2009 to 2012, in %			
Regressors	**All establishments**		**Only env. estab.**
	OLS (clustered standard errors)	**Two-level mixed GLM**	**Two-level mixed GLM**
Innovations			
Ecoinnointens	7.89 (2.49)***	7.88 (2.65)***	7.17 (2.05)**
Otherinno	3.78 (4.46)***	3.78 (3.81)***	-
Airclimateinno	5.11 (1.98)**	5.11 (1.99)**	4.43 (1.43)
Natureinno	-5.49 (-1.42)	-5.49 (-0.95)	-3.97 (-0.65)
Recycinno	1.82 (0.65)	1.82 (0.52)	0.39 (0.10)
Waterinno	0.32 (0.13)	0.31 (0.07)	-0.46 (-0.10)
Regional var.			
Popdens	0.03 (0.64)	0.03 (0.50)	0.09 (0.51)
Secshare	0.18 (2.91)***	0.18 (2.55)***	0.58 (2.93)***
Control var.			
Age	4.54 (4.79)***	4.54 (4.75)***	4.32 (1.71)*
Capitalnew	4.06 (4.63)***	4.06 (4.47)***	5.26 (2.22)**
Competition	-3.53 (-3.88)***	-3.53 (-3.97)***	-4.86 (-2.12)**
Exportshare	-0.01 (-0.23)	-0.01 (-0.21)	0.06 (0.84)
Highqual	-0.02 (-0.77)	-0.02 (-0.74)	-0.09 (-1.33)
Overtime	2.41 (2.39)**	2.39 (2.44)**	0.24 (0.08)
Profitsituation	4.06 (4.57)***	4.07 (4.63)***	1.40 (0.61)
Size09	-0.06 (-1.68)*	-0.06 (-1.17)	-0.07 (-0.77)
Tariff	-0.48 (-0.53)	-0.48 (-0.51)	-2.36 (-0.99)
Wagedyn0911	0.00 (-0.01)	0.00 (-0.02)	-0.05 (-2.02)**

German Länder			
Baden	6.10 (2.93)***	6.08 (2.82)***	9.42 (1.65)*
Bavaria	5.52 (2.58)***	5.53 (2.53)***	6.53 (1.18)
Berlin/Bre./Ham.	3.58 (1.83)*	3.58 (1.44)	8.30 (1.26)
Brandenburg	3.20 (1.64)*	3.22 (1.50)	9.05 (1.59)
Hesse	3.44 (1.58)	3.44 (1.43)	9.04 (1.49)
Lowsax	5.73 (1.90)*	5.75 (2.55)***	18.92 (3.40)***
Meckpom	1.74 (0.82)	1.74 (0.75)	10.96 (1.75)*
Northwestf	2.96 (1.65)*	2.96 (1.41)	5.28 (0.99)
Rhineland	6.48 (2.95)***	6.48 (2.63)***	15.25 (2.34)**
Saarland	3.20 (0.89)	3.28 (1.22)	5.91 (0.91)
Saxony	3.81 (2.07)**	3.81 (1.87)*	7.22 (1.42)
Saxonyanh	1.82 (0.92)	1.82 (0.86)	12.15 (2.40)**
Schleswig	8.69 (2.62)***	8.69 (3.17)***	14.21 (2.10)**
	No. obs.: 6,677 F (48, 394) = 6.05***	No. obs.: 6,677 Wald χ2 (48) = 206.39***	No. obs.: 1,035 Wald χ2 (47) = 69.52**

Note: T (for OLS) and Z-statistics are given in parentheses; *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Sector dummies and constants are included but not reported.

Table 4-6: Determinants of employment growth from 2011 to 2012 and from 2011 to 2014

Dependent variable: Empdev1112/Empdev1114—Employment growth rate from 2011 to 2012/2011 to 2014, in %

Regressors	**All establishments**		**Only environmental establishments**	
	2011-2012	**2011-2014**	**2011-2012**	**2011-2014**
Innovations				
Ecoinnointens	3.01 (2.70)***	3.59 (1.65)*	2.63 (1.65)*	6.24 (2.44)**
Otherinno	2.35 (4.55)***	2.93 (3.53)***	-	-
Airclimateinno	2.78 (1.60)	-0.33 (-0.13)	2.30 (1.33)	2.76 (0.96)
Natureinno	-1.42 (-0.41)	2.84 (0.52)	-2.18 (-0.56)	7.30 (1.29)
Recycinno	0.85 (0.75)	0.34 (0.13)	1.08 (0.74)	2.99 (0.92)
Waterinno	0.99 (0.80)	0.52 (0.17)	0.76 (0.49)	3.74 (1.05)
Regional var.				
Popdens	0.05 (1.80)*	0.10 (2.08)**	0.03 (0.32)	0.11 (0.98)
Secshare	0.06 (1.62)*	0.06 (0.89)	0.21 (1.59)	0.07 (0.45)
Control var.				
Age	-0.08 (-0.17)	1.27 (1.44)	-1.06 (-0.85)	-2.11 (-1.16)
Capitalnew	0.42 (0.81)	1.66 (1.74)*	-0.93 (-0.52)	2.53 (1.28)
Competition	-1.48 (-2.76)***	-3.51 (-4.29)***	0.00 (0.00)	-2.33 (-1.13)
Exportshare	0.00 (0.04)	0.00 (0.04)	0.01 (0.34)	-0.02 (-0.49)
Highqual	-0.01 (-0.28)	0.05 (1.47)	-0.05 (-1.37)	0.00 (-0.06)
Overtime11	2.14 (4.37)***	3.58 (4.18)***	1.67 (1.22)	1.91 (0.78)
Profitsituation11	3.57 (8.04)***	6.19 (7.34)***	6.06 (4.27)***	9.57 (4.08)***
Size11	-0.01 (-1.23)	-0.04 (-1.53)	-0.01 (-0.63)	-0.01 (-0.38)
Tariff	-0.68 (-1.44)	-2.02 (-2.35)**	-0.25 (-0.18)	-2.38 (-1.17)
Wagedyn0911	0.01 (1.58)	0.01 (0.75)	0.00 (0.33)	0.02 (0.82)
German Länder				
Baden	0.27 (0.27)	3.63 (2.40)**	0.77 (0.20)	-0.97 (-0.27)
Bavaria	1.20 (1.23)	6.35 (3.97)***	1.25 (0.41)	5.19 (1.45)
Berlin/Bre./Ham.	0.19 (0.17)	1.41 (0.96)	1.42 (0.46)	-0.49 (-0.11)
Brandenburg	2.69 (2.36)**	2.59 (1.51)	5.14 (1.70)*	1.48 (0.37)
Hesse	2.34 (2.12)**	6.04 (3.43)***	1.56 (0.49)	8.78 (1.43)
Lowsax	0.81 (0.64)	3.80 (2.41)**	1.84 (0.55)	0.05 (0.01)
Meckpom	1.89 (1.32)	2.42 (1.46)	4.78 (0.85)	-7.87 (-2.20)**

Northwestf	-0.30 (-0.28)	5.64 (3.64)***	2.13 (0.63)	6.38 (1.49)
Rhineland	0.12 (0.10)	1.43 (0.70)	2.60 (0.83)	-0.23 (-0.05)
Saarland	0.48 (0.34)	4.95 (2.02)**	1.36 (0.44)	6.77 (1.58)
Saxony	0.72 (0.73)	3.63 (2.67)***	1.29 (0.47)	2.38 (0.65)
Saxonyanh	0.19 (0.19)	0.89 (0.70)	5.39 (1.78)*	4.09 (1.35)
Schleswig	1.87 (1.22)	5.93 (2.00)**	6.19 (1.88)*	12.69 (2.36)**
	No. obs.: 6,689 $F(48, 394) = 7.31^{***}$	No. obs.: 5,255 $F(48, 389) = 6.91^{***}$	No. obs.:1,035 $F(47, 285) = 1.83^{***}$	No. obs.: 832 $F(47, 261) = 3.46^{***}$

Note: OLS – Regressions with clustered standard errors. T-statistics are given in parentheses; *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Sector dummies and constants are included but not reported.

Results of the short-term models

The estimation results of a model for all the firms in the sample show that highly innovative environmental technology fields such as measurement, analytics, engineering or environmental research (*ecoinnointens*) and air/climate (*airclimateinno*) are significantly positively correlated with the employment development from 2009 to 2012 (Table 4-5).[35] The positive influence of ecoinnointens is confirmed for the time periods of 2011 to 2012 and 2011 to 2014 (Table 4-6). For the other, also innovative environmental technology fields, no significant positive effects on the employment development are detected. Other, not environmentally related innovations (*otherinno*) also trigger employment growth in all analyzed time periods but the coefficient is clearly smaller compared to innovation-intensive eco-innovations (Tables 4-5/4-6).

Table 4-7: Eco-innovation and employment growth from 2009 to 2012 – results of treatment effects models

Output variable: Empdev0912—Employment growth rate from 2009 to 2012, in %	
Treatment variables	Propensity score matching The propensity scores of each subject are estimated using probit models
Ecoinnointens	$Ecoinnointens_i = \beta_0 + \beta_1 size09_i + \beta_2 invest_i^{***} + \beta_3 highqual_i^{***} + \beta_4 age_i + \beta_5 secshare_i + \beta_6 westeast_i + \varepsilon_i$ Statistics for the probit equation: LR Chi^2 (6) = 80. Pseudo R^2=0.04. Average treatment effect: 10.49 (2.60)*** Number of observations: 10138. Z-statistics are given in parentheses.
Airclimateinno	$Airclimateinno_i = \beta_0 + \beta_1 size09_i^{***} + \beta_2 invest_i^{***} + \beta_3 highqual_i^{***} - \beta_4 age_i + \beta_5 secshare_i^{**} + \beta_6 westeast_i^{*} + \varepsilon_i$ Statistics for the probit equation: LR Chi^2 (6) = 110. Pseudo R^2=0.04 Average treatment effect: 2.29 (0.84) Number of observations: 10138. Z-statistics are given in parentheses.
Recycinno	$Recycinno_i = \beta_0 + \beta_1 size09_i + \beta_2 invest_i^{***} + \beta_3 highqual_i - \beta_4 age_i + \beta_5 secshare_i^{*} + \beta_6 westeast_i^{***} + \varepsilon_i$

[35] This result only holds for innovative environmental establishments. Models including dummies for all establishments for the different environmental subfields did not yield significant results. Only innovative firms in the respective environmental technology fields show a better employment development.

	Statistics for the probit equation: LR Chi^2 (6) = 30. Pseudo R^2=0.02 Average treatment effect: -2.77 (-0.94) Number of observations: 10138. Z-statistics are given in parentheses.
Waterinno	$Waterinno_i = \beta_0 + \beta_1 size09_i + \beta_2 invest_i^{***} + \beta_3 highqual_i^{***} - \beta_4 age_i + \beta_5 secshare_i + \beta_6 westeast_i + \varepsilon_i$ Statistics for the probit equation: LR Chi^2 (6) = 35. Pseudo R^2=0.03 Average treatment effect: -4.57 (-1.52) Number of observations: 10138. Z-statistics are given in parentheses.

Note: *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. For the eco-innovation field "nature" the estimation of a treatment effects model was not possible because of the lack of fitting matches.

To check the robustness of this interesting result that eco-innovativeness is crucial for employment, we also estimated treatment effects models (see Table 4-7). The "treated" firms are those being innovative in the different environmental fields, whereas the counterfactuals are all establishments (environmental and non-environmental) without innovation activities in the respective environmental field. The analysis shows that *ecoinnointens* as treatment variable is highly significant, which confirms the finding that specific innovative technology fields in the environmental sector, such as measurement technologies, are associated with a higher employment growth. On the other hand, this is not the case for "older" technology fields, such as water purification technologies. For these fields, corresponding treatment effect models were not significant (see Table 4-7).

The positive role of agglomeration effects is confirmed by our econometric analysis. Firms profiting from localization effects measured by a strong presence of similar firms in the NUTS 3 unit (*secshare*) are characterized by disproportionately positive employment growth from 2009 to 2012. This result is not confirmed for the time period of 2011 to 2014. Employment growth is also triggered by a high product demand measured by the proxies *profit situation* and *overtime* (see Table 4-5/4-6). Firms equipped with modern capital stock (*capitalnew*) also exhibit better employment growth. Furthermore, the employment growth of younger firms (*age*) was disproportionally dynamic from 2009 to 2012, whereas high competitive pressure (*competition)* seems to force firms to reduce their employment. No significant influence of the wage development (*wagedyn0911*) on employment is observable. From 2009 to 2012, the German *Länder Baden*, *Bavaria*, *Lower Saxony* (*lowsax*), *Rhineland, Saxony* and *Schleswig* show a more dynamic development compared to *Thuringia* as the base category.

Concerning our different estimation approaches, the two-level mixed GLM and the OLS estimates with clustered standard errors show only marginal differences so that in Table 4-6 only the OLS estimates are reported.

A separate estimation restricted to the sample containing only firms in the environmental sector shows some interesting specificities of the determinants of employment growth in this sector. From 2009 to 2012, the importance of localization effects seems to be higher for the environmental sector, the respective coefficient for the variable *secshare* is more than three times higher in the model restricted to the sample of environmental firms compared to the model with all firms (Table 4-5). This prominent role of agglomeration forces for the environmental sector may be explained by the fact that external information sources (other firms and research institutions) are disproportionally important for the relatively young and innovative environmental firms (see also Horbach et al. 2013). Furthermore, the environmental sector seems to provide employment opportunities in some eastern German *Länder*, especially for Saxony-Anhalt, which confirms the results of a recent analysis of Horbach (2014a).

Specificities of the long-term models (2002-2012)

Combining the Establishment Panel with the Establishment History Panel allows a long-term analysis of the employment growth in the environmental sector compared to the economy as a whole from 2002 to 2012. The main shortcoming of such an analysis is that the filter question of whether a firm belongs to the environmental sector is only available in 2012, so firms may be assigned to the environmental sector although they did not produce environmental goods and services in 2002. Furthermore, it is not useful to include short-term variables such as the profit situation or overtime in the long-term model.

Table 4-8: Determinants of employment growth from 2002 to 2012

Dependent variable: EmpDev0212—Employment growth rate from 2002 to 2012, in %		
Regressors	**All establishments** **Two-level mixed GLM**	**Only environmental establishments** **Two-level mixed GLM**
Innovations		
Ecoinnointens	16.02 (3.20)***	12.99 (2.22)**
Otherinno	6.76 (3.86)***	-
Airclimateinno	7.88 (1.88)*	5.77 (1.15)
Natureinno	35.36 (3.37)***	39.19 (3.58)***
Recycinno	7.12 (1.29)	3.08 (0.50)
Waterinno	15.75 (2.16)**	12.62 (1.63)*
Regional variables		
Popdens	0.03 (0.22)	-0.21 (-0.71)
Secshare	0.45 (3.65)***	0.40 (1.30)
Control variables		
Firm age	-1.26 (-11.52)***	-1.04 (-4.01)***
Capitalnew	12.46 (7.56)***	12.19 (3.07)***
Competition	-5.99 (-3.79)***	-4.18 (-1.12)
Exportshare	0.10 (2.33)**	0.18 (1.72)*
Highqual	-0.17 (-2.53)***	-0.05 (-0.33)
Size02	-0.29 (-3.24)***	-0.22 (-1.68)*
Tariff	-7.67 (-4.62)***	-12.35 (-3.09)***
Wagedev0111	0.03 (1.89)*	0.05 (0.66)
German Länder		
Baden	20.63 (4.73)***	14.00 (1.41)
Bavaria	20.97 (4.89)***	7.03 (0.72)
Berlin/Bre./Ham.	13.54 (2.82)***	14.53 (1.31)
Brandenburg	-0.73 (-0.16)	-5.06 (-0.47)
Hesse	16.38 (3.61)***	12.43 (1.20)
Lowsax	21.99 (4.96)***	16.07 (1.58)

Meckpom	2.33 (0.51)	-2.87 (-0.26)
Northwestf	23.53 (5.64)***	13.33 (1.46)
Rhineland	22.36 (4.63)***	14.17 (1.31)
Saarland	21.41 (4.43)***	21.11 (2.08)**
Saxony	7.97 (1.92)*	0.61 (0.07)
Saxonyanh	1.13 (0.26)	-1.69 (-0.19)
Schleswig	24.68 (5.36)***	21.89 (2.16)**
	No. obs.: 5,817 Wald $\chi 2$ (46) = 462.84***	No. obs.: 1,018 Wald $\chi 2$ (45) = 119.62***

Note: Z-statistics are given in parentheses; *, ** and *** denote significance at the 10%, 5% and 1% level, respectively. Sector dummies and constants are included but not reported.

All in all, the long-term models (2002-2012) corroborate our findings presented above for the short-term period from 2009 to 2012 (Table 4-8). The result that highly eco-innovative technology fields lead to higher employment effects compared to the overall economy is also confirmed for the long-term period. These results confirm that the crucial variable measuring the impact on employment growth of environmental establishments is *ecoinnointens*. This variable shows higher coefficients (that are all significant) compared to *otherinnovation* in all models in Tables 4-5, 4-6 and 4-8. Hence, the results from our econometric analysis support our second main research hypothesis (see Section 1). Interestingly, in contrast to the short-term analysis, innovative firms operating in the field of nature protection also showed disproportionately large positive employment growth compared to the economy as a whole. Concerning the results for the German *Länder* (NUTS 1 level), there are some differences between the two time periods. In the long-term model, the environmental sector did not yet provide a disproportionately large number of employment opportunities for the eastern German *Länder* because—in contrast to the short-term model—the dummy variables for Saxony-Anhalt and Mecklenburg-Western Pomerania remain insignificant from 2002 to 2012.

4.4 Summary and conclusions

This paper provides an empirical analysis of labor demand in the environmental sector compared to other sectors of the German economy. Our research questions were: (1) Do labor demand and employment growth differ between environmental establishments and establishments that do not produce environmental goods or services? (2) Which determinants of labor demand foster employment growth and which determinants hinder it in the environmental sector?

For our empirical analysis we combined three data bases: the Establishment History Panel, the IAB Establishment Panel and regional data at NUTS 3 level (*Landkreise* and *kreisfreie Städte*). The main data source was the IAB Establishment Panel containing a detailed question on the environmental sector in 2012. The environmental sector comprises goods and services which prevent environmental damage in different fields such as air or water pollution. 15.4% (2,413 firms) of all the firms in the 2012 wave of the sample reported that they belonged to the environmental sector. Similar filter questions were introduced in 1999 and 2005, but unfortunately, the panel mortality due to the long time lags did not allow an econometric analysis of employment dynamics based on these questions. The question on environmental goods and services in the 2012 wave was used to identify the firms belonging to the environmental sector. Combining the 2009, 2012 and 2014 waves then made it possible to calculate the employment development in the environmental sector from 2009 to 2012, from 2011 to 2012 and from 2011 to 2014. The use of further waves of the Establishment Panel enabled us to include lagged independent variables to avoid endogeneity problems. To capture the role of agglomeration forces, we combined our two datasets with official data at NUTS 3 level.

The results of our descriptive analysis strongly support our first research question: Environmental firms show a more dynamic employment development especially for highly innovative firms.

The analysis of our second research question on the determinants of employment growth relies on the application of econometric methods. For the estimation of a labor demand function the following drivers were considered: innovation activities for different environmental and other innovation fields, proxies for product demand; export shares to take into account the fact that the growth of international trade may boost employment in export-oriented firms and innovation activities. Furthermore, we analyzed the influence of wages on labor demand using lagged values for the wage growth rate. We also explored the question of whether regional agglomeration forces foster employment growth in the environmental sector compared to the German economy as a whole. Barriers to employment growth, such as high competitive pressure and collective wage agreements were also analyzed.

We estimated different regression models to analyze the employment dynamics of the environmental sector compared to the rest of the economy. A general model including all firms in the sample shows that highly innovative environmental technology fields such as measurement, analytics, engineering or research are characterized by a significantly positive employment development from 2009 to 2012 and from 2011 to 2014 compared to all other firms in the sample. Other innovations also boost employment but the coefficient is lower compared to eco-innovation-intensive establishments. A good profit situation as a proxy for demand is positively correlated with employment. As expected, high competitive pressure is negatively correlated with employment growth whereas the existence of positive agglomeration effects boosts employment significantly. Young firms exhibit more dynamic employment growth.

A regression restricted to environmental firms shows that agglomeration effects seem to be quantitatively more important for environmental establishments. Furthermore, the environmental sector appears to provide employment opportunities for eastern German Länder – political measures to reinforce positive localization effects in these regions seem to be fruitful.

Our analysis supports the view that environmental policy may yield a dual benefit. Besides positive environmental effects, the environmental sector may also lead to a higher employment growth compared to the rest of the economy. However, this potential employment effect highly depends on the environmental subfields that are supported and, on the innovativeness of those establishments. In consequence, our results suggest: If environmental policies aim to realize this potential dual benefit, they should primarily support environmental establishments which are active in innovative environmental fields. Of course this is only one of several crucial dimensions, but according to our findings, it may increase positive employment impacts and thus may help to maximize the dual benefit of environmental protection. The positive impact of innovation and agglomeration on employment growth in environmental establishment may lead to further implications for policy makers: The promotion of eco-innovation activities, the development and expansion of regional networks / clusters as well as knowledge spillovers between environmental establishments seems to be a promising groundwork for future employment growth in this field.

4.5 Appendix of chapter 4

Table 4-9: Descriptive statistics and definitions of the variables

Variables	Description	Mean	St. Dev.
Endogenous variables			
Empdev0912	Growth rate of number of employees from 2009 to 2012	6.69	36.26
Empdev1112	Growth rate of number of employees from 2011 to 2012	2.75	24.15
Empdev1114	Growth rate of number of employees from 2011 to 2014	6.29	35.46
Empdev0212	Growth rate of number of employees from 2002 to 2012	14.38	60.96
NUTS 3 level			
Popdens	Population density / 100	7.54	10.07
Secshare	Share of a firm's sector in the NUTS 3 unit	11.81	9.48
Innovation variables			
	Innovative firms (at least one innovation in 2011) in the environmental fields (1 yes, 0 no):		
Ecoinnointens	Measurement, analytics, project, research, noise, soil, other	0.02	0.14
Airclimateinno	Air, climate technologies, renewable energy, energy saving	0.03	0.17
Natureinno	Protection of nature, landscape management	0.01	0.07
Recycinno	Waste disposal, recycling	0.01	0.12

Waterinno	Water pollution, waste water treatment	0.01	0.09
Otherinno	Other innovative firms (at least one innovation in 2011) (1 yes, 0 no)	0.32	0.47
Control variables			
Age	Foundation of the firm after (1) or before 1990 (0)	0.58	0.49
Competition	High competitive pressure (1), little or no comp. p. (0)	0.34	0.47
Export	Export share of turnover (as %)	6.60	17.75
Invest	Investments carried-out in 2011 (1 yes, 0 no)	0.65	0.48
Overtime	Overtime in 2008 or 2009 (1 yes, 0 no)	0.50	0.50
Overtime11	Overtime in 2011 (1 yes, 0 no)	0.63	0.48
Profitsituation	Good/very good profit situation in 2008 or 2009 (1 yes, 0 other)	0.32	0.47
Profitsituation11	Good/very good profit situation in 2011 (1 yes, 0 other)	0.41	0.49
Size02	Number of employees / 100 in 2002	1.66	9.68
Size09	Number of employees / 100 in 2009	1.41	9.15
Size11	Number of employees / 100 in 2011	1.33	9.19
Tariff	Existence of a wage agreement (1 yes, 0 no)	0.42	0.49
Wagedyn0911	Growth of wages per employee from 2009 to 2011	12.11	63.92
Wagedyn0111	Growth of wages per employee from 2001 to 2011	18.24	46.22
WestEast	Located in western Germany (1) or eastern Germany (0)	0.61	0.49
Technological capabilities			
Capstocknew	State-of-the-art capital stock (1), older capital stock (0)	0.65	0.48
Highqual	Share of employees with university degree (as %)	9.87	19.28
Sector dummies	*1 yes, 0 no (for all sector dummies)*		
Sec1	Agriculture, forestry and fishery	0.02	0.15
Sec2	Mining, quarrying of stones, energy supply	0.02	0.14
Sec3	Food products, beverages and tobacco	0.02	0.15
Sec4	Textiles, leather	0.01	0.10
Sec5	Wood, paper, printing	0.02	0.14
Sec6	Chemical industry, rubber and plastics, glass	0.04	0.19

Sec7	Basic metals and fabricated metals	0.05	0.21
Sec8	Electrical machinery and apparatus	0.02	0.14
Sec9	Machinery	0.04	0.19
Sec10	Motor vehicles and other transport equipment	0.01	0.12
Sec11	Furniture and other products	0.02	0.13
Sec12	Construction sector	0.08	0.27
Sec13	Wholesale and retail trade	0.15	0.35
Sec14	Transport and logistics	0.04	0.19
Sec15	Information and communication	0.02	0.14
Sec16	Services: banking sector, insurance etc.	0.17	0.38
Sec17	Architectural and engineering offices	0.03	0.16
Sec18	Public sector and other services	0.25	0.43
German Länder	*1 yes, 0 other Land*		
Baden	Baden-Wuerttemberg	0.07	0.26
Bavaria	Bavaria	0.08	0.27
Berlin/Brem/HH	Berlin, Bremen, Hamburg	0.12	0.34
Brandenburg	Brandenburg	0.07	0.25
Hesse	Hesse	0.06	0.24
Lowsax	Lower Saxony	0.07	0.25
Meckpom	Mecklenburg-Western Pomerania	0.07	0.25
Northwestf	North Rhine-Westphalia	0.10	0.30
Rhineland	Rhineland-Palatinate	0.05	0.23
Saarland	Saarland	0.04	0.20
Saxony	Saxony	0.07	0.26
Saxonyanh.	Saxony-Anhalt	0.07	0.25
Schleswig	Schleswig-Holstein	0.05	0.23
Thuringia	Thuringia	0.07	0.25

Source: IAB Establishment Panel, own calculations.

5 The Greenness-of-Jobs Index (GOJI): measuring the greening of jobs by a text-mining based index and employment statistics data[36]

Abstract

The transition towards a greener, less carbon-intensive economy is supposed to lead to a greening of jobs, i.e., to an increasing percentage of environmentally friendly requirements within occupations and to a rising demand for labor in these occupations. Thus far, to what extent the greening of occupations is occurring and how it is distributed over occupational aggregates, sectors and regions remain open questions. To measure the greening of jobs, the paper introduces the new task-based *Greenness-of-Jobs Index* (*GOJI*) and provides first descriptive statistics. I derive the GOJI by performing text-mining algorithms on yearly data from 2011 to 2016 of BERUFENET, an occupational database provided by the German Federal Employment Agency. Using employment statistics data, the descriptive results show a notable greening of jobs, which varies greatly between occupational aggregates, sectors and regions.

JEL-Classification: J23, J24, O33, Q55, R23

Keywords: Human capital, occupational tasks, structural change, green jobs, text mining

5.1 Introduction

As already discussed in chapter 2, in both science and public statistics, the topic of green jobs has been discussed widely in recent years. However, there is still no common definition and measurement concept but, instead, several coexisting approaches. The general problem is that most occupations are not 100 percent green or 100 percent non-

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[36] An earlier version of this chapter is part of the following discussion paper: Janser, M. (2018): The greening of jobs in Germany. First evidence from a text mining based index and employment register data. *IAB-Discussion Paper* 14/2018. Nuremberg: IAB.

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green. This chapter proposes an approach to identify the greenness of jobs by occupational requirements, i.e. by the share of environmental-related “green” tasks in the total number of occupational requirements. This method helps to calculate the greenness of every single occupation.

5.2 Data

To address the objectives of this paper, I develop a new occupational index and link employment data sources into one comprehensive panel dataset at occupational level. First, I use BERUFENET data and text mining results to create the Greenness-of-Jobs Index (*GOJI*). Second, I weight the *GOJI* by occupational, sectoral and regional employment statistics data. The project dataset includes both weighted and unweighted versions.

5.2.1 Occupational BERUFENET data for basic index development

BERUFENET is an online database provided by the Federal Employment Agency in Germany. It covers all items of the classification of occupations (Klassifikation der Berufe 2010, KldB2010, see also BA 2015a and Paulus/Matthes 2013). The purpose of this database is two-fold: it is used by vocational counselors and job placement officers at local employment agencies for career guidance and job placement, but it also serves the general public as a free database for career orientation[37]. BERUFENET is continuously updated by an editorial team who receives and implements change requests from the Federal Employment Agency resulting from the operational advisory processes. The updates are based on both official sources such as training regulations and requests for change from the counseling processes of the federal employment agencies. Both the application in public services and the central content management lead to a high degree of completeness and currency. BERUFENET has already been used for research projects, e.g. to derive occupational tasks (Dengler et al. 2014) as well as to develop an index for the degree of substitutability of occupations due to digitalization and automation (Dengler/Matthes 2015). The data extract of BERUFENET used for this project contains information about the requirements of occupations for the years 2006 and 2011 to 2016. Both occupations and requirements together form an n:n occupations-requirements matrix. The data only include occupations that are actively used in the job placement system of the Federal Employment Agency. Furthermore, occupations of civil servants and military services are not present in the data.

The requirements of BERUFENET are divided into three dimensions: core requirements, additional requirements and requirements groups (Dengler et al. 2014). Core requirements are compulsory parts of every vocational training, further training or course of study. If occupations do not have a formal syllabus these requirements contain

[37] https://berufenet.arbeitsagentur.de/ (last accessed on Oct. 31, 2018).

competencies that are usually carried out in practice. In turn, additional requirements comprise those competencies that may be relevant for the pursuit of the occupation, but are non-compulsory elements of official curricula of occupations. For example, core requirements for roofers are "tile a roof" and "roof drainage", whereas additional requirements are "scaffolding", "energy consulting" and "photovoltaics" (among others). The latter requirement of "photovoltaics" illustrates the matrix format of the BERUFENET: in the case of a roofer it is an additional requirement, in the case of an engineer for renewable energies, it is listed as a core requirement. A third dimension is called "requirement groups". Requirement groups collect knowledge areas or tools that might also be relevant for practicing the occupation (e.g. competence group "CAD software", competence group "roof types"). Unlike core and additional requirements, requirement groups are applied very differently in BERUFENET. Hence, and in line with Dengler et al. 2014, these requirement groups are not used in the following.

BERUFENET contains comprehensive lists of occupational requirements for every single occupation, but it does not include actual job descriptions of job offers. Therefore, this study is based on the overall requirements of every occupation as a set of common requirements rather than an analysis of current job offers. As BERUFENET is continuously being edited and developed on the basis of feedback from employers, employees and public institutions (e.g. to include new regulations of vocational training courses), it is still a dynamic, but more stable source of occupational requirements. Based on the information about requirements, it is not always possible to identify the firms' final products and services. The approach of this paper is therefore unable to identify jobs that have no environment-related requirements but are involved in the production of green goods and services (e.g. an office clerk who sells solar panels). As there are already several studies dealing with the issues of green employment in the green goods and services sector (e.g. Horbach et al. 2009; Becker/Shadbegian 2009; Deschenes 2013; Horbach/Janser 2016; Elliott/Lindley 2017), my contribution is to extend this knowledge with a focus on tasks and occupations.

The general approach of this paper for calculating the greenness of jobs is largely based on Consoli et al. (2016), who work with data from the US American occupational database O*NET[38]. The basic blocks of their research are green tasks, which are flagged in O*NET. These green tasks flags are a result of the "Green Task Development Project (GTDP)" (National Center for O*NET Development 2010a). In Germany, neither BERUFENET nor any other data source provides information similar to the green flag of O*NET.[39] Therefore, one of the steps in the groundwork for this paper is identifying

[38] https://www.onetonline.org/ (last accessed on 31 Oct., 2018)

[39] The only environmental-related information in BERUFENET is the occupational field "occupations in environmental protection and nature conservation", which covers currently 38 occupations. (https://berufenet.arbeitsagentur.de/ (last accessed on 31 Oct., 2018) > Berufsfelder >Landwirtschaft, Natur, Umwelt > Berufe im Umwelt- und Naturschutz). Compared to the broader definition of green tasks

‘green tasks’ in Germany. To achieve this goal, I use a text mining approach which is presented in the next section. Before moving on to this stage, I will briefly introduce the other data sources used for this project.

5.2.2 Statistical data to aggregate at occupational, sectoral and regional level

Aggregating the Greenness-of-Jobs Index at occupational, sectoral and regional level requires statistical macro data of the Federal Employment Agency. All employment statistics I use for the *GOJI* aggregations cover data on every employee liable for social security contributions in Germany. In the descriptives based on statistical data, I exclude marginally employed workers and trainees. At the end of the weighting process, there are *GOJI* values at 16 aggregate levels for each year (2006 and 2011 to 2016). Table 5-1 illustrates the *GOJI* aggregation levels resulting from this procedure. Some of them are presented in the remainder of this paper.[40]

Table 5-1: GOJI aggregation levels

Aggregation dimension	**Aggregation level**		**Number of breakdown levels (here: 2016)**
	Digit level	**Level name**	
Occupational (Classification of Occupations, KldB2010 / 2006: KldB1988)	5	Occupational type	1,192
	3 *(3plus5)*	Occupational group *(extension: plus 5th digit)*	140 *(424)*
	2 *(2plus5)*	Occupational main group *(extension: plus 5th digit)*	36 *(132)*
	1 *(1plus5)*	Occupational areas *(extension: plus 5th digit)*	9 *(36)*
	S2 *(S2plus5)*	Occupational segment *(extension: plus 5th digit)*	14 *(20)*
	S1 *(2plus5)*	Occupational sector *(extension: plus 5th digit)*	5 *(55)*
	5th digit	Requirements level	4
Sectoral (Classification of Economic Activities, WZ 2008)	2	Divisions	88
	1	Sections	21
Regional (Nomenclature of Territorial Units for Statistics, NUTS)	NUTS 3	Districts	429
	NUTS 1	Federal States	16

Source: Employment Statistics of the Federal Employment Agency, own calculations. Note: The 5th digit of KldB2010 provides additional information about the requirements level.

of this paper, the definition of the occupational field is much narrower and is based on an output-oriented approach (environmental goods and services).

[40] Further GOJI aggregates are shown in the Appendix of chapter 5. A selection of csv files with aggregated GOJI values is available on request from the author.

5.3 The Greenness-of-Jobs Index (*GOJI*)

5.3.1 Identification of green tasks by text mining

The source used for the semantic analysis of the present paper is the so-called 'requirements catalogue' of BERUFENET, which contains yearly text information about the three requirements dimensions mentioned above. For example, the requirements catalogue of 2014 contains 14,546 words, which are subjected to computational content analysis. This analysis is based on lexicometrics with a focus on frequency analysis and key term extraction (Wiedemann 2016). I apply a deductive approach (Ignatow/Mihalcea 2016) combining qualitative and quantitative content analysis. The aim of this step is to extract key terms associated with typical areas of activities, products and services in the green economy from national and international studies. Due to the explorative nature of this early stage I use qualitative content analysis methods (Mayring 2014). After an extensive literature review[42], I created a 'green tasks dictionary' in the sense of a controlled list of relevant words. This dictionary is the basis of the quantitative content analysis of the BERUFENET data.

As in many other text mining cases, the decision about the central definition of the text mining subject is crucial for the entire project and had to be made at this stage of the project. For the present paper, the definition of the character of a 'green task' is particular important. The literature above revealed that there is no standard scientific definition for green tasks. This is my definition, which is used for the rest of the analysis, following the definition of general tasks by Acemoglu/Autor (2011): ***Green tasks*** are the explicitly *environmentally friendly* occupational requirements related to the production of output (goods and services) and to any other organizational process. These requirements may be related to all steps along the entire value chain. This includes knowledge areas, technologies and practices to reduce the use of fossil fuels, to decrease pollution and greenhouse gas emissions, to increase the efficiency of energy usage and material usage, to recycle materials, to develop and adopt renewable sources of energy, to protect and promote biodiversity.

The decisive criterion in this context is the explicitly *environmentally friendly* specific task content. It was necessary to choose this rigid 'explicit' approach to avoid the definition of 'green' becoming a matter of subjective decision. Either the process of production or the products and services included in the title of the specific tasks can be used as an indicator for green tasks. Environmentally friendly covers all products and actions that actively foster the ecologically sustainable development goals of the *green economy* paradigm. There are many different definitions of the green economy and its characteristics. I adopt the definition of Dierdorff et al. (2009: 3) and extend it to include further green economy aspects which are stressed in literature (see literature review): the

[42] The list of studies taken into account is documented in the appendix.

green economy comprises all economic activities to reduce the use of fossil fuels, to decrease pollution and greenhouse gas emissions, to increase the efficiency of energy usage and material usage, to recycle materials, to develop and adopt renewable sources of energy, to protect and promote biodiversity. To distinguish between green tasks and green skills, I adapt the general skills definition by Acemoglu/Autor (2011): *green skills* are a worker's endowment with capabilities for performing various green tasks. Workers apply their green skill endowments to green tasks in exchange for wages, and green skills applied to green tasks produce output. The output need not necessarily be explicitly environmentally friendly. In the remainder of this paper, I focus on green tasks to pursue my research objectives.

In accordance with the extended definition of green tasks, I worked with different thesauri[43] in order to define a basic set of keywords, which I extended using the literature review. The goal was to obtain a list with a wide range of different topics but a focus on the most relevant keywords. This strategy was adopted to avoid a too broad range of matches that might lead to less reliable results. Additionally, I aggregated words with the same root by reducing the words to their word stem ('stemming'). At the end of this process, I obtained a *'green tasks dictionary'* by collecting the most frequently used key words in a structured list. Furthermore, I grouped the dictionary words by categories of keywords (see Table 5-2). This allocation to categories was derived from the main topic areas of the green economy literature. Each keyword was allocated to only one category (the one with the most frequent references).

Table 5-2: List of keyword categories

	Category of Keywords	Category Code	Number of keywords
1	Energy production & storage	EN	19
2	Mobility & tourism	MOB	34
3	Building	BUILD	21
4	Farming, forestry, food, consumer goods	FFFC	19
5	Energy efficiency & further climate protection	CP	10
6	Emission protection (air, water, soil, noise)	EP	27
7	Circular economy, (raw) material efficiency & waste management	CE	13
8	Environmental protection (general)	EPGEN	10
	Total number of green tasks keywords	GT	153

Source: BERUFENET, own calculations.

On the basis of the green tasks dictionary I used the method of regular expressions to identify those job requirements in BERUFENET that contain key words from the dictionary. Those requirements were coded as 'green tasks'. For the computational

[43] I use the German and English versions of the multilingual thesaurus of the European Union: http://eurovoc.europa.eu/drupal/?q=download/subject_oriented (e.g. parts from Subject 52 Environment, 66 Energy) as well as open content sources of http://www.openthesaurus.de and https://de.wiktionary.org/.

content analysis and automatic coding I used text-mining packages of the statistical software R. The subject of the semi-automatic coding was job requirements in the requirements catalog generated from BERUFENET. The coding led to one class of 'green tasks' codes, comprising nine sub-codes for the main topic areas of the green economy introduced in the green tasks dictionary. I applied this process for the year 2006 and for 2011 to 2016. The results of the frequency analysis after the coding procedure are presented in the section *'Descriptive analysis'*.

5.3.2 From green tasks to the weighted Greenness-of-Jobs Index *GOJI*

Unweighted Greenness-of-Jobs Index

To measure the share of environment-related requirements ('green tasks') involved in a specific occupation, I develop a Greenness-of-Jobs Index (*GOJI*). The index exploits the information provided in BERUFENET's 'requirements' section to shed light on the state and development of the greenness of occupations. Rather than simply distinguishing between green ('1') and non-green ('0'), *GOJI* facilitates analyses of occupations within a huge range of different 'shades of green'.

The basis of *GOJI* is a '*green tasks-occupations matrix'* to allocate the number of green tasks to each individual occupation. The matrix is grouped by two requirement dimensions of core and additional requirements. To use the total number of (both green and non-green) requirements as the denominator, I expand the matrix to include the total count of requirements per individual occupation, which is also grouped by core and additional requirements. Occupations with a higher requirements level usually contain a larger number of requirements and thus have a higher probability of containing more green tasks than occupations with lower requirements. To avoid this bias the relative Greenness-of-Jobs Index (*GOJI*) always reports the number of green requirements as a proportion of the total number of requirements.

By means of the *green tasks-occupations matrices* for 2006 and 2011 to 2016, I calculate the greenness of occupations for each year. To calculate the shares per year, I apply a similar approach to that used by Consoli et al. (2016). However, their approach works only with cross-sectional data. Furthermore, it does not include the division into core and additional requirements or identify green tasks by themselves. They instead use the O*NET information of 'green task', which is not available for the German occupational classification system. Hence, I have to adapt the models and develop additional approaches due to the different data sources and the structure of BERUFENET:

$$\boldsymbol{GOJI}_{\boldsymbol{core}_{\boldsymbol{occ8d,t}}} = \frac{\sum \boldsymbol{gr\_core}_{\boldsymbol{occ8d,t}}}{\sum \boldsymbol{r\_core}_{\boldsymbol{occ8d,t}}}$$

where

$\boldsymbol{GOJI}_{\boldsymbol{core}_{\boldsymbol{occ8d,t}}}$ is the ‘green core tasks index’ *(0…1)* of occupation *occ8d* (8-digit level). Occupation *occ8d* is based on the index system of BERUFENET. This index is called the “occupational code number” (Berufskennziffer, BKZ).

$\sum \boldsymbol{gr\_core}_{\boldsymbol{occ8d,t}}$ is the number of green core requirements for occupation *occ8d* (8-digit level) in year *t*

$\sum \boldsymbol{r\_core}_{\boldsymbol{occ8d,t}}$ is the number of all core requirements for occupation *occ8d* (8-digit level) in year *t*

The $\boldsymbol{GOJI}_{\boldsymbol{core}}$ describes the proportion of green core tasks in the total of core requirements for occupation *occ8d (8-digit level)* in year *t*. Because the core requirements cover those activities that are most essential for practicing the occupation, this index has the highest generalizability for each job within this occupation. However, due to its stability the core requirements are relatively static and changes last longer than additional requirements. Hence, $GOJI_{core}$ is most helpful to measure green core occupations with green requirements at the center of their occupational conception. It is rather useful for long-term observations of the transition dynamics of the greening of jobs.

The $\boldsymbol{GOJI}_{\boldsymbol{add}}$ describes the proportion of green additional tasks in the total sum of additional requirements for occupation *occ8d (8-digit level)* in year *t*:

$$\boldsymbol{GOJI}_{\boldsymbol{add}_{\boldsymbol{occ8d,t}}} = \frac{\sum \boldsymbol{gr\_add}_{\boldsymbol{occ8d,t}}}{\sum \boldsymbol{r\_add}_{\boldsymbol{occ8d,t}}}$$

where

$GOJI_{add_{occ8d,t}}$ is the ‘green additional tasks index’ *(0…1)* of occupation *occ8d* (8-digit level) in year *t,*

$\sum gr\_add_{occ8d,t}$ is the number of green additional requirements for occupation *occ8d* (8-digit level) in year *t*, and

$\sum r\_add_{occ8d,t}$ is the number of all additional requirements for occupation *occ8d* (8-digit level) in year *t.*

The additional requirements are those that can be activities of an occupation but are not part of its core occupational conception. The time spent on additional requirements depends strongly on the specific job. The $GOJI_{add}$ is well-suited for analyzing short-term dynamics within the green requirements composition of occupations, because there is much higher fluctuation of BERUFENET contents in additional requirements than in core requirements.

The $\boldsymbol{GOJI}_{\boldsymbol{total}}$ facilitates the measurement of the share of green requirements in the total requirements. It describes the proportion of green core and additional requirements in the total sum of core and additional requirements for occupation *occ8d (8-digit level)* in year t.

$$\boldsymbol{GOJI_{total_{occ8d,t}}} = \frac{\sum \boldsymbol{gr\_core_{occ8d,t}} + \sum \boldsymbol{gr\_add_{occ8d,t}}}{\sum \boldsymbol{r\_core_{occ8d,t}} + \sum \boldsymbol{r\_add_{occ8d,t}}}$$

where

$GOJI_{total_{occ8d,t}}$ is the unweighted 'green total index' (0…1) of occupation occ8d (8-digit level) in year *t,*

$\sum gr\_core_{occ8d,t}$ is the number of green core requirements for occupation *occ8d (8-digit level)* in year *t,*

$\sum r\_core_{occ8d,t}$ is the number of all core requirements for occupation *occ8d (8-digit level)* in year *t,*

$\sum gr\_add_{occ8d,t}$ is the number of green additional requirements for occupation *occ8d (8-digit level)* in year *t*, and

$\sum r\_add_{occ8d,t}$ is the number of all additional requirements for occupation *occ8d (8-digit level)* in year *t.*

The $GOJI_{total}$ is based on the assumption that the requirements are equally distributed in terms of working time on average. An alternative assumption might be that the core requirements take up a larger part of the working time than the additional requirements. For robustness checks, I also test a weighted index $\boldsymbol{GOJI_{wtotal}}$ that takes this assumption into account. As the time component of core requirements should theoretically be larger than that of additional requirements, I choose a weight of 2/3 for core requirements and 1/3 for additional requirements. The aim of this 2/3-to-1/3 partition is to give the core tasks a higher weight. The results of these tests show only little differences to $GOJI_{total}$. To reduce the complexity of the paper, I do not use the results for the $GOJI_{wtotal}$ in this paper.[44]

Using the example of the occupation *chimney sweep*[45], Table 5-3 illustrates the calculation of the *GOJI* values. This occupation has five core requirements and sixteen additional requirements. The codes of text mining include the associated category of green tasks keywords.

[44] A different division, e.g. 3/4 to 1/4, would also be conceivable. Ideally, the real composition should be approximated by further methods such as a worker-level survey. This would be another interesting perspective for future research. The test results based on $GOJI_{wtotal}$ are available from the author on request.

[45] Occupational title in German: Schornsteinfeger. Administrative identifiers: 42212100 (KldB2010 8-digit level) / 8211 (BKZ). Source: https://berufenet.arbeitsagentur.de/berufenet/faces/index?path=null/suchergebnisse/kurzbeschreibung/berufkompetenzen&dkz=8211 (last accessed on 31 Oct., 2018).

Table 5-3: Example of (unweighted) GOJI: Occupation 'chimney sweep' (c.s.) 2016

Requirements	Codes (after text mining)	Elements of Greenness-of-Jobs Index (GOJI)		
Core requirements (N_{core}=5)		$gr\_core_{c.s.2016}$	$r\_core_{c.s.2016}$	$GOJI_{core_{c.s.2016}}$
Fire safety			1	
Emission/Immission control	green (gt03_APM)	1	1	
Fireplace inspection			1	
Customer advisory service, customer care			1	
Measurement			1	
		1	5	0.200
Additional requirements (N_{add}=16)		$gr\_add_{c.s.2016}$	$r\_add_{c.s.2016}$	$GOJI_{add_{c.s.2016}}$
Energy consulting	green (gt02_EEFF)	1	1	
Energy saving order (EnEV)	green (gt02_EEFF)	1	1	
Energy savings technology	green (gt02_EEFF)	1	1	
Heating and chimney construction			1	
Gas firings			1	
Danger defense (prevention)			1	
Heating technology			1	
Tiled stove construction			1	
Chimney stoves			1	
Sweep			1	
Ventilation systems	green (gt02_EEFF)	1	1	
Ventilation technology	green (gt02_EEFF)	1	1	
Oil heatings			1	
Pellet heating systems, woodchip heating systems	green (gt01_EPES)	1	1	
Environmental law	green (gt09_ECP)	1	1	
Environment protection, env. technology	green (gt09_ECP)	1	1	
		8	16	0.500
$GOJI_{total_{c.s.2016}} = \frac{\sum gr\_core_{c.s.2016} + \sum gr\_add_{c.s.2016}}{\sum r\_core_{c.s.2016} + \sum r\_add_{c.s.2016}}$		$gr\_total_{c.s.2016}$	$r\_total_{c.s.2016}$	$goji_{total_{c.s.2016}}$
		9	21	0.429

Source: BERUFENET, own calculations

Employment-weighted $GOJI_x$ at aggregated occupational level

a) Occupational aggregation from 8-digit level to 5-digit level

Both administrative employment data and statistical employment data are only available at higher aggregated levels, beginning with the 5-digit level of KldB2010. For example, the BeH includes information on the last occupation of every employee at the 5-digit level of the KldB2010, but not at the 8-digit level. So far, the GOJI is only based on the individual occupation level (BKZ-/'8-digit-level' of KldB2010). To achieve the goal of this paper—analyzing employment impacts of the greening of jobs—it is necessary to link employment data with the GOJI. Therefore, $\boldsymbol{GOJI_{o(bkz)}}$ has to be aggregated to the next level, which is the 5-digit level of the German classification of occupations (Klassifikation der Berufe 2010—KldB2010). To transform $\boldsymbol{GOJI_{occ(8-digit)}}$ into $\boldsymbol{GOJI_{occ(\geq 5-digit)}}$, I use a procedure similar to that used by Dengler et al. (2014): the greenness index of the 8-digit occupations is added up and the total is divided by the number of 8-digit occupations within the 5-digit occupation.

$$emp_{\ occ8d\in5d} = \frac{emp_{occ5d}}{N_{\ occ8d\in5d}}$$

where $emp_{occ8d\in5d}$ is the estimated number of employees per 8-digit level occupation within the occupational group (5-digit level), emp_{occ5d} denotes the total number of employees within the occupational group (5-digit level) and $N_{occ8d\in5d}$ stands for the number of occupations at the 8-digit level within the occupational group (5-digit level).

A weakness of this procedure is caused by a structural difference between occupational data and employment data. As Dengler et al. (2014) point out, the general problem with aggregating occupational data from the 8-digit to the 5-digit-level is that there is no information available about how many people are employed in individual occupations at the 8-digit-level. This information is only available at the 5-digit level. Thus the employment share of every 8-digit level occupation in a 5-digit level aggregate has to be estimated. The assumption of this approach is that the number of employees in individual occupations is equally distributed. This might lead to some bias in the remaining steps. As there is no pattern to explain which 5-digit occupations comprise more individual occupations and which comprise less, I assume that the bias is randomly distributed and averages out in total. The same applies to the aggregation of the *GOJI*. If employment data were available at the 8-digit level this would be a natural basis for a weighting scheme. As this is not the case, I again apply the approach used by Dengler et al. (2014) and divide the total sum of the *GOJI* within each 5-digit level occupation by the number of individual occupations within the 5-digit occupational type. Taking the occupational group of '*Occupations in renewable energy technology—complex tasks*' as an example, Table 5-4 illustrates how this aggregation procedure is implemented in the *GOJI* data.

Table 5-4: Aggregation to occupational-type-level (KldB 2010, from 8- to 5-digit level): Example of 'Occupations in renewable energy technology—complex tasks' 2014

Individual Occupation 8-digit level of KldB 2010 (ID + Title)	Occupational type 5-digit level of KldB 2010 (ID + Title)	Number of employees 5-digit level	Number of employees 8-digit level	$GOJI_{core}$ 8-digit level	$GOJI_{core}$ 5-digit level (aggregate)
26243-100 Solar technician	26243 Occupations in renewable energy tech.—complex tasks	2,671	Equal distribution assumption: 2,671:3= 890.33	0.200	(0.200 + 0.100 + 0.333) : 3 = 0.211
26243-101 Wind energy technician				0.100	
26243-108 Specialist solar tech.				0.333	

Source: BERUFENET, employment statistics of the Federal Employment Agency, own calculations.

In the example of '*chimney sweep*' the aggregation to the 5-digit level is straightforward, because the 5-digit level of this occupation covers only one single occupation (here: # 42212 of KldB2010).

b) Occupational aggregation from 5-digit level to higher aggregated levels

The following step uses the employment data at the 5-digit level as starting point for the weighting. Employment weights $\boldsymbol{w}$ are based on the number of employees of occupational type *occ5d (5-digit level of KldB2010)* as a proportion of the total number of employees working in the X*d* digit-level of the KldB 2010 occupational classification:

$$\boldsymbol{w_{occ5dtoXd,t} = \frac{emp_{occ5d\,\in d\,,t}}{\sum\, emp_{occ5d\,\in Xd,t}}}$$

where $\boldsymbol{emp_{occ5d\,\in d\,,t}}$ is the number of employees in the individual 5-digit group within the x-digit group and $\boldsymbol{\sum\, emp_{occ5d\,\in Xd,t}}$ is the sum of employees (5-digit group) within the x-digit. In the next step, the products of weights and *GOJI* are added and lead to the *GOJI* at x-digit level (employment-weighted):

GOJI at aggregated occupational levels (employment-weighted at X d(igit) level of KldB2010)

$$\boldsymbol{GOJI_{core,add,(w)total_{occXd,t}} = \sum_{occ5d \in Xd=1}^{n} w_{occ5dtoXd,t} * GOJI_{core,add,total_{occ5d,t}}}$$

The example of 'chimney sweep' illustrates the weighting by employment (Table 5-5).

Table 5-5: Aggregation from 8digit to 5digit level: Example of GOJI weighted by employment: Occupation 'chimney sweep'

Example of	Index	Operation	Result
Weight	$\boldsymbol{w_{\#42212to\#422,2014}}$	$\boldsymbol{\frac{emp_{\#42212\,,2014}}{\sum\, emp_{occ5d\,\in\#422d,2014}} = \frac{6525}{13959} =}$	$\boldsymbol{= 0.467}$
Greenness-of-jobs index (*GOJI*) (here: aggregation to 3-digit-level)	$\boldsymbol{GOJI_{core_{\#422,2014}}}$	$\boldsymbol{\sum_{\#42202}^{\#42293} w_{occ5dto3d,2014} * GOJI_{core_{occ5d,2014}}}$ = 0.365*0.074+0.258*0.154+0.25*0.215+**0.200*0.467**+0.384*0.013+0.100*0.077= ⇩ = 0.0269 + 0.040 + 0.054 + **0.093** + 0.005 + 0.008 =	$\boldsymbol{= 0.226}$

Note: As an example, I use the occupation 'chimney sweep'. This occupation has the classification number 42212 (5-digit level) and 433 (3-digit level), respectively. The title of the 3-digit level is 'Occupations in environmental protection engineering'.

Conversion of GOJI from occupational 5-digit level to sectoral and regional level

The aggregations of occupational and employment data from the 5-digit level to higher aggregated levels (e.g. from 5-digit to 3-digit level) is also applicable in analogy for calculating the sectoral and regional distribution of employees with green occupations. I also use the employment data at the five-digit level as the base for the weight.

Weights $\boldsymbol{w}$ are based on the employees of occupational type occ5d (5-digit level of KldB2010) as a proportion of the total number of employees working in industry WZ-x or region NUTS-x.

Calculation of weight 'employment share of occupational type occ5d in industry WZx in year t':

$$w_{occ5dtoWZx,t} = \frac{emp_{occ5d \in WZx,t}}{\sum emp_{occ5d \in WZx,t}}$$

where $emp_{occ5d \in WZx,t}$ is the number of employees of the specific occupational type (5-digit group) $occ5d$ within the WZ-x industry in year t and $\sum emp_{occ5d \in WZx,t}$ is the sum of employees of all occupational types (5-digit group) within the WZ-x industry.

The weight is now applied to the corresponding GOJI:

Greenness-of-jobs index at sectoral level (employment-weighted WZ-x level)

$$GOJI_{core,add,(w)total_{WZx,t}} = \sum_{occ5d \in WZx=1}^{n} w_{occ5dtoWZx,t} * GOJI_{core,add,total_{occ5d,t}}$$

Calculation of weight 'employment share of occupational type occ5d in region NUTSx in year t:

$$w_{occ5dtoNUTSx,t} = \frac{emp_{occ5d \in NUTSx,t}}{\sum emp_{occ5d \in NUTSx,t}}$$

where $emp_{occ5d \in NUTSx,t}$ is the number of employees of the specific occupational type $occ5d$ (5-digit group) within the NUTS-x region in year t and $\sum emp_{occ5d \in NUTSx,t}$ is the sum of employees of all occupational types $occ5d$ (5-digit group) within the NUTS-x region. The weight is now applied to the corresponding GOJI:

Greenness-of-Jobs Index at regional level (employment-weighted NUTS-x level)

$$GOJI_{core,add,total_{NUTSx,t}} = \sum_{occ5d \in NUTSx=1}^{n} w_{occ5dtoNUTSx,t} * goji_{core,add,total_{occ5d,t}}$$

5.4 Descriptive analysis

This section provides unique descriptive evidence about the greenness and greening of jobs along all dimensions of the research objectives: it contains information about the prevalence of green tasks in the BERUFENET and about the greenness and greening of occupations at the level of individual occupations to describe both the input and output of measuring the greenness of occupations. Furthermore, the section presents the occupational, sectoral and regional distribution of the greenness and greening of jobs.

5.4.1 The Greenness-of-Jobs Index at individual occupation level

Green tasks—the main components for measuring the greenness of jobs

As mentioned above, measuring the greenness of jobs starts with applying text mining procedures to the BERUEFENET data. Including both core and additional requirements, the yearly occupations-requirements matrices from the BERUFENET result in the following quantity structure (see Table 5-6):

Table 5-6: Quantity structure of occupations-requirements matrices derived from BERUFENET

Year / Occ.classif.	Number of indiv. occupations	Number of requirements('tasks')	Cells of n:n occupations-requirements matrices
2006 KldB1988	6,423	5,724	36.8M
2012 KldB2010	3,926	6,670	26.2M
2013	3,952	6,709	26.5M
2014	3,961	6,745	26.7M
2015	3,953	6,819	27.0M
2016	4,251	7,325	31.1M
∆ 2012-2016	325	655	5.0M
as %	8.3%	9.8%	18.9%

Sources: BERUFENET, Classifications: KldB2010 (2011-2016) and KldB1988 (2006), own calculations.
Note: The decrease in the number of occupations between 2006 and 2011 is a technical effect due to the change in the occ. classification from KldB1988 to KldB2010. Therefore the total numbers of occupations in 2006 and 2011 et seq. cannot be compared, although the total number of requirements is still comparable.

Table 5-6 reveals a considerable increase in the number of occupations and requirements between 2012 and 2016: the number of individual occupations rose by 8.3 percent and the number of requirements by 9.8 percent. The resulting n:n-matrix, with about 26.2 to 36.8 million cells per year, is the basis for the text mining and the calculation of the Greenness-of-Jobs Index. The content and relative frequency of the green tasks keywords identified by text mining procedures can be visualized by word clouds (see also Appendix of chapter 5). The comparison of the word clouds between 2006 and 2016 shows that there are changes in terms of the quantity and content of green tasks. The most obvious transition takes place in terms of 'technical environmental protection' (In German: 'Technischer Umweltschutz'). This concept has been replaced entirely either by the more general term of 'environmental protection' (In German: 'Umweltschutz') or by more specific key terms. This might also represent the decreasing relevance of end-of-pipe technologies which used to be more strongly—but not solely—associated with technical environmental protection. As Horbach et al. (2009) report, end-of-pipe technologies have lost significance in contrast to integrated environmental protection. Other keywords exhibit increased frequencies of occurrence, for example 'building insulation (heat insulation)' (In German: 'Gebäudedämmung (Wärmeschutz)'), which might have been triggered by the more stringent requirements of the Energy Saving Ordinance (Energieeinsparverordnung, EnEV) and other regulations covered by the German CO_2 Building Modernization Program (In German: 'Gebäudesanierungsprogramm', for further details see Kuckshinrichs et al. 2010 and Rosenow 2013). Sometimes just the spelling was changed, such as in the case of photovoltaics (from 'Photovoltaik' to 'Fotovoltaik'), which shows the importance of fuzzy logic features of the text mining algorithm. In 2016, we also see genuine new terms, such as 'electric and hybrid vehicles' (In German: 'Elektro- und Hybridfahrzeuge') or 'smart home': these two examples refer to new technological trends in the fields of mobility and energy efficiency in buildings. For further information, the Appendix includes the complete time series of word clouds from 2006 and 2012 to 2016 as well as word clouds from 2016 grouped by each of the keyword categories.

Table 5-7 contains the results of the frequency analysis after the semi-automatic coding, showing especially how many BERUFENET requirements are identified as 'green' and how many occupations contain those green tasks.

Table 5-7: Frequency table of matches from keywords to green tasks and occupations, 2012/ 2016—differentiating green tasks categories

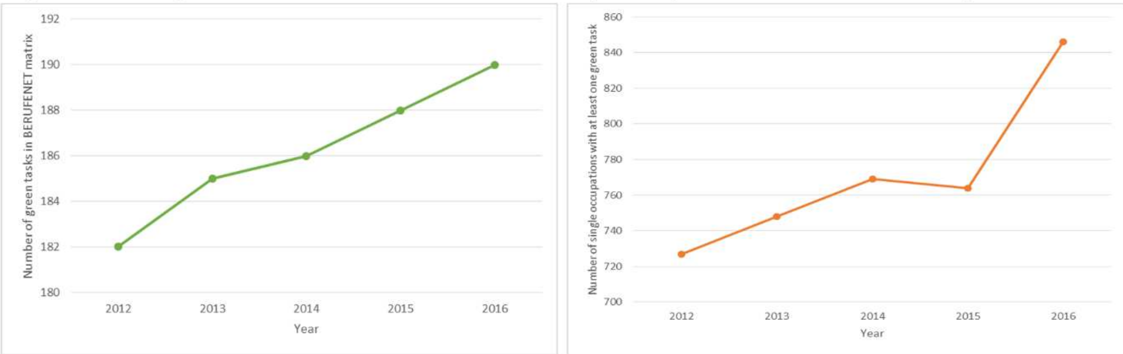
Green tasks category	Number of keywords	1st step: Keyword-requirements matches		2nd step: Green tasks-occupations matches	
		2012	**2016**	**2012**	**2016**
Energy production & storage	20	14	15	58	71
Mobility & tourism	34	50	53	106	131
Building	21	19	21	268	295
Farming, forestry, food, cons. goods	19	15	16	91	107
Energy efficiency & further climate protection	9	10	11	42	75
Emiss.protection (air, water, soil, noise)	27	26	26	146	168
Circular economy	13	24	24	87	92
Environmental protection (general)	10	25	25	256	306
Green tasks (total)	153	**182**	**190**	**727**	**846**
Share of total number of requirements		2.7%	2.6%	18.5%	19.9%
Note: Total number of …		… requirements		… indiv. occupations	
		6,670	7,325	3,926	4,251

Source: BERUFENET, own calculations.

According to Table 5-7, 190 requirements were environment-related ('green tasks') in 2016. This represents 2.6 percent of all the requirements in BERUFENET. In that year, the 190 green tasks were included in 846 occupations, i.e. 19.9 percent of all individual occupations had at least one green task in their requirements profile. Considering the mid-term period 2012 to 2016, it can be seen that the number of green tasks increased from 182 to 190 (+4.4 percent). However, the relative share of matched requirements remained the same or even decreased slightly in 2016 (from 2.7 percent to 2.6 percent), as the overall number of requirements increased more strongly during this period (+9.8 percent). In contrast, the total number of matched 'green occupations'—occupations containing at least one green task—grew faster than 'non-green occupations': between 2012 and 2016, the total number of green occupations rose by 16.4 percent from 727 to 846, whereas the remaining occupations increased by 8.3 percent. Consequently the share of green occupations increased more than average from 18.4 percent to 19.9 percent during this period. With regard to the mid-term perspective from 2012 to 2016, Figure 5-1 illustrates the slight tendency towards a greening of requirements ('green tasks') and occupations.

Figure 5-1: Number of green tasks and occupations in BERUFENET 2012-2016

a) Number of green tasks | **b) Occupations with at least one green task**

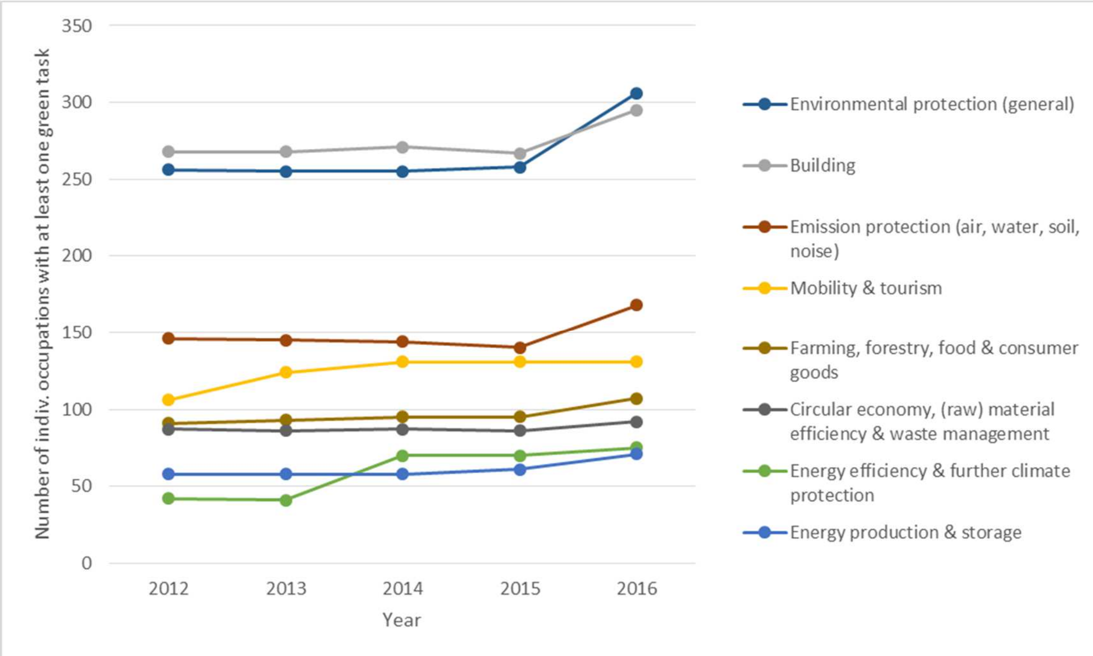


Source: BERUFENET, own calculations. Note: Figure 5-1a shows the number of "green tasks", i.e., the hits after matching the green keywords with the requirements in BERUFENET 2012-2016. Figure 5-1b shows the number of "green occupations", i.e. those occupations with at least one hit after matching the green tasks with occupations in BERUFENET 2012-2016.

The additional use of green-task categories makes it possible to identify those green environmental fields that cause the overall change in requirements and occupations. Table 5-7 also shows the distribution of matches in BERUFENET across the green tasks categories and their development between 2012 and 2016. In the first step, i.e. the keyword-requirements matches, the category of 'building' exhibits the largest growth, by 10.5 percent, whereas 'mobility & tourism' has the largest number of green tasks (2016: 53). 'Emission protection', 'environmental protection (general)' and 'circular economy' show a relatively large number of green tasks but no increase in tasks between 2012 and 2016. 'Farming, forestry, food & consumer goods', 'energy production & storage' and 'energy efficiency & further climate protection' have smaller shares of the total number of green tasks, but each of them exhibited a slight increase in their number of green tasks—gaining one new green task each.

Analyzing the second step of matching at the level of green tasks categories, Figure 5-2 confirms that this step leads to a considerable number of hits. For example, in 2016 the 25 green tasks of 'environmental protection (general)' are matched with 306 individual occupations (growth rate 2006-2012: 19.5 percent). This is also the largest share of all the occupations with at least one green task, followed by the green tasks category 'building', matched with 295 occupations (growth rate 2006-2012: 10.1 percent). The remaining green tasks categories have fewer hits (from 168 in 'emission protection' to 71 hits in 'energy production') but they all show a positive growth rate between 2012 and 2016 (from 5.7 percent in 'circular economy' to 78.6 percent in 'energy efficiency').

Figure 5-2: Green-task occupations 2012-2016, grouped by green task categories



Source: BERUFENET, own calculations. Note: The figure illustrates the number of occupations (8-digit level KldB2010) with at least one green task in 2012-2016, grouped by green tasks categories The appendix comprises two corresponding tables with the time series of matches from green tasks to occupations.

Greenness of jobs as a level: ranking of individual occupations by $GOJI_{total}$ 2016

Table 5-8 provides a first idea of the distribution and values of *GOJI* at 8-digit level by showing five occupations with maximum, medium and minimum $GOJI_{total}$ values respectively in 2016. For example, the occupation 'specialist in environmental protection' has the largest $GOJI_{total}$. For this occupation, the first value in the column $GOJI_{total}$ is 0.889, i.e. 88.9 percent of the tasks performed by a specialist in environmental protection are 'green' in the sense of this paper. The three columns on the right contain the *GOJI* specifications based on core and additional requirements ($GOJI_{core}$ and $GOJI_{add}$), or based on the total number of skill requirements weighted by the requirements-type ($GOJI_{wtotal}$). Table 5-8 indicates that occupations with the largest $GOJI_{total}$ values have both large $GOJI_{core}$ and large $GOJI_{add}$ values. Consequently, the difference between $GOJI_{total}$ and $GOJI_{wtotal}$ is relatively small. In contrast, the example occupations from the center of the distribution show relatively high $GOJI_{core}$ values but small or no $GOJI_{add}$ values. The smallest $GOJI_{total}$ values are 0.024. This group at the bottom of the distribution does not show a specific pattern: pos. 781 and 785 do not have any $GOJI_{core}$ values, pos. 782 to 784 only have $GOJI_{core}$ values but no $GOJI_{add}$ at all. Therefore, it can be concluded that the composition of green tasks within each 'green occupation' (with $GOJI_{total} > 0$) differs considerably.

Table 5-8: Greenness of jobs: ranking of individual occupations by $GOJI_{total}$: Top 5/Medium 5/Last 5 $GOJI_{total}$ values in 2016 (Kldb2010, 8-digit)

Pos.	Occupational title (English translation)	$GOJI_{total}$	$GOJI_{core}$	$GOJI_{add}$	$GOJI_{wtotal}$
	Top 5				
1	Specialist—Environmental protection	**0.889**	0.900	0.875	0.892
2	Environmental advisor	**0.850**	0.833	0.857	0.841
3	Recycling specialist	**0.769**	0.750	0.778	0.759
4	Environmental auditor	**0.765**	0.750	0.769	0.756
5	Environmental management officer	**0.750**	0.700	0.786	0.729
…	**Medium 5 (Median $GOJI_{total}$: 0.083)**				
388	Woodworking mechanic—Wood-based panel industry	**0.083**	0.250	0.042	0.183
389	Woodworking mechanic—Sawmill industry	**0.083**	0.250	0.050	0.183
390	Standardization expert	**0.083**	0.250	0.000	0.167
391	Master of hydraulic engineering	**0.083**	0.182	0.000	0.121
392	Technician—Machine tech. (process engineering)	**0.083**	0.167	0.000	0.111
…	**Last 5**				
781	Engineer—Viticulture	**0.025**	0.000	0.042	0.014
782	Motor mechanic	**0.024**	0.125	0.000	0.083
783	Engineer—Air-conditioning system technology	**0.024**	0.043	0.000	0.029
784	Engineer—Refrigeration system technology	**0.024**	0.037	0.000	0.025
785	Traffic construction engineer	**0.024**	0.000	0.043	0.014

Source: BERUFENET, own calculations.
Note: The ranking covers the entire range of green tasks across all categories.

The GOJI variations differentiated by green tasks categories make it possible to identify occupations grouped and ranked by individual categories. Examples of top-5 occupations by green task categories are included in the following table.

Table 5-9: Greenness-of-jobs ranking of single occupations grouped by green tasks categories: Examples for top 5 of $GOJI_{gtcat,total}$ values in 2016 (Kldb2010, 8-digit)

Pos.	Occupational title grouped by green tasks category (gtcat)	$GOJI_{gtcat,total}$	$GOJI_{gtcat,core}$	$GOJI_{gtcat,add}$	$GOJI_{gtcat,wtotal}$
	Top 5—Energy production & storage				
1	Specialist—solar technology	**0.250**	0.364	0.000	0.242
2	Climate protection manager	**0.250**	0.200	0.263	0.221
3	Energy consultant	**0.188**	0.250	0.167	0.222
4	Engineer—renewable energies	**0.171**	0.222	0.118	0.187
5	Tech. assistant—renewable raw materials	**0.167**	0.071	0.300	0.148
	Top 5—Circular economy, (raw) material efficiency & waste management				
1	Recycling specialist	**0.692**	0.750	0.667	0.722
2	Specialist in recycling & waste mgmt.	**0.526**	0.667	0.462	0.598
3	Waste advisor	**0.526**	0.667	0.462	0.598
4	Waste manager	**0.421**	0.857	0.167	0.627
5	Technician for waste technology	**0.381**	0.667	0.267	0.533
	Top 5—Environmental protection (general)				
1	Environmental management officer	**0.417**	0.300	0.500	0.367
2	Environmental expert	**0.412**	0.444	0.375	0.421
3	Environmental auditor	**0.412**	0.750	0.308	0.603
4	Head of expert office for the environment	**0.320**	0.214	0.455	0.294
5	Water pollution control officer	**0.308**	0.167	0.429	0.254

Source: BERUFENET, own calculations. Note: Each occupation may appear in different groups of green tasks categories, because each $GOJI_{gtcat}$ value represents only the share of green tasks from the specific green tasks category in the total number of requirements. For example, the occupation 'Water pollution control officer' contains four tasks related to environmental protection (one green core task and three green additional tasks) and is thus ranked in the green tasks list of 'Environmental protection (general)' with $GOJI_{gtcat,total}$ = 0.308). It is also ranked in the green tasks list of 'Emission protection (…, water, …)' with $GOJI_{gtcat,total}$ = 0.231, of which this occupation contains three green (core) tasks.

Greening of jobs as a delta value: ranking of occupations by Δ $GOJI_{total}$ 2012-2016

Table 5-9 lists examples of the top, median and end of the distribution of these greening occupations. The first section of Table 5-9 covers the five occupations with the largest growth in $GOJI_{total}$. For instance, between 2012 and 2016 the occupation of 'technician—environmental protection technology (landscape ecology)' increased from 0.300 to 0.520, thus representing a rise of 0.220 in $GOJI_{total}$ (i.e. the share of green tasks increased by 22 percentage points). In the center of the distribution we see occupations such as 'dietary cook' or 'body and vehicle construction mechanic—body maintenance', which exhibit a greening of 0.035 and 0.034, respectively. The latter occupation is also an example of an occupation that had no green task at all in 2012. The lowest level of greening can be observed in the occupation of 'agricultural laboratory technician' with a delta of 0.001. The entire list of greening occupations documents the wide range of different occupations that show an increase in *GOJI* between 2012 and 2016.

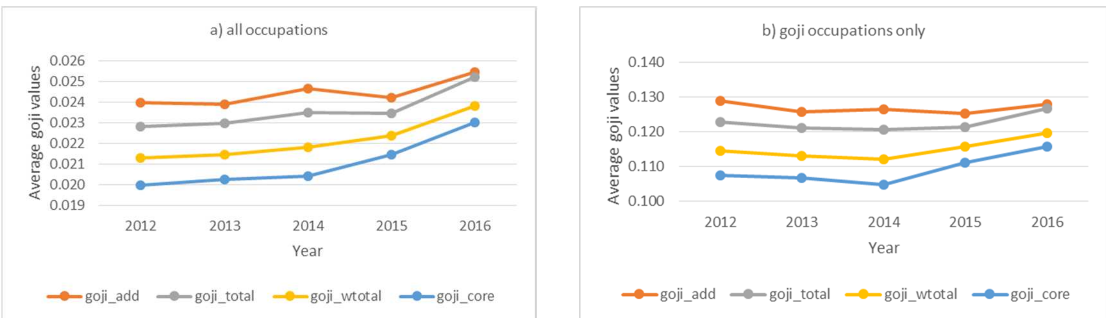
Table 5-10: Greening of jobs: ranking of individual occupations by *GOJI*— Top/Medium/Last 5 of Δ $GOJI_{total}$ 2012-2016 (Kldb2010, 8-digit)

Pos.	Occupational title (English translation)	$GOJI_{total}$ Δ abs.	2012	2016
	Top 5			
1	Technician—Environmental protection techn.(landscape ecology)	0.220	0.300	0.520
2	Technician—Waste technology	0.212	0.407	0.619
3	Extension specialist (heat, cold and sound insulation work)	0.199	0.176	0.375
4	Wood preservation expert	0.144	0.056	0.200
5	Two-wheeler mechatronic technician—Production	0.139	0.111	0.250
...	**Medium 5 (Median Δ$GOJI_{total}$: 0.035)**			
71	Dietary cook	0.035	0.080	0.115
72	Specialist agricultural farmer—Agricultural technology	0.035	0.056	0.091
73	Electronics technician—Energy & building services engineering	0.035	0.042	0.077
74	Master chimney sweep	0.035	0.238	0.273
75	Body and vehicle construction mechanic—Body maintenance	0.034	0.000	0.034
...	**Last 5**			
133	Food inspector	0.003	0.050	0.053
134	Helpers—Wood, wickerwork	0.002	0.048	0.050
135	Engineer—Interior design	0.002	0.040	0.042
136	Technician—Construction engineering	0.002	0.038	0.040
137	Agricultural laboratory technician	0.001	0.037	0.038

Source: BERUFENET, own calculations.

The relative growth of *GOJI* levels between 2012 and 2016 is also illustrated in graphs a and b in Figure 5-3. Figure 5-3a covers all occupations and Figure 5-3b focuses on the occupations with a $GOJI_{total}$ larger than zero. In the years between 2014 and 2016 one can see the stronger increase of $GOJI_{core}$, which by definition also leads to rises in $GOJI_{total}$.

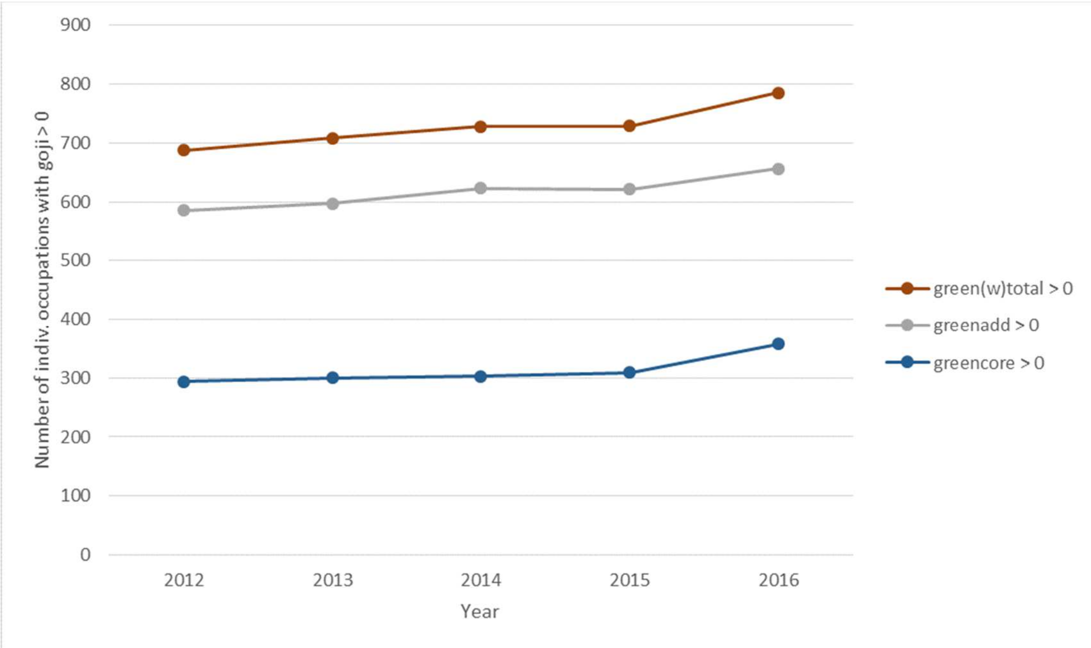
Figure 5-3: Average GOJI of occupations (2012-2016, 8-digit level KldB2010)



Source: BERUFENET, own calculations. Note: The figures illustrate the average GOJI values of a) all occupations and b) GOJI occupations only (with $GOJI_{total} > 0$) (2012-2016, 8-digit level KldB2010).

Looking at the differences in terms of core and additional requirements, Figure 5-4 documents that the number of occupations with $GOJI_{add} > 0$ have the highest absolute number of new arrivals. In contrast, the occupations with $GOJI_{core} > 0$ include fewer new occupations (+63) but show the highest rate of increase (+21.4 percent). Nevertheless, the number of occupations with $GOJI_{add}$ > 0 (656) is still almost twice as high as the number of occupations with $GOJI_{core}$ > 0 (357). This indicates that up to now it is above all the large number of green additional tasks that is responsible for the large number of occupations with $GOJI_{total}$ > 0, whereas the strong increase in the number of green core tasks is responsible for the substantial growth of $GOJI_{total.}$ Overall, 137 individual occupations experienced an increase in $GOJI_{total}$ between 2012 and 2016.

Figure 5-4: Number of occupations with GOJI > 0 (8-digit level KldB2010)



Source: BERUFENET, own calculations.

To compare the general development of the *GOJI* values of occupations, I examine two groups: all occupations (also including occupations with a *GOJI* value of zero) and only occupations with a $GOJI_{total}$ larger than zero. Based on this distinction, Table 5-11 summarizes the development of different *GOJI* variations between 2012 and 2016. According to this table, the total number of occupations with $GOJI_{total}$ > 0 increases by 14.1 percent to 785 individual occupations. Relative to the total number of 3,946 individual occupations in 2016, this is a share of 19.9 percent 'green' occupations (2012: 18.6 percent). As a first interim result, I can state that a greening of occupations is occurring that amounts to 14.1 percent in terms of the growth of individual occupations that have an unweighted $GOJI_{total}$ larger than zero from 2012 to 2016. But does the level of *GOJI* also increase? Within the group of all occupations, the average $GOJI_{total}$ rises by 10.6 percent from 0.023 to 0.025. When distinguishing between requirement types, the growth of $GOJI_{core}$ is even higher (15.3 percent), whereas the growth of $GOJI_{add}$ is lower (6.2 percent). Because the core requirements have twice the weight of the additional requirements in the $GOJI_{wtotal}$, its growth is 1.2 percentage points larger than $GOJI_{total}$.

If these comparisons are restricted to the group of occupations with $GOJI_{total}$ > 0 ('*GOJI* occupations'), we see that the average values of $GOJI_{core}$ and $GOJI_{(w)total}$ also rise. With regard to $GOJI_{core}$ and $GOJI_{(w)total}$, the absolute growth of the *GOJI* value is even higher than in the overall group, whereas the relative growth as a percentage is lower than in the group of all occupations. Only the $GOJI_{add}$ values show a slight decrease in the group of *GOJI* occupations, probably because many other new requirements were included in these occupations, which leads to a reduction in the share of green tasks and thus to a drop in the *GOJI* value. Nevertheless, the second interim result is that there is also a greening of the extent of green tasks represented by $GOJI_{total}$ in individual occupations.

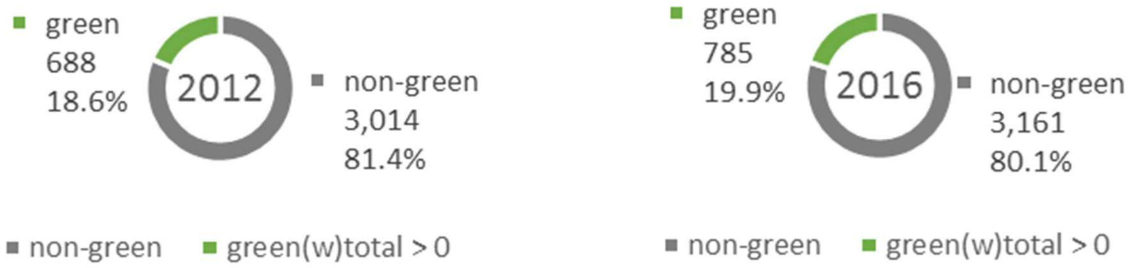
Table 5-11: Average *GOJI* values of individual occupations (8-digit level)—a) all occupations and b) *GOJI* occupations only (with $GOJI_{total}$ > 0), 2012-2016

Year	Total number of occupations		Average *GOJI* values							
			all occupations				*GOJI* occupations ($GOJI_{total}$ > 0)			
	all	*GOJI*	$GOJI_{total}$	$GOJI_{core}$	$GOJI_{add}$	$GOJI_{wtotal}$	$GOJI_{total}$	$GOJI_{core}$	$GOJI_{add}$	$GOJI_{wtotal}$
2012	3,702	688	0.023	0.020	0.024	0.021	0.123	0.251	0.152	0.115
2016	3,946	785	0.025	0.023	0.025	0.024	0.127	0.254	0.153	0.120
Δ2012-16	244	97	0.002	0.003	0.001	0.003	0.004	0.008	-0.001	0.005
in %	6.6%	14.1%	10.6%	15.3%	6.2%	11.8%	3.3%	7.7%	-0.8%	4.5%

Source: BERUFENET, own calculations.

Figure 5-5 shows the growing share of occupations with $GOJI_{total}$ larger than zero. In 2016, 785 (19.9 percent) of the total of 3,946 occupations had a $GOJI_{total}$ value larger than zero, i.e. these '*GOJI* occupations' have green tasks in their requirements portfolio at least to certain extent.

Figure 5-5: Share of occupations (8-digit level) with $GOJI_{total}$ > 0 in 2012 and 2016



Source: BERUFENET, own calculations.

With regard to the unweighted *GOJI,* this subsection has shown that both the number of occupations with *GOJI* > 0 and the level of *GOJI* values increases between 2012 and 2016. The different values show that the level of greenness varies depending on the *GOJI* type examined (core/add/total). It is therefore crucial to decide precisely which aspect of greenness should be considered for an in-depth analysis. The empirical example in the section 'econometric analysis' shows the differences this decision yields in econometric analysis.

At the individual-occupation (8-digit) level I can show that there is a greening of jobs with respect to the unweighted *GOJI*. However, at this stage it is not possible to consider the employment development associated with the greenness and greening of jobs, because in German employment statistics and administrative employment data, the occupational data are coded at the 5-digit level.

5.4.2 The employment-weighted distribution of the greenness of jobs

The GOJI at aggregated occupational levels

The use of employment statistics data facilitates an aggregation of the *GOJI* at every occupational, industrial and regional level. The only limitation is the availability of employment statistics at the relevant breakdown level. Table 5-12 5-12 illustrates the number of aggregates with a *GOJI* larger than zero within the hierarchical structure of KldB 2010. The table documents the aggregation levels available after the aggregation procedure. There is the unweighted *GOJI* at 5-digit level after applying an equal distribution assumption. Furthermore, there are five aggregates of KldB 2010 as well as these five aggregates plus the information about the requirement level (5th digit of Kldb2010). All in all the table corroborates the results of the descriptive analysis at individual-occupation (8-digit) level: between 2012 and 2016 the number of occupational *GOJI* aggregates increases—both after the aggregation to 5-digit level using an equal distribution assumption and after the aggregation to 3-digit level using weights derived from the specific employment share of the occupational groups.

Table 5-12: The hierarchical structure of the classification of occupations 2010 (KldB 2010) and their number of aggregates with *GOJI* > 0

Breakdown level (Digit level KldB 2010)	Year	Number of breakdown levels	Number of aggregates with *GOJI* > 0		
			$goji_{total}$>0	$goji_{core}$>0	$goji_{add}$>0
Unweighted *GOJI* at 5-digit level (equal distribution assumption)					
Occupational type	2012	1,174	355	166	311
5-digit level	2016	1,192	376	184	329
	Δ2012-16	18	21	18	18
	in %	1.5%	5.9%	10.8%	5.8%
Employment-weighted GOJI					
Occupational groups, main groups and areas					
Occupational group	2012	140	82	49	78
3-digit level	2016	140	84	53	80
	Δ2012-16	0	2	4	2
	in %	0.0%	2.4%	8.2%	2.6%
Occupational main group	2012	36	34	28	33
2-digit level	2016	36	34	30	33
Occupational areas	2012	9	9	9	9
1-digit level	2016	9	9	9	9
Occupational segments and sectors					
Occupational segments	2012	14	14	13	14
S2-digit level	2016	14	14	14	14
Occupational sectors	2012	5	5	5	5
S1-digit level	2016	5	5	5	5
Occupational aggregates plus requirement level (5th digit)					
Occ. areas + req. level	2012	422	170	96	149
3-digit level + 5th digit	2016	424	173	106	151
Occ. main group + req. level	2012	131	90	62	80
2-digit level + 5th digit	2016	132	90	66	80
Occ. group + req. level	2012	36	31	29	28
1-digit level + 5th digit	2016	36	31	29	27
Occ. segments + req. level	2012	54	44	36	39

S2-digit level + 5th digit	2016	55	44	37	39
Occ. sectors + req. level	2012	20	17	16	16
S1-digit level + 5th digit	2016	20	17	16	15

Source: BERUFENET, employment statistics data from the Federal Employment Agency, own calculations. Note: I do not use the 4-digit level, because the number of sub-groups included there is 700, which is relatively close to the 5-digit level (1,286 breakdown levels).

At the 2-digit level and higher levels the greening of jobs in absolute numbers of aggregates with *GOJI* larger than zero becomes less obvious. In Table 5-12, only little development of the *GOJI* values is discernible. However, a look at the development of *GOJI* values within these higher aggregated levels reveals that a greening of jobs is still visible even at this level. For example, Table 5-13 presents the $GOJI_{total}$ values at the level of occupational sectors (S1-digit level). These values show a growth in $GOJI_{total}$ of 0.002 in the occupational sector concerning the production of goods, and a growth of 0.001 in the occupational sectors comprising occupations in personal services as well as occupations in business administration and other business-related services. This detailed view also reveals the occurrence of 'degreening' (-0.002) in service occupations in the IT sector and the natural sciences as well as in 'S5: Other occupations in commercial services'. This development is caused by a more substantial increase in non-green requirements and/or a loss of green tasks in individual occupations within these occupational sectors. The reduction in the number of jobs within occupations with $GOJI_{total}$ > 0 may also contribute to this phenomenon.

Table 5-13: Occupational sectors and their greenness of jobs 2012-2016

	$GOJI_{total}$		
Occupational sectors (S1-digit level of KldB2010)	**2012**	**2016**	**∆2012-16**
S1: Occupations in the production of goods	0.030	0.032	0.002
S2: Occ. in personal services	0.001	0.002	0.001
S3: Occ. in business administration and other business-related services	0.001	0.002	0.001
S4: Service occupations in the IT sector and the natural sciences	0.020	0.018	-0.002
S5: Other occupations in commercial services	0.046	0.044	-0.002

Sources: BERUFENET, employment statistics data from the Federal Employment Agency, own calculations.

Looking at the less highly aggregated level of occupational segments (S2-digit level of KldB2010, see Table 5-14) it becomes clear that the developments of (de)greening differ within occupational sectors. For example, the occupational sector 'S1: Occupations in the production of goods' (∆2012-16: 0.002) covers 'S11: Occupations in agriculture, forestry and horticulture' which experiences a drop of -0.014, as well as 'S12: Manufacturing occupations' and 'S13: Occupations concerned with production technology', each of which rise by 0.002.

Table 5-14: The employment-weighted *GOJI* of occupational segments 2012-2016

	$GOJI_{total}$		
Occupational segments (S2-digit level of KldB2010)	**2012**	**2016**	**∆2012-16**
S11: Occupations in agriculture, forestry and horticulture	0.080	0.066	-0.014
S12: Manufacturing occupations	0.008	0.010	0.002
S13: Occupations concerned with production technology	0.012	0.014	0.002
S14: Occupations in building and interior construction	0.088	0.089	0.001
S21: Occupations in the food industry, in gastronomy and in tourism	0.004	0.006	0.002
S22: Medical and non-medical health care occupations	0.000	0.001	0.001
S23: Service occupations in social sector and cultural work	0.001	0.001	0.000
S31: Occupations in commerce and trade	0.002	0.002	0.000
S32: Occupations in business management and organization	0.000	0.000	0.000
S33: Business-related service occupations	0.000	0.005	0.005
S41: Service occupations in the IT sector and the natural sciences	0.020	0.018	-0.002
S51: Safety and security occupations	0.020	0.022	0.002
S52: Occupations in traffic and logistics	0.048	0.046	-0.002
S53: Occupations in cleaning services	0.050	0.048	-0.002

Sources: BERUFENET, employment statistics data from the Federal Employment Agency, own calculations.

With regard to the level of greenness-of-jobs, Table 5-14 also provides an overview of the substantial differences between the occupational aggregates. At the highest level of aggregation, occupational sectors (S1-digit level), the occupational sector 'S5: Other occupations in commercial services' has the highest *GOJI* value in 2016 (0.044). Looking at the level below that, occupational segments (S2-digit level), it becomes obvious that this high value is driven mainly by the two occupational segments 'S52: Occupations in traffic and logistics' (0.046) and 'S53: Occupations in cleaning services' (0.048). However there are even higher values at this level, e.g. 'S14: Occupations in building and interior construction' is the occupational segment with the highest *GOJI* value in 2016 (0.089). With a $GOJI_{core}$ of 0.046, the occupational area '(3) construction, architecture, surveying and technical building services' shows the highest value at this level, closely followed by '(1) Agriculture, forestry, farming, and gardening' with a value of 0.042. After the third largest value of 0.020 ('(5) Traffic, logistics, safety and security'), the only areas remaining have a very small $GOJI_{core}$. Three occupational areas show a value of 0.000 due to rounding to three decimal places. In fact, they all have shares larger than zero, but with very low values.

Another informative perspective is the *GOJI* aggregated to the requirement level. Table 5-15 shows that occupations with the requirement level of '2: Skilled tasks' have the highest $GOJI_{total}$ value (0.021), which is driven in particular by the high value of $GOJI_{add}$ (0.024). The second largest group in $GOJI_{total}$, occupations with the requirement level of '1: Unskilled/semiskilled tasks' (0.015) has seen a decrease of -7.3 percent (-0.001). In this group, $GOJI_{add}$ even fell to zero. Exhibiting a 15.9 percent increase (+ 0.002), occupations with the requirement level of '3: Complex tasks' have the largest increase in $GOJI_{total}$ values, with both level and growth being driven mainly by the $GOJI_{add}$ values (2016: 0.015). These developments suggest that the greening of jobs is mainly driven by the increase in occupations with complex tasks, skilled tasks and highly complex tasks. The occupations with unskilled/semiskilled tasks still have a relatively large $GOJI_{core}$ value, but they are the only group that show decreasing *GOJI* values.

Table 5-15: Employment-weighted *GOJI* grouped by requirement level

Requirement level (5th digit of KldB 2010)	$GOJI_{total}$ 2016	$GOJI_{total}$ Δ2012-16	$GOJI_{core}$ 2016	$GOJI_{add}$ 2016
1: Unskilled/semiskilled tasks	0.015	-0.001	0.015	0.000
2: Skilled tasks	0.021	0.001	0.015	0.024
3: Complex tasks	0.011	0.002	0.006	0.015
4: Highly complex tasks	0.007	0.001	0.003	0.009

Source: BERUFENET, statistics data from the Federal Employment Agency, own calculations.

As mentioned above, I apply the aggregation procedure for the 5-digit level, and—as employment-weighted *GOJI*—for every breakdown level for the 3-, 2-, 1-, S1- and S2-digit-levels of the occupational classification KldB2010. Furthermore, I calculate employment-weighted *GOJI* values for each of these breakdown levels differentiated according to the requirement level (5th digit) of KldB2010. The appendix presents some of these employment-weighted aggregates. The aggregation procedure also facilitates the calculation of an employment-weighted overall *GOJI* for Germany, which may be regarded as an overall indicator for the greening of jobs in Germany. Table 5-16 provides an overview of the development of this 'German greening of jobs index ($GOJI_{.de}$)' between 2012 and 2016.

Table 5-16: The employment-weighted overall $GOJI_{.de}$ (KldB 2010) 2012-2016

Year	$GOJI_{total}$	$GOJI_{core}$	$GOJI_{add}$	Total employment	Full-green employment equivalents
2012	0.0196	0.0143	0.0202	27,168,448	532,946
2016	0.0198	0.0150	0.0199	29,772,496	589,589
Δ2012-16	0.0002	0.0007	-0.0003	2,604,048	56,643
in %	1.0%	4.6%	-1.7%	9.6%	10.6%

Source: BERUFENET, statistics data from the Federal Employment Agency, own calculations. For a full times series see appendix.

In order to calculate the total employment development relative to $GOJI_{total}$, ('full-green employment equivalents'), I add up the individual employment data in relation to $GOJI_{total}$. After this step I obtain the hypothetical number of employees with a pseudo $GOJI_{total}$ of 1. Using these 'full-green equivalents', we see from Table 5-16 that in 2016 there are 0.59 million persons employed in occupations with a hypothetical $GOJI_{total}$ of 1 (all $GOJI_{total}$ of the 29.77 million employment relationships with $GOJI_{total} > 0$ are added together). Between 2012 and 2016, the full-green equivalents increased by 10.6 percent. The development of this overall $GOJI_{total}$ differs considerably between the green task categories. As this describes only the raw employment development grouped by levels of $GOJI_{total}$, the econometric analysis is going to disentangle the association between the greenness of jobs and employment growth.

The sectoral distribution of the GOJI

The sectoral distribution of the GOJI identifies the industries in which the greening takes place. Table 5-17 presents the industry sections (1-digit level) of the Classification of Economic Activities, Edition 2008 (WZ 2008). Considering the greenness of industries in 2016, the table shows industry section 'E. Water supply; sewerage, waste management, remediation activities' as being the one with the largest $GOJI_{total}$ (0.108), followed by 'H. Transportation and storage' (0.063) and 'F. Construction' (0.057). In terms of the greening of jobs within industries, section 'O. Public administration and defense; compulsory social security' reports the largest growth in the absolute $GOJI_{total}$ value by +0.006, whereas 'I. Accommodation and food service activities' has the largest relative growth rate (+69 percent) with an increase in $GOJI_{total}$ of 0.003. With -0.008 (-15.8 percent), the strongest loss of $GOJI_{total}$—in both the absolute value and the percentage share—can be observed for 'A. Agriculture, forestry and fishing'. This corroborates the finding in the occupational aggregates presented above (Table 5-14), where occupations in 'S 11. Occupations in agriculture, forestry and horticulture' show a strong decrease.

Table 5-17: Industry sections and their employment-weighted Greenness-of-Jobs Index (ISIC Rev. 4 / WZ 2008, 1-digit level), 2012-2016

	$GOJI_{total}$			
GOJI distribution in industry sections	2012	2016	Δ2012-16	in %
A. Agriculture, forestry and fishing	0.052	0.044	-0.008	-15.8%
B. Mining and quarrying	0.020	0.022	0.002	9.0%
C. Manufacturing	0.010	0.009	0.000	-1.6%
D. Electricity, gas, steam and air conditioning supply	0.027	0.031	0.004	13.9%
E. Water supply; sewerage, waste management, remediation activities	0.107	0.108	0.001	1.1%
F. Construction	0.054	0.057	0.003	5.8%
G. Wholesale and retail trade; repair of motor vehicles / motorcycles	0.006	0.008	0.002	37.9%
H. Transportation and storage	0.066	0.063	-0.003	-3.8%
I. Accommodation and food service activities	0.004	0.008	0.003	69.0%
J. Information and communication	0.002	0.002	0.000	18.2%
K. Financial and insurance activities	0.001	0.001	0.000	14.6%
L. Real estate activities	0.026	0.029	0.003	10.9%
M. Professional, scientific and technical activities	0.008	0.009	0.001	12.8%
N. Administrative and support service activities	0.028	0.027	-0.001	-2.6%
O. Public administration & defense; compulsory social security	0.016	0.022	0.006	36.5%
P. Education	0.005	0.006	0.001	13.6%
Q. Human health and social work activities	0.003	0.004	0.000	15.0%

R. Arts, entertainment and recreation	0.008	0.009	0.001	9.1%
S. Other service activities	0.010	0.011	0.001	9.6%
T. Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0.007	0.007	0.000	0.1%
U. Activities of extraterritorial organizations and bodies	0.014	0.017	0.003	20.8%

Note: Industry sections according to the International Standard Industrial Classification of All Economic Activities, Rev.4 (ISIC Rev. 4) and Classification of Economic Activities, Edition 2008 (WZ 2008).
Sources: BERUFENET, employment statistics data from the Federal Employment Agency, own calculations.

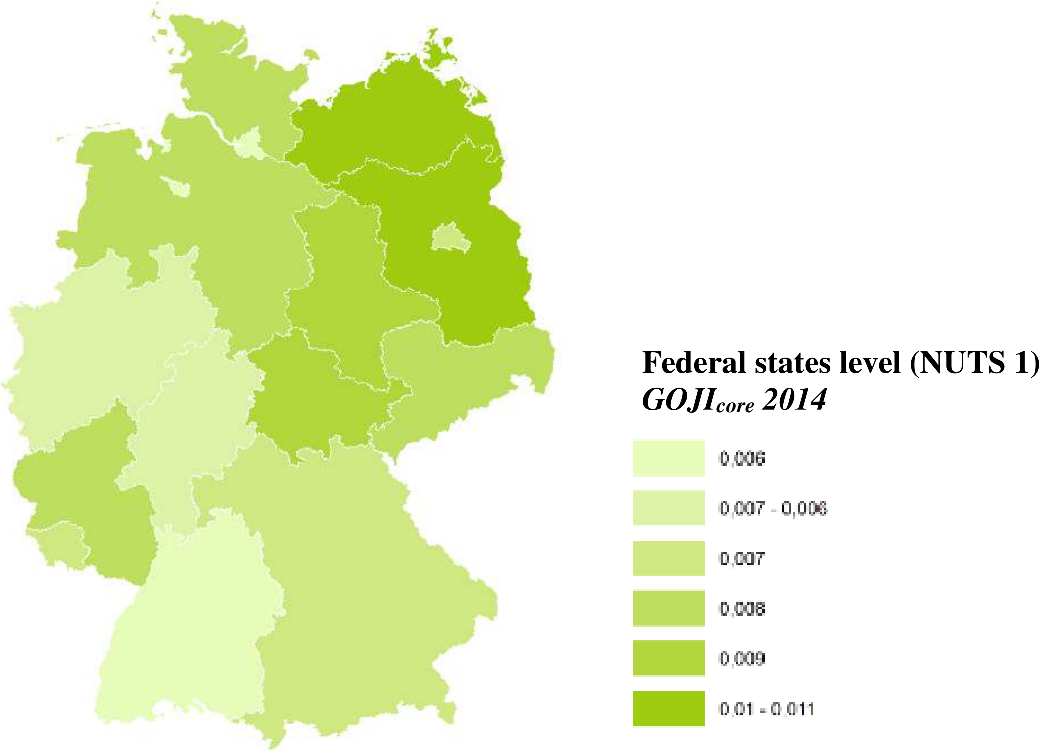
The regional distribution of the GOJI

Analogous to the industry aggregates, I also apply the weighting procedure to NUTS-1 level (federal state level) and NUTS-3 level (county level). As part of the results of this conversion, the following two maps should give an example of $GOJI_{core}$ at NUTS-1 / federal state level (Figure 5-6) and at NUTS-3 /county level (Figure 5-7). The two maps reveal pronounced differences between federal states and between counties. In the first place, this reflects the spatial disparities in terms of occupational distributions between regions. Figure 5-6 shows relatively high *GOJI* values in the north-eastern states of Mecklenburg-Vorpommern and Brandenburg, as well as in the states of Saxony-Anhalt, Thuringia and Rhineland-Palatinate, which might reflect to some extent the relatively large share of agricultural and other ‘green-by-nature’ occupations. Meanwhile, however, renewable energy production also influences this distribution. For example, several manufacturers of wind power plants are located in Mecklenburg-Vorpommern[46] and there is a considerable amount of biogas production in Brandenburg[47]. Some states, such as Bavaria and Baden-Wuerttemberg, have lower *GOJI* values despite the fact that many people work in green occupations there. This is probably due to a greater heterogeneity of occupations (many green occupations, but also many/more non-green occupations). This reason might also hold for the city states of Berlin, Hamburg and Bremen. Moreover, these and other large cities do not have many ‘green-by-nature’ occupations, e.g. in the context of agriculture. The reflections on federal states (Figure 5-6) can be applied to a large extent to the county level, too. Interestingly, Figure 5-7 reveals that within some federal states there is considerably more heterogeneity between counties (e.g. in Bavaria or Baden-Wuerttemberg). Hence, the greenness of specific counties seems to stem partly from county-level characteristics, which should be taken into account in future analyses.

[46] Report on the wind energy industry in Mecklenburg-Vorpommern (German language): URL: https://www.energie-und-management.de/nachrichten/alle/detail/mecklenburg-vorpommern-vorwaerts-mit-dem-wind-101817 (last accessed on Oct 30, 2018).

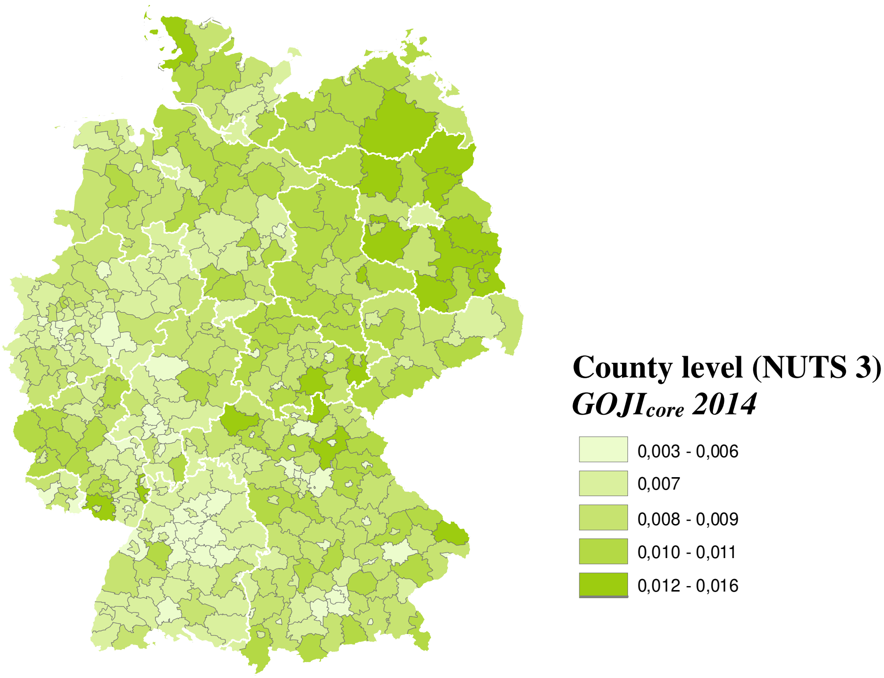
47 Statistics about renewable energies in the federal states of Germany (German language): URL: https://www.foederal-erneuerbar.de/landesinfo/bundesland/BB/kategorie/bioenergie/auswahl/189-anzahl_und_dichte_vo (last accessed on Oct 30, 2018).

Figure 5-6: GOJI$_{core\ 2014}$ at federal state level (NUTS 1), weighted by employment



Source: BERUFENET, employment statistics data from the Federal Employment Agency, own calculations. Note: Federal states: NUTS Classification (NUTS 1)

Figure 5-7: GOJI$_{core\ 2014}$ at county level (NUTS 3), weighted by employment



Source: BERUFENET, employment statistics data from the Federal Employment Agency, own calculations. Note: County codes: NUTS Classification (NUTS 3).

5.5 Summary and conclusions

To sum up, this chapter contributes to the literature in two ways: First, it introduces a novel approach that develops the Greenness-of-Jobs Index *GOJI* based on text mining with data from the German BERUFENET. Second, it describes the greenness and greening of jobs using employment weighted *GOJI* aggregates.

The first objective of the paper is to develop an index to measure both the extent of the greenness of jobs and the development of greenness over time, i.e., the greening of jobs. At the beginning of the project I conduct a comprehensive literature review to compile a "green task dictionary". Based on this dictionary I apply the text mining procedures to BERUFENET data for every year. After a two-step matching process, the green tasks and all other information on each occupation's requirements are used to compute the unweighted Greenness-of-Jobs Index *GOJI.*

The *GOJI* is a continuous value from 0 to 1 and is calculated for every occupation. There are three *GOJI* variations: core requirements ($GOJI_{core}$), additional requirements ($GOJI_{add}$), and a combination of both ($GOJI_{total}$). At the end of this step there are 785 individual occupations in 2016 with a $GOJI_{total}$ larger than zero. Compared to 2012, the percentage of occupations with a $GOJI_{total}$ larger than zero has risen from 18.6 percent to 19.9 percent. The $GOJI_{total}$ of those "green occupations" lies between 0.024 and 0.889 with a median of 0.083, i.e. the greenness of occupations varies widely. But not only the number of "*GOJI* occupations" has increased, also the *GOJI* level. 137 occupations have experienced an increase in their $GOJI_{total}$ between 2012 and 2016. This study does not claim to cover all green jobs, but it provides first evidence of all occupations with green requirements even if they are not necessarily associated with the production or provision of green goods and services. It might be worthwhile combining the *GOJI* with output-oriented approaches in a follow-up project.

The second objective is to describe the occupational, sectoral, and regional distributions of the greenness and greening of jobs. To analyze the distribution of the *GOJI* in Germany and to prepare the data for record linkage, I calculate several occupational, sectoral, and regional aggregates. The descriptive results show that there is an increase in the $GOJI_{total}$ at each level of aggregation. Even at the highest occupational aggregate, the overall German Greenness-of-Jobs Index ($GOJI_{de}$), a slight growth is observable: the $GOJI_{de}$ has grown from 0.0196 in 2012 to 0.0198 in 2016, which is an increase of one percent. Noteworthy, at this level the differences between $GOJI_{core}$ and $GOJI_{add}$ come to light. Whereas the higher $GOJI_{add}$ value of 0.0199 shows a slight decrease of -1.7%, the smaller $GOJI_{core}$ value (0.0150 in 2016) grows by 4.6 percent.

To measure the true magnitude of the greenness of jobs, I also introduce the "full-green employment equivalent (FGE)". According to the FGE in 2016, there were 590 thousand full-green employment equivalents in Germany. A comparison of the FGE reveals that between 2012 and 2016 there was an increase in FGE of 56,643, i.e., a plus of 10.6 percent.

The *GOJI* aggregates at industry level show heterogeneous developments in terms of the *GOJI* and reveal many examples of greening and degreening sectors*:* the sector “public administration and defense; compulsory social security” exhibits the largest growth in the absolute $GOJI_{total}$ value, whereas “accommodation and food service activities” has the largest relative growth rate. The strongest reduction in $GOJI_{total}$—both as an absolute and relative value—can be observed for “agriculture, forestry, and fishing”.

The same heterogeneity appears with respect to the regional distribution of the *GOJI*. Nevertheless, there are some patterns that are visible in each year: the eastern part of Germany has higher *GOJI* values, and larger cities have lower *GOJI* values than rural areas.

The practical and political implications of the results of this paper are twofold:

1) As shown in the study, it is possible to identify the greenness and greening of jobs using existing administrative data without expensive surveys and new data sources. This approach might therefore be an efficient way to officially measure the green transitions of employment in Germany. If similar data sources exist in other countries, this approach can be adopted or used for international comparisons. Methodologically, the combination of text mining, index development and aggregation has the potential to be applied to other societal transition processes, e.g., the ongoing digitalization (see Genz et al. 2018 for a first application).

A necessary prerequisite for every application is the availability of up-to-date information on occupations, especially about the current requirements. Although the BERUFENET is updated regularly, there is still room for institutional improvement. It seems that the job requirements of training occupations lag somewhat behind current developments. A more proactive role of the participating institutions, like the Chamber of Handicrafts and the Chamber of Industry and Commerce, who are responsible for the contents of the vocational trainings in Germany, could lead to a more up-to-date data basis for practice and research. For this reason the use of web crawling and machine-learning procedures to analyze online job offers might be a promising approach to anticipate current developments on the labor market (Hermes and Schandock 2016). Furthermore, a flag of “green task” similar to that in the U.S.-American O*NET database would be a helpful feature of the BERUFENET.

2) The descriptive analysis of the *GOJI* distribution revealed a large heterogeneity between occupational aggregates, industries, and regions. This heterogeneity should be kept in mind especially before policy implications are drawn. If the promotion of green jobs is a policy target, the results of this paper suggest that it is more advisable to promote the transformation of existing occupations rather than to design new occupations, though this may be necessary in individual cases. Furthermore, the large heterogeneity of the distribution of the *GOJI* demands a precise alignment of policy instruments.

5.6 Appendix of chapter 5

5.6.1 Appendix A.1—Text mining

A.1.1 Text sources used for developing the green tasks dictionary (selection)

Allen, C.; Clouth, S. (2012): A guidebook to the green economy, issue 1: green economy, green growth, and low-carbon development—history, definitions and a guide to recent publications. New York: United Nations.

Altenburg, T.; Assmann, C. (Eds.) (2017): Green industrial policy: concept, policies, country experiences. Geneva, Bonn: UN Environment; German Development Institute.

Bauer, S.; Thobe, I.; Wolter, M.-I.; Helmrich, R; Schandock, M.; Zika, G.; Röttger, C.; Mohaupt, F. (2017): Qualifikationen, Berufe und Branchen für den Übergang in eine Green Economy—eine Bestandsaufnahme. Umwelt, Innovation, Beschäftigung 2017/1. Dessau: Umweltbundesamt.

BMU (2009): GreenTech made in Germany 2.0: Umwelttechnologie-Atlas für Deutschland mit CD-ROM. Munich: Vahlen.

BMU (2012): GreenTech made in Germany 3.0. Environmental technology atlas for Germany. Berlin: Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU).

BMU/UBA (2011): Umweltwirtschaftsbericht 2011. Berlin: Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Umweltbundesamt (UBA).

BMU/BDI (2012): Memorandum für eine Green Economy: Eine gemeinsame Initiative des BDI und BMU. Berlin: Bundesministerium für Umwelt, Naturschutz (BMU) und Reaktorsicherheit; Bundesverband der Deutschen Industrie e.V. (BDI).

Cedefop, ILO (2010): Skills for green jobs: European synthesis report. Luxembourg: Publications Office of the European Union.

Cedefop; OECD LEED (eds.) (2015): Green skills and innovation for inclusive growth. Cedefop reference series for inclusive growth No. 100. Thessaloniki: Cedefop.

DOC (2010): Measuring the green economy. Washington DC: United States Department of Commerce (DOC).

European Centre for the Development of Vocational Training (ed.) (2012): Green skills and environmental awareness in vocational education and training: Synthesis report. Thessaloniki: Cedefop research paper No. 24.

Eurostat (2016): Environmental goods and services sector accounts—Handbook. 2016 edition. Luxembourg: Publications Office of the European Union.

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A.1.2 Matches "keywords to green tasks" 2006, 2011-2016 by green tasks category

Table 5-18: Frequency table of matches from keywords to requirements 2006, 2011-2016

Green tasks category	Number of keywords	Keyword-requirements matches						
		2006	2011	2012	2013	2014	2015	2016
Energy production & storage	20	8	14	14	14	14	14	15
Mobility & tourism	34	35	48	50	52	52	53	53
Building	21	16	19	19	19	19	20	21
Farming, forestry, food, cons. goods	19	15	15	15	15	16	16	16
Energy efficiency & climate protection	9	10	10	10	11	11	11	11
Emission protection (air, water, soil, noise)	27	25	26	26	26	26	26	26
Circular economy	13	24	24	24	24	24	24	24
Environmental protection (gen.)	10	23	25	25	25	25	25	25
Green tasks (total)	153	155	180	182	185	186	188	190
Share of total number of requirements		2.7%	2.7%	2.7%	2.8%	2.8%	2.8%	2.6%
Note: Total number of requirements		5,724	6,561	6,670	6,709	6,745	6,819	7,325

Source: BERUFENET, own calculations.

A.1.3 Matches "green tasks to occupations" 2011-2016 by green tasks category

Table 5-19: Frequency table of matches from green tasks to occupations 2006, 2011-2016

Green tasks category	Number of keywords	Green tasks-occupations matches					
		2011	2012	2013	2014	2015	2016
Energy production & storage	20	55	58	58	58	61	71
Mobility & tourism	34	103	106	124	131	131	131
Building	21	263	268	268	271	267	295
Farming, forestry, food, cons. goods	19	92	91	93	95	95	107
Energy efficiency & further climate protection	9	42	42	41	70	70	75
Emission prot.(air, water, soil, noise)	27	145	146	145	144	140	168
Circular economy	13	86	87	86	87	86	92
Environmental protection (gen.)	10	256	256	255	255	258	306
Green Occupations (total)	153	720	727	748	769	764	846
Share of total number of occup.		18.4%	18.5%	18.9%	19.4%	19.3%	19.9%
Note: Total number of occ.		3,909	3,926	3,952	3,961	3,953	4,251

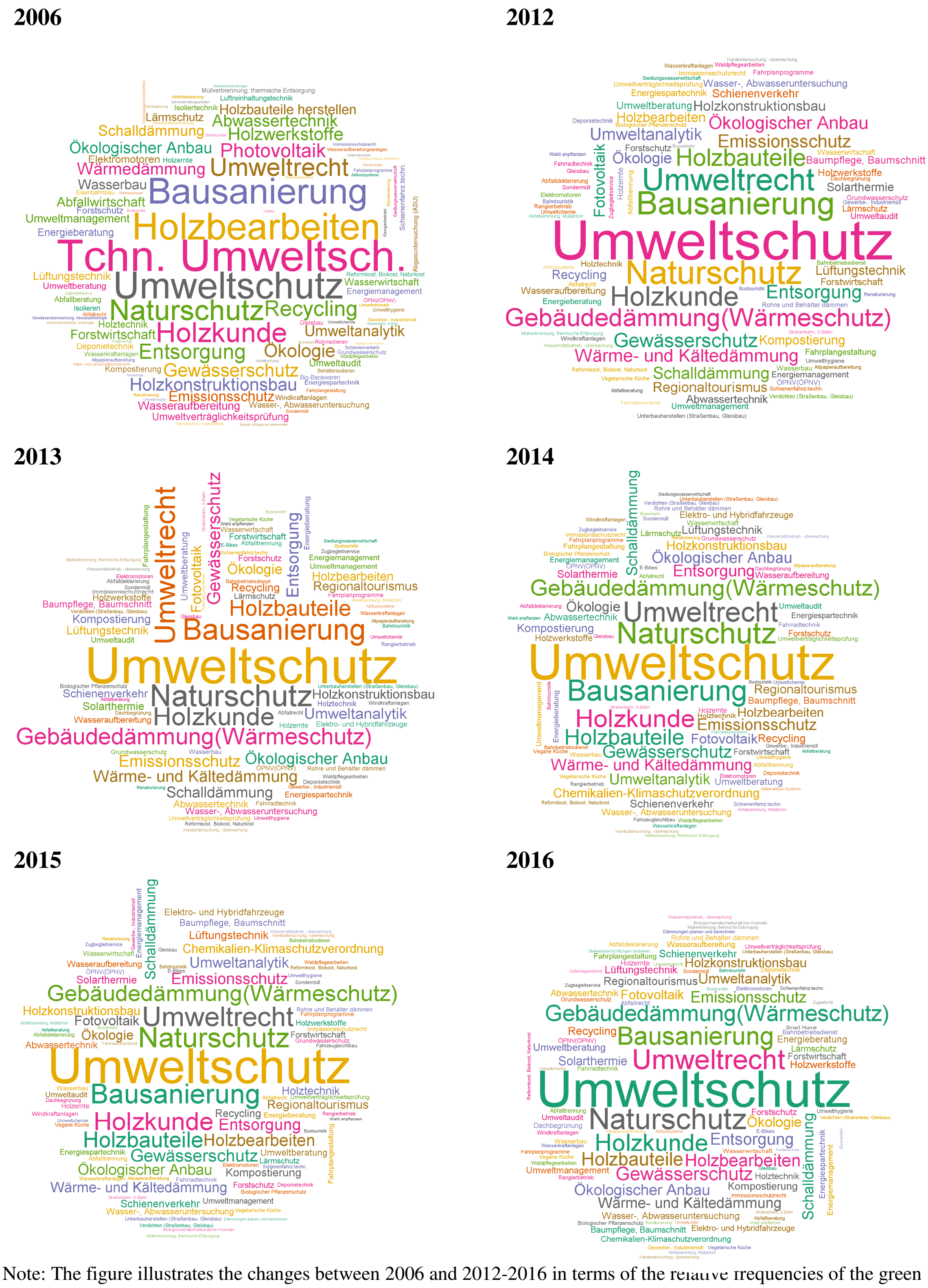
Source: BERUFENET, own calculations.

A.1.4 Word clouds

Figure 5-8: Word cloud 2016 (detailed view, including all keyword matches)

Note: The figure illustrates the relative frequencies of the green tasks keywords weighted by their appearance in the requirements section of the BERUFENET 2016. The size of the terms represents their weighted frequency, i.e. the larger the word the higher the frequency. The key words are presented in the original German language. Source: BERUFENET; own calculations.

Figure 5-9: Word clouds 2006 and 2012-2106 (time series)



Note: The figure illustrates the changes between 2006 and 2012-2016 in terms of the relative frequencies of the green tasks keywords weighted by their appearance in the requirements section of the BERUFENET. The size of the terms represents their weighted frequency, i.e. the larger the word the higher the frequency. The key words are presented in the original German language. Source: BERUFENET; own calculations.

Figure 5-10: Word clouds 2016 (grouped by green tasks categories)

1. Energy

2. Mobility & Tourism

3. Building

4. Farming, forestry, food, consumer goods

5. Energy efficiency & further climate protection

6. Further emission protection (air, water, soil, noise)

7. Circular economy, (raw) material efficiency (general) & waste management

8. Environmental protection

Note: Word cloud of the frequency of green tasks dictionary keywords weighted by their appearance in the BERUFENET requirements in 2016. The size of the terms represents their weighted frequency, i.e. the larger the word the higher the frequency. The key words are presented in the original German language. Source: BERUFENET; own calculations. Note: Each of these word clouds has been also created for the years 2006, and 2011 to 2015. They are available from the author on request.

5.6.2 Appendix A.2—Descriptives

A.2.1 Single occupations with GOJI > 0

Table 5-20: Number of single occupations with GOJI > 0 (2012-2016, 8-digit level KldB2010)

Year	Number of occupations	Number of occupations with GOJI > 0		
		$goji_{total}$>0	$goji_{core} > 0$	$goji_{add} > 0$
2012	3,702	688	294	585
2013	3,731	708	300	597
2014	3,738	728	303	623
2015	3,770	729	309	621
2016	3,946	785	357	656
Δ2012-2016	325	97	63	71
in %	6.6%	14.1%	21.4%	12.1%

Source: BERUFENET, own calculations.

A.2.2 Average GOJI values of single occupations

Table 5-21: Average GOJI values of single occupations (8-digit level)— a) all occupations and b) GOJI occupations only (with GOJItotal > 0) (2012-2016)

Year	Number of occupations		Average GOJI values					
			$goji_{total}$		$goji_{core}$		$goji_{add}$	
	all	GOJI	all	GOJI	all	GOJI	all	GOJI
2012	3,702	688	0.023	0.123	0.020	0.251	0.024	0.152
2013	3,731	708	0.023	0.121	0.020	0.252	0.024	0.149
2014	3,738	728	0.024	0.121	0.020	0.252	0.025	0.148
2015	3,770	729	0.023	0.121	0.021	0.262	0.024	0.147
2016	3,946	785	0.025	0.127	0.023	0.254	0.025	0.153
Δ2012-2016	244	97	0.002	0.002	0.003	0.008	0.001	-0.001
in %	6.6%	14.1%	10.6%	10.6%	15.3%	7.7%	6.2%	-0.8%

Source: BERUFENET, own calculations.

A.2.3 The employment-weighted overall GOJI.de

Table 5-22: The employment-weighted overall $GOJI_{de}$ (KldB 2010) 2012-2016

Year	$GOJI_{total}$	$GOJI_{core}$	$GOJI_{add}$	Employment total	"Full-green employment equivalents"
2012	0.0196	0.0143	0.0202	27,168,448	532,946
2013	0.0197	0.0144	0.0202	27,699,292	545,932
2014	0.0203	0.0144	0.0211	28,329,396	574,566
2015	0.0200	0.0149	0.0204	29,117,380	581,964
2016	0.0198	0.0150	0.0199	29,772,496	589,589
Δ2012-16	0.0002	0.0007	-0.0003	2,604,048	56,643
in %	1.0%	4.6%	-1.7%	9.6%	10.6%

Source: BERUFENET, Statistics data from the Federal Employment Agency, own calculations.

A.2.4 GOJI values for occupational areas (KldB2010, 1-digit level)

Table 5-23: Occupational areas and their greenness of jobs (1-digit level of KldB2010, 2012-2016)

Occupational area: KldB2010-ID and title		$GOJI_{total}$		$GOJI_{core}$		$GOJI_{add}$	
		2012	2016	2012	2016	2012	2016
1	Occupations in agriculture, forestry, farming, and gardening	0.080	0.066	0.091	0.070	0.091	0.056
2	Occupations in production of raw materials and goods, and manufacturing	0.009	0.012	0.003	0.005	0.013	0.015
3	Occupations in construction, architecture, surveying and technical building services	0.088	0.089	0.062	0.065	0.086	0.084
4	Occupations in natural sciences, geography and informatics	0.020	0.018	0.010	0.010	0.025	0.022
5	Occupations in traffic, logistics, safety & security	0.046	0.044	0.041	0.041	0.040	0.037
6	Occupations in commercial services, trading, sales, the hotel business and tourism	0.003	0.003	0.001	0.002	0.004	0.004
7	Occupations in business organization, accounting, law and administration	0.000	0.002	0.000	0.000	0.000	0.004
8	Occupations in health care, the social sector, teaching and education	0.001	0.001	0.000	0.000	0.001	0.001
9	Occupations in philology, literature, humanities, social sciences, economics, media, art, culture, and design	0.001	0.001	0.001	0.001	0.001	0.001

Source: BERUFENET, Statistics data from the Federal Employment Agency, own calculations.

A.2.5 GOJI values for occupational main groups (KldB2010, 2-digit level)

Table 5-24: Occupational main groups and their greenness of jobs (2-digit level of KldB2010, 2012-2016)

Occupational main group: KldB2010-ID and title		$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
11	Occupations in agriculture, forestry, and farming	0.074	0.060	0.108	0.062	0.056	0.044
12	Occupations in gardening and floristry	0.085	0.071	0.077	0.076	0.120	0.067
21	Occupations in production and processing of raw materials, glass- and ceramic-making and -processing	0.007	0.006	0.004	0.005	0.006	0.003
22	Occupations in plastic-making and -processing, and wood-working and -processing	0.032	0.038	0.020	0.033	0.038	0.035
23	Occupations in paper-making and -processing, printing, and in technical media design	0.006	0.006	0.000	0.001	0.009	0.008
24	Occupations in metal-making and -working, and in metal construction	0.001	0.001	0.001	0.001	0.001	0.001
25	Technical occupations in machine-building and automotive industry	0.017	0.018	0.001	0.006	0.024	0.024
26	Occupations in mechatronics, energy electronics and electrical engineering	0.013	0.019	0.005	0.006	0.018	0.026
27	Occupations in technical research and development, construction, and production planning and scheduling	0.002	0.004	0.000	0.002	0.004	0.005
28	Occupations in textile- and leather-making and -processing	0.000	0.000	0.000	0.000	0.000	0.001
29	Occupations in food-production and -processing	0.000	0.006	0.000	0.000	0.001	0.011
31	Occupations in construction scheduling, architecture and surveying	0.027	0.028	0.005	0.006	0.040	0.041
32	Occupations in building construction above and below ground	0.060	0.062	0.042	0.049	0.051	0.049
33	Occupations in interior construction	0.102	0.104	0.073	0.085	0.101	0.099
34	Occupations in building services engineering and technical building services	0.125	0.127	0.092	0.090	0.122	0.121
41	Occupations in mathematics, biology, chemistry and physics	0.024	0.020	0.000	0.000	0.036	0.031
42	Occupations in geology, geography and environmental protection	0.321	0.324	0.274	0.276	0.338	0.341
43	Occupations in computer science, information and communication technology	0.000	0.000	0.000	0.000	0.000	0.000
51	Occupations in traffic and logistics (without vehicle driving)	0.015	0.014	0.012	0.014	0.016	0.011
52	Drivers and operators of vehicles and transport equipment	0.102	0.101	0.100	0.101	0.103	0.102
53	Occupations in safety and health protection, security and surveillance	0.020	0.022	0.018	0.015	0.023	0.028
54	Occupations in cleaning services	0.050	0.048	0.038	0.037	0.019	0.017

Occupational main group: KldB2010-ID and title		*GOJI$_{total}$* 2012	*GOJI$_{total}$* 2016	*GOJI$_{core}$* 2012	*GOJI$_{core}$* 2016	*GOJI$_{add}$* 2012	*GOJI$_{add}$* 2016
61	Occupations in purchasing, sales and trading	0.002	0.003	0.000	0.000	0.003	0.004
62	Sales occupations in retail trade	0.001	0.002	0.001	0.002	0.002	0.003
63	Occupations in tourism, hotels and restaurants	0.009	0.007	0.005	0.005	0.011	0.008
71	Occupations in business management and organization	0.000	0.000	0.000	0.000	0.000	0.000
72	Occupations in financial services, accounting and tax consultancy	0.000	0.000	0.000	0.000	0.000	0.000
73	Occupations in law and public administration	0.001	0.015	0.000	0.000	0.002	0.028
81	Medical and health care occupations	0.000	0.000	0.000	0.000	0.000	0.000
82	Occupations in non-medical healthcare, body care, wellness and medical technicians	0.001	0.001	0.001	0.001	0.001	0.002
83	Occupations in education and social work, housekeeping, and theology	0.000	0.000	0.000	0.000	0.001	0.000
84	Occupations in teaching and training	0.003	0.003	0.000	0.000	0.005	0.007
91	Occupations in in philology, literature, humanities, social sciences, and economics	0.004	0.004	0.000	0.000	0.005	0.005
92	Occupations in advertising and marketing, in commercial and editorial media design	0.000	0.000	0.000	0.000	0.000	0.000
93	Occupations in product design, artisan craftwork, fine arts and the making of musical instruments	0.005	0.008	0.007	0.007	0.004	0.008
94	Occupations in the performing arts and entertainment	0.001	0.000	0.003	0.002	0.000	0.000

Sources: BERUFENET, Employment statistics data from the Federal Employment Agency, own calculations.

A.2.6 GOJI values for occupational groups (KldB2010, 3-digit level)

Table 5-25: Occupational groups and their greenness of jobs (3-digit level of KldB2010, 2012-2016)

Occupational main group: KldB2010-ID and title		*GOJI$_{total}$* 2012	*GOJI$_{total}$* 2016	*GOJI$_{core}$* 2012	*GOJI$_{core}$* 2016	*GOJI$_{add}$* 2012	*GOJI$_{add}$* 2016
111	Occupations in farming	0.043	0.035	0.003	0.002	0.063	0.051
112	Occupations in animal husbandry	0.000	0.000	0.000	0.000	0.000	0.000
113	Occupations in horse keeping	0.000	0.000	0.000	0.000	0.000	0.000
114	Occupations in fishing	0.040	0.037	0.000	0.000	0.061	0.058
115	Occupations in animal care	0.000	0.000	0.000	0.000	0.000	0.000
116	Occupations in vini- and viticulture	0.046	0.046	0.000	0.000	0.081	0.082
117	Occupations in forestry, hunting and landscape preservation	0.267	0.248	0.581	0.400	0.105	0.070
121	Occupations in gardening	0.100	0.081	0.091	0.086	0.142	0.076
122	Occupations in floristry	0.000	0.000	0.000	0.000	0.000	0.000

Occupational main group: KldB2010-ID and title		$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
211	Occupations in underground and surface mining and blasting engineering	0.008	0.011	0.003	0.007	0.010	0.012
212	Conditioning and processing of natural stone and minerals, production of building materials	0.005	0.001	0.000	0.000	0.008	0.001
213	Occupations in industrial glass-making and -processing	0.011	0.012	0.011	0.012	0.000	0.000
214	Occupations in industrial ceramic-making and -processing	0.000	0.000	0.000	0.000	0.000	0.000
221	Occupations in plastic- and rubber-making and -processing	0.000	0.000	0.000	0.000	0.000	0.000
222	Occupations in color coating and varnishing	0.000	0.000	0.000	0.000	0.000	0.000
223	Occupations in wood-working and -processing	0.077	0.093	0.048	0.080	0.090	0.085
231	Technical occupations in paper-making and -processing and packaging	0.023	0.023	0.000	0.004	0.037	0.031
232	Occupations in technical media design	0.000	0.000	0.000	0.000	0.000	0.000
233	Occupations in photography and photographic technology	0.000	0.000	0.000	0.000	0.000	0.000
234	Occupations in printing technology, print finishing, and book binding	0.000	0.000	0.000	0.000	0.000	0.000
241	Occupations in metal-making	0.000	0.000	0.000	0.000	0.000	0.000
242	Occupations in metalworking	0.000	0.000	0.000	0.001	0.000	0.000
243	Occupations in treatment of metal surfaces	0.012	0.019	0.000	0.000	0.016	0.023
244	Occupations in metal constructing and welding	0.001	0.001	0.003	0.003	0.000	0.000
245	Occupations in precision mechanics and tool making	0.000	0.000	0.000	0.000	0.000	0.000
251	Occupations in machine-building and -operating	0.021	0.011	0.000	0.000	0.031	0.018
252	Technical occupations in the automotive, aeronautic, aerospace and ship building industries	0.006	0.035	0.004	0.022	0.006	0.040
261	Occupations in mechatronics, automation and control technology	0.001	0.001	0.000	0.000	0.003	0.002
262	Technical occupations in energy technologies	0.028	0.033	0.010	0.013	0.038	0.042
263	Occupations in electrical engineering	0.000	0.010	0.000	0.000	0.001	0.015
271	Occupations in technical research and development	0.000	0.000	0.000	0.000	0.000	0.000
272	Draftspersons, technical designers, and model makers	0.004	0.011	0.001	0.009	0.007	0.012
273	Technical occupations in production planning and scheduling	0.003	0.003	0.000	0.000	0.005	0.005
281	Occupations in textile making	0.001	0.001	0.000	0.000	0.001	0.001
282	Occupations in the production of clothing and other textile products	0.000	0.000	0.000	0.000	0.000	0.000
283	Occupations in leather- and fur-making and -processing	0.000	0.001	0.000	0.000	0.001	0.002

Occupational main group: KldB2010-ID and title		$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
291	Occupations in beverage production	0.017	0.012	0.000	0.000	0.033	0.024
292	Occupations in the production of foodstuffs, confectionery and tobacco products	0.000	0.000	0.000	0.000	0.000	0.000
293	Cooking occupations	0.000	0.009	0.000	0.000	0.000	0.017
311	Occupations in construction scheduling and supervision, and architecture	0.032	0.032	0.006	0.007	0.048	0.048
312	Occupations in surveying and cartography	0.000	0.000	0.000	0.000	0.000	0.000
321	Occupations in building construction	0.052	0.056	0.021	0.032	0.052	0.050
322	Occupations in civil engineering	0.083	0.084	0.106	0.105	0.047	0.047
331	Floor layers	0.138	0.149	0.018	0.028	0.189	0.211
332	Painters and varnishers, plasterers, occupations in the waterproofing of buildings, preservation of structures and wooden building components	0.059	0.054	0.017	0.029	0.077	0.067
333	Occupations in the interior construction and dry walling, insulation, carpentry, glazing, roller shutter and jalousie installation	0.135	0.145	0.151	0.170	0.098	0.097
341	Occupations in building services engineering	0.069	0.081	0.025	0.025	0.084	0.107
342	Occupations in plumping, sanitation, heating, ventilating, and air conditioning	0.131	0.126	0.077	0.081	0.178	0.147
343	Occupations in building services and waste disposal	0.220	0.216	0.233	0.226	0.116	0.114
411	Occupations in mathematics and statistics	0.004	0.005	0.000	0.000	0.006	0.006
412	Occupations in biology	0.019	0.020	0.001	0.001	0.029	0.030
413	Occupations in chemistry	0.029	0.023	0.000	0.000	0.043	0.035
414	Occupations in physics	0.003	0.003	0.000	0.000	0.004	0.004
421	Occupations in geology, geography and meteorology	0.094	0.091	0.023	0.023	0.122	0.118
422	Occupations in environmental protection engineering	0.364	0.366	0.233	0.242	0.417	0.413
423	Occupations in environmental protection management and environmental protection consulting	0.426	0.458	0.484	0.508	0.398	0.435
431	Occupations in computer science	0.000	0.000	0.001	0.001	0.000	0.000
432	Occupations in IT-system-analysis, IT-application-consulting and IT-sales	0.000	0.000	0.000	0.000	0.000	0.000
433	Occupations in IT-network engineering, IT-coordination, IT-administration and IT-organization	0.000	0.000	0.000	0.000	0.000	0.000
434	Occupations in software development and programming	0.000	0.000	0.000	0.000	0.000	0.000
511	Technical occupations in railway, aircraft and ship operation	0.011	0.018	0.024	0.037	0.007	0.007
512	Occupations in the inspection and maintenance of traffic infrastructure	0.003	0.104	0.003	0.115	0.003	0.029

Occupational main group: KldB2010-ID and title		$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
513	Occupations in warehousing and logistics, in postal and other delivery services, and in cargo handling	0.006	0.003	0.002	0.002	0.009	0.003
514	Service occupations in passenger traffic	0.063	0.061	0.067	0.062	0.047	0.045
515	Occupations in traffic surveillance and control	0.210	0.214	0.222	0.228	0.191	0.194
516	Management assistants in transport and logistics	0.013	0.014	0.012	0.017	0.013	0.011
521	Driver of vehicles in road traffic	0.112	0.109	0.095	0.095	0.121	0.119
522	Drivers of vehicles in railway traffic	0.385	0.385	0.800	0.800	0.125	0.125
523	Aircraft pilots	0.000	0.000	0.000	0.000	0.000	0.000
524	Ship's officers and masters	0.000	0.000	0.000	0.000	0.000	0.000
525	Drivers and operators of construction and transportation vehicles and equipment	0.010	0.011	0.013	0.014	0.008	0.009
531	Occupations in physical security, personal protection, fire protection and workplace safety	0.018	0.020	0.017	0.014	0.020	0.025
532	Occupations in police and criminal investigation, jurisdiction and the penal institution	0.004	0.003	0.000	0.000	0.006	0.006
533	Occupations in occupational health and safety administration, public health authority, and disinfection	0.093	0.096	0.050	0.064	0.106	0.104
541	Occupations in cleaning services	0.050	0.048	0.038	0.037	0.019	0.017
611	Occupations in purchasing and sales	0.000	0.000	0.000	0.000	0.000	0.000
612	Trading occupations	0.000	0.000	0.000	0.000	0.001	0.001
613	Occupations in real estate and facility management	0.036	0.037	0.001	0.001	0.055	0.058
621	Sales occupations in retail trade (without product specialization)	0.000	0.000	0.000	0.000	0.000	0.000
622	Sales occupations (retail trade) selling clothing, electronic devices, furniture, motor vehicles and other durables	0.004	0.006	0.003	0.006	0.005	0.005
623	Sales occupations (retail) selling foodstuffs	0.001	0.005	0.001	0.002	0.000	0.009
624	Sales occupations (retail) selling drugstore products, pharmaceuticals, medical supplies and healthcare goods	0.009	0.008	0.000	0.000	0.017	0.015
625	Sales occupations (retail) selling books, art, antiques, musical instruments, recordings or sheet music	0.000	0.000	0.000	0.000	0.000	0.000
631	Occupations in tourism and the sports (and fitness) industry	0.069	0.066	0.041	0.052	0.085	0.068
632	Occupations in hotels	0.003	0.003	0.000	0.000	0.005	0.004
633	Gastronomy occupations	0.000	0.000	0.000	0.000	0.001	0.000
634	Occupations in event organization and management	0.006	0.006	0.000	0.000	0.012	0.011
711	Managing directors and executive board members	0.000	0.000	0.000	0.000	0.000	0.000
712	Legislators and senior officials of special interest organizations	0.004	0.006	0.000	0.000	0.007	0.008

Occupational main group: KldB2010-ID and title		*GOJI*$_{total}$ 2012	*GOJI*$_{total}$ 2016	*GOJI*$_{core}$ 2012	*GOJI*$_{core}$ 2016	*GOJI*$_{add}$ 2012	*GOJI*$_{add}$ 2016
713	Occupations in business organization and strategy	0.000	0.000	0.000	0.000	0.000	0.000
714	Office clerks and secretaries	0.000	0.000	0.000	0.000	0.000	0.000
715	Occupations in human resources management and personnel service	0.000	0.000	0.000	0.000	0.000	0.000
721	Occupations in insurance and financial services	0.000	0.000	0.000	0.000	0.000	0.000
722	Occupations in accounting, controlling and auditing	0.000	0.000	0.000	0.000	0.000	0.000
723	Occupations in tax consultancy	0.000	0.000	0.000	0.000	0.000	0.000
731	Occupations in legal services, jurisdiction, and other officers of the court	0.000	0.001	0.000	0.000	0.000	0.002
732	Occupations in public administration	0.001	0.019	0.000	0.000	0.002	0.036
733	Occupations in media, documentation and information services	0.000	0.000	0.000	0.000	0.000	0.000
811	Doctors’ receptionists and assistants	0.000	0.000	0.000	0.000	0.000	0.000
812	Laboratory occupations in medicine	0.000	0.000	0.000	0.000	0.000	0.000
813	Occupations in nursing, emergency medical services and obstetrics	0.000	0.000	0.000	0.000	0.000	0.000
814	Occupations in human medicine and dentistry	0.001	0.001	0.002	0.002	0.000	0.000
815	Occupations in veterinary medicine and non-medical animal health practitioners	0.000	0.000	0.000	0.000	0.000	0.000
816	Occupations in psychology and non-medical psychotherapy	0.001	0.001	0.000	0.000	0.001	0.001
817	Occupations in non-medical therapy and alternative medicine	0.002	0.002	0.000	0.000	0.002	0.003
818	Occupations in pharmacy	0.000	0.000	0.000	0.000	0.000	0.000
821	Occupations in geriatric care	0.000	0.000	0.000	0.000	0.000	0.000
822	Occupations providing nutritional advice or health counselling, and occupations in wellness	0.012	0.014	0.000	0.000	0.018	0.020
823	Occupations in body care	0.002	0.004	0.003	0.003	0.001	0.007
824	Occupations in funeral services	0.000	0.000	0.000	0.000	0.000	0.000
825	Technical occupations in medicine, orthopedic and rehabilitation	0.000	0.000	0.000	0.000	0.000	0.000
831	Occupations in education and social work, and pedagogic specialists in social care work	0.000	0.000	0.000	0.000	0.000	0.000
832	Occupations in housekeeping and consumer counselling	0.003	0.002	0.000	0.000	0.005	0.003
833	Occupations in theology and church community work	0.000	0.000	0.000	0.000	0.000	0.000
841	Teachers in schools of general education	0.000	0.000	0.000	0.000	0.000	0.000
842	Teachers for occupation-specific subjects at vocational schools and in-company instructors in vocational training	0.007	0.006	0.002	0.002	0.010	0.008

Occupational main group: KldB2010-ID and title		$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
843	Teachers and researcher at universities and colleges	0.000	0.000	0.000	0.000	0.000	0.000
844	Teachers at educational institutions other than schools (except driving, flying and sports instructors)	0.000	0.000	0.000	0.000	0.000	0.000
845	Driving, flying and sports instructors at educational institutions other than schools	0.018	0.021	0.000	0.000	0.045	0.065
911	Occupations in philology	0.000	0.000	0.000	0.000	0.000	0.000
912	Occupations in the humanities	0.000	0.000	0.000	0.000	0.000	0.000
913	Occupations in the social sciences	0.006	0.005	0.000	0.000	0.007	0.006
914	Occupations in economics	0.000	0.000	0.000	0.000	0.000	0.000
921	Occupations in advertising and marketing	0.000	0.000	0.000	0.000	0.000	0.000
922	Occupations in public relations	0.000	0.000	0.000	0.000	0.000	0.000
923	Occupations in publishing and media management	0.000	0.000	0.000	0.000	0.000	0.000
924	Occupations in editorial work and journalism	0.000	0.000	0.000	0.000	0.000	0.000
931	Occupations in product and industrial design	0.000	0.000	0.000	0.000	0.000	0.000
932	Occupations in interior design, visual marketing, and interior decoration	0.007	0.013	0.005	0.004	0.008	0.017
933	Occupations in artisan craftwork and fine arts	0.005	0.004	0.003	0.003	0.005	0.005
934	Artisans designing ceramics and glassware	0.000	0.000	0.000	0.000	0.000	0.000
935	Artisans working with metal	0.000	0.000	0.000	0.000	0.000	0.000
936	Occupations in musical instrument making	0.028	0.030	0.085	0.092	0.000	0.000
941	Musicians, singers and conductors	0.000	0.000	0.000	0.000	0.000	0.000
942	Actors, dancers, athletes and related occupations	0.000	0.000	0.000	0.000	0.000	0.000
943	Presenters and entertainers	0.000	0.000	0.000	0.000	0.000	0.000
944	Occupations in theatre, film and television productions	0.000	0.000	0.000	0.000	0.000	0.000
945	Occupations in event technology, cinematography, and sound engineering	0.000	0.000	0.000	0.000	0.000	0.000
946	Occupations in stage, costume and prop design,	0.000	0.000	0.000	0.000	0.000	0.000
947	Technical and management occupations in museums and exhibitions	0.007	0.006	0.031	0.025	0.000	0.000

Sources: BERUFENET, Employment statistics data from the Federal Employment Agency, own calculations.

A.2.7 GOJI values for occupational main groups and requirements level (2-digit level plus 5th digit)

Table 5-26: Greenness index grouped by a combination of occupational main group and requirements level (in percent, weighted)

Occupational main group: KldB2010-ID and title		Requirements level	$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
11	Occupations in agriculture, forestry, and farming	1 Unskilled/semi-skilled	0.028	0.020	0.028	0.020	0.000	0.000
		2 Specialist	0.095	0.085	0.161	0.078	0.089	0.076
		3 Complex specialist	0.141	0.141	0.177	0.162	0.117	0.123
		4 Highly complex	0.112	0.116	0.152	0.156	0.091	0.092
12	Occupations in gardening and floristry	1 Unskilled/semi-skilled	0.058	0.025	0.025	0.025	0.167	0.000
		2 Specialist	0.093	0.093	0.098	0.105	0.102	0.099
		3 Complex specialist	0.103	0.102	0.026	0.025	0.136	0.134
		4 Highly complex	0.106	0.101	0.146	0.138	0.081	0.078
21	Occupations in production and processing of raw materials, glass- and ceramic-making and -processing	1 Unskilled/semi-skilled	0.015	0.015	0.015	0.015	0.000	0.000
		2 Specialist	0.002	0.001	0.000	0.000	0.004	0.001
		3 Complex specialist	0.007	0.009	0.000	0.011	0.011	0.004
		4 Highly complex	0.087	0.089	0.042	0.043	0.111	0.114
22	Occupations in plastic-making and -processing, and wood-working and -processing	1 Unskilled/semi-skilled	0.012	0.013	0.012	0.013	0.000	0.000
		2 Specialist	0.038	0.048	0.018	0.038	0.053	0.051
		3 Complex specialist	0.054	0.055	0.088	0.087	0.035	0.035
		4 Highly complex	0.085	0.086	0.127	0.130	0.057	0.057
23	Occupations in paper-making and -processing, printing, and in technical media design	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.009	0.011	0.000	0.002	0.015	0.015
		3 Complex specialist	0.002	0.002	0.000	0.000	0.004	0.003
		4 Highly complex	0.004	0.003	0.000	0.000	0.005	0.005
24	Occupations in metal-making and -working, and in metal construction	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.001	0.001	0.001	0.002	0.001	0.001
		3 Complex specialist	0.001	0.001	0.000	0.000	0.002	0.002
		4 Highly complex	0.000	0.000	0.000	0.000	0.000	0.000

Occupational main group: KldB2010-ID and title		Requirements level	$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
25	Technical occupations in machine-building and automotive industry	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.019	0.019	0.001	0.007	0.026	0.025
		3 Complex specialist	0.026	0.034	0.003	0.005	0.039	0.049
		4 Highly complex	0.014	0.018	0.006	0.005	0.018	0.025
26	Occupations in mechatronics, energy electronics and electrical engineering	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.014	0.017	0.006	0.007	0.020	0.022
		3 Complex specialist	0.017	0.023	0.004	0.005	0.023	0.031
		4 Highly complex	0.010	0.052	0.003	0.004	0.014	0.074
27	Occupations in technical research and development, construction, and production planning and scheduling	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0.003	0.008	0.000	0.004	0.006	0.011
		3 Complex specialist	0.004	0.004	0.000	0.003	0.007	0.006
		4 Highly complex	0.000	0.000	0.000	0.000	0.000	0.000
28	Occupations in textile- and leather-making and -processing	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0.001	0.002	0.000	0.000	0.002	0.003
		4 Highly complex	0.014	0.015	0.000	0.000	0.020	0.021
29	Occupations in food-production and -processing	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.001	0.011	0.000	0.000	0.001	0.020
		3 Complex specialist	0.001	0.001	0.000	0.000	0.002	0.002
		4 Highly complex	0.000	0.000	0.000	0.000	0.000	0.000
31	Occupations in construction scheduling, architecture and surveying	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0.024	0.026	0.015	0.015	0.029	0.032
		3 Complex specialist	0.018	0.020	0.003	0.006	0.027	0.028
		4 Highly complex	0.030	0.030	0.004	0.004	0.047	0.047

Occupational main group: KldB2010-ID and title		Requirements level	$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
32	Occupations in building construction above and below ground	1 Unskilled/semi-skilled	0.057	0.057	0.057	0.057	0.000	0.000
		2 Specialist	0.064	0.069	0.036	0.046	0.072	0.076
		3 Complex specialist	0.054	0.054	0.049	0.048	0.054	0.055
		4 Highly complex	0.001	0.002	0.000	0.000	0.002	0.003
33	Occupations in interior construction	1 Unskilled/semi-skilled	0.106	0.105	0.106	0.105	0.000	0.000
		2 Specialist	0.102	0.105	0.068	0.082	0.114	0.116
		3 Complex specialist	0.090	0.095	0.083	0.084	0.093	0.099
		4 Highly complex	N/A	N/A	N/A	N/A	N/A	N/A
34	Occupations in building services engineering and technical building services	1 Unskilled/semi-skilled	0.318	0.306	0.318	0.306	0.000	0.000
		2 Specialist	0.110	0.112	0.072	0.071	0.134	0.131
		3 Complex specialist	0.095	0.109	0.080	0.077	0.106	0.138
		4 Highly complex	0.108	0.119	0.074	0.080	0.127	0.139
41	Occupations in mathematics, biology, chemistry and physics	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.031	0.024	0.000	0.000	0.045	0.035
		3 Complex specialist	0.029	0.032	0.000	0.000	0.055	0.059
		4 Highly complex	0.022	0.023	0.000	0.001	0.033	0.034
42	Occupations in geology, geography and environmental protection	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0.429	0.417	0.253	0.246	0.491	0.478
		3 Complex specialist	0.328	0.375	0.367	0.400	0.310	0.365
		4 Highly complex	0.254	0.241	0.224	0.218	0.267	0.250
43	Occupations in computer science, information and communication technology	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0.000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0.000	0.000	0.000	0.000	0.000	0.000
		4 Highly complex	0.000	0.000	0.001	0.001	0.000	0.000

Occupational main group: KldB2010-ID and title		Requirements level	$GOJI_{total}$		$GOJI_{core}$		$GOJI_{add}$	
			2012	2016	2012	2016	2012	2016
51	Occupations in traffic and logistics (without vehicle driving)	1 Unskilled/semi-skilled	0.003	0.003	0.003	0.003	0.000	0.000
		2 Specialist	0.026	0.024	0.018	0.023	0.032	0.020
		3 Complex specialist	0.058	0.076	0.062	0.081	0.049	0.067
		4 Highly complex	0.009	0.008	0.009	0.008	0.008	0.008
52	Drivers and operators of vehicles and transport equipment	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.111	0.110	0.109	0.109	0.112	0.111
		3 Complex specialist	0.000	0.000	0.000	0.000	0.000	0.000
		4 Highly complex	0.000	0.000	0.000	0.000	0.000	0.000
53	Occupations in safety and health protection, security and surveillance	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.014	0.016	0.019	0.016	0.011	0.014
		3 Complex specialist	0.055	0.063	0.011	0.009	0.099	0.118
		4 Highly complex	0.074	0.067	0.053	0.047	0.085	0.078
54	Occupations in cleaning services	1 Unskilled/semi-skilled	0.050	0.048	0.050	0.048	0.000	0.000
		2 Specialist	0.052	0.052	0.000	0.000	0.081	0.080
		3 Complex specialist	0.023	0.022	0.000	0.000	0.042	0.039
		4 Highly complex	N/A	N/A	N/A	N/A	N/A	N/A
61	Occupations in purchasing, sales and trading	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0,000	0.003	0.004	0.000	0.000	0.005
		3 Complex specialist	0,000	0.002	0.002	0.000	0.000	0.004
		4 Highly complex	0,001	0.000	0.000	0.000	0.000	0.000
62	Sales occupations in retail trade	1 Unskilled/semi-skilled	0,000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0,001	0.002	0.003	0.001	0.002	0.002
		3 Complex specialist	0,000	0.000	0.000	0.000	0.000	0.000
		4 Highly complex	0,000	0.000	0.000	0.000	0.000	0.000

Occupational main group: KldB2010-ID and title		Requirements level	$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
63	Occupations in tourism, hotels and restaurants	1 Unskilled/semi-skilled	0,000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0,000	0.011	0.009	0.006	0.007	0.014
		3 Complex specialist	0,000	0.016	0.016	0.004	0.003	0.023
		4 Highly complex	0,000	0.012	0.010	0.004	0.005	0.016
71	Occupations in business management and organization	1 Unskilled/semi-skilled	0,000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0,000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0,000	0.000	0.000	0.000	0.000	0.000
		4 Highly complex	0,000	0.001	0.001	0.001	0.001	0.000
72	Occupations in financial services, accounting and tax consultancy	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0,000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0,000	0.000	0.000	0.000	0.000	0.000
		4 Highly complex	0,000	0.000	0.000	0.000	0.000	0.000
73	Occupations in law and public administration	1 Unskilled/semi-skilled	N/A	0.000	N/A	0.000	N/A	0.000
		2 Specialist	0.000	0.016	0.000	0.000	0.001	0.030
		3 Complex specialist	0.000	0.018	0.000	0.000	0.000	0.035
		4 Highly complex	0.007	0.012	0.000	0.003	0.011	0.017
81	Medical and health care occupations	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0.000	0.000	0.000	0.000	0.000	0.000
		4 Highly complex	0.001	0.001	0.001	0.001	0.000	0.000
82	Occupations in non-medical healthcare, body care, wellness and medical technicians	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.001	0.001	0.001	0.001	0.000	0.002
		3 Complex specialist	0.003	0.007	0.000	0.000	0.005	0.012
		4 Highly complex	0.000	0.000	0.000	0.000	0.000	0.000

Occupational main group: KldB2010-ID and title		Requirements level	$GOJI_{total}$ 2012	$GOJI_{total}$ 2016	$GOJI_{core}$ 2012	$GOJI_{core}$ 2016	$GOJI_{add}$ 2012	$GOJI_{add}$ 2016
83	Occupations in education and social work, housekeeping, and theology	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0.005	0.004	0.000	0.000	0.008	0.006
		4 Highly complex	0.000	0.000	0.000	0.000	0.000	0.000
84	Occupations in teaching and training	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0.000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0.011	0.013	0.002	0.002	0.024	0.035
		4 Highly complex	0.001	0.001	0.000	0.000	0.001	0.001
91	Occupations in in philology, literature, humanities, social sciences, and economics	1 Unskilled/semi-skilled	0.000	0.000	0.000	0.000	0.000	0.000
		2 Specialist	0.000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0.000	0.000	0.000	0.000	0.000	0.000
		4 Highly complex	0.004	0.005	0.000	0.000	0.005	0.005
92	Occupations in advertising and marketing, in commercial and editorial media design	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0.000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0.000	0.000	0.000	0.000	0.000	0.000
		4 Highly complex	0.000	0.000	0.000	0.000	0.000	0.000
93	Occupations in product design, artisan craftwork, fine arts and the making of musical instruments	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0.003	0.007	0.008	0.008	0.001	0.006
		3 Complex specialist	0.005	0.004	0.016	0.014	0.001	0.001
		4 Highly complex	0.012	0.012	0.000	0.000	0.017	0.017
94	Occupations in the performing arts and entertainment	1 Unskilled/semi-skilled	N/A	N/A	N/A	N/A	N/A	N/A
		2 Specialist	0.000	0.000	0.000	0.000	0.000	0.000
		3 Complex specialist	0.000	0.000	0.000	0.000	0.000	0.000
		4 Highly complex	0.001	0.001	0.006	0.005	0.000	0.000

Sources: BERUFENET, Employment statistics data from the Federal Employment Agency, own calculations.

6 The greening of jobs and labor market outcomes: first evidence from the GOJI and employment register data[48]

Abstract

In the last years, the percentage of environmentally friendly requirements within occupations has increased considerably. In many countries, the ongoing strive towards environmental sustainability is supposed to lead to a rising demand for labor in these green or greening occupations. But is there really an increasing demand for these occupations? It is not clear yet, whether the greenness and greening of occupations affects employment and wages within these occupations. To fill this gap, the chapter analyzes the level and growth of the greenness of jobs and its relationship with employment and wage growth. The key element of this analysis is the new task-based GOJI, presented in the previous chapter. The econometric analysis is based on employment register data from 2011 to 2016. The estimation results reveal that the overall level of greenness of occupations is positively correlated with employment growth. Furthermore, the increase of greenness is related to a slight increase in wage growth.

JEL-Classification: J23, J24, O33, Q55, R23

Keywords: Human capital; Occupational tasks; Green jobs; Structural change; Employment Growth; Wage Growth

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[48] An earlier version of this chapter is part of the following discussion paper: Janser, M. (2018): The greening of jobs in Germany. First evidence from a text mining based index and employment register data. *IAB-Discussion Paper* 14/2018. Nuremberg: IAB.

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6.1 Introduction

Global environmental challenges such as climate change, loss of biodiversity, and environmental pollution have led to numerous initiatives aimed at improving environmental sustainability. These initiatives take place at international (e.g., OECD 2011; UNEP 2011), supranational (e.g., EC 2015), national (e.g., BMBF 2014), and local levels (e.g., Stappen/Schels 2002), and all aim towards a greener, less carbon-intensive economy. From a labor market perspective, these green transitions are supposed to lead to changes in both occupational demand and labor market outcomes, such as employment and wage growth.

Despite a large body of literature on concepts and initiatives about green jobs, the scale of the actual transition in the labor market remains largely unexplored. To what extent a greening of jobs is taking place and how such a transition is related to labor market outcomes likewise remain unclear.

Using a full sample of employment register data, this paper is the first to analyze the greening of jobs and its relation to employment and wage growth. With Germany as a case study, I apply a new text-mining-based index to calculate the percentage of green tasks within specific occupations (Greenness-of-Jobs Index, *GOJI*).

I define *green tasks* as explicitly environmentally friendly occupational requirements related to the production of output (goods and services) and to any operating process. These requirements may be related to every step along the entire value chain. They include knowledge areas, technologies, and practices for reducing the use of fossil fuels, decreasing pollution and greenhouse gas emissions, increasing the efficiency of energy usage and material usage, recycling materials, developing and adopting renewable sources of energy, and protecting and promoting biodiversity.

Germany constitutes a particularly good case for studying the greening of jobs, because it was, and somewhat still remains, an environmental pioneer, with its relatively strong environmental regulation, energy turnaround towards renewable energies, large environmental sector, and a civil society in which environmental protection still has a relatively high value. Nonetheless, and much like other developed countries, Germany now faces an ongoing public debate about the scope and speed of environmental transitions (e.g., several public conflicts about the lignite phase-out, the future of fossil-fuel based mobility, and stricter emission limits). Moreover, as in many other countries, the public debate about the potential economic and social costs of environmental protection still continues.

Nonetheless, structural changes such as the existing climate protection targets, environmental regulations, and changes in consumer behavior have already intensified the transitions towards a greener, less carbon-intensive economy. These economic structural changes are also supposed to impact the labor market. Both employers and employees have to adapt their practices and integrate new skills. In addition to the formation of new occupations, the percentage of environmentally friendly requirements within occupations, i.e., the *greening of occupations,* is supposed to increase. This growing demand for green requirements may also lead to a rising labor demand for occupations meeting these requirements, i.e., the *greening of employment*. Together, these two trends form the *greening of jobs,* the analytical focus of this paper.

Most previous studies base their analysis on an output-oriented identification of green jobs (e.g., Rennings/Zwick 2002; Hillebrand et al. 2006; Becker/Shadbegian 2009; DOC 2010; Lehr et al. 2012; DOL/BLS 2013a/b; OECD/Cedefop 2014; UN et al. 2014; Antoni et al. 2015; Eurostat 2016a; Horbach/Janser 2016; UN et al. 2017). Yet none of these approaches cover non-output-related job tasks, such as integrated environmental protection or the application of clean technologies (e.g., energy management within firms). Indeed, only a few studies have started to apply a task-based approach to the greenness of occupations and its associations with employment (Peters 2014, Vona et al. 2015, Consoli et al. 2016). These studies treat the greenness of occupations as a static parameter, i.e., as fixed over time. Yet the green transition, which is supposed to lead to a change of occupations over time, requires a dynamic model of the *greening of jobs*, i.e., a change in the greenness of an occupation over time. Thus far, little is known about the extent to which the greening of occupations as a dynamic parameter takes place, how it is distributed, or how the greening of occupations is associated with employment and wage growth. Vona et al. (2015: 2) name policy advice as a further reason for measuring and analyzing the change of greenness of jobs: "Understanding the extent to which greening the economy can induce significant changes in the demand for certain skills and, most cogently, which skills these might be, is crucial to inform policy."

Given differences in environmental and climate policies, a large difference in the greening of jobs may exist between regions, such as countries or federal states. However, for many regions there is only little or no information available about the greenness of jobs While some studies have measured the greenness of occupations and its associations with employment in countries such as the United States (Deschenes 2013; Peters 2014; Vona et al. 2015; Consoli et al. 2016) and Australia (Annandale et al. 2004), no method has yet been established for measuring the greenness of occupations and its relationship to labor demand in other countries.

To fill these research gaps, and using Germany as a case study, this paper develops an indicator for measuring the greening of occupations; describes the occupational, sectoral, and regional distribution of the greening of jobs; and examines the relationship between the greening of occupations and labor market outcomes such as employment and wages.

First to answer the question of what indicator is best for analyzing the greenness and greening of occupations—given the available data structure in Germany— the paper introduces the task-based *Greenness-of-Jobs Index* (*GOJI*). For each individual occupation, this index describes the percentage of the total number of all requirements relevant for protecting the environment (*green tasks*). The *GOJI* facilitates a task-based measurement of the greenness and greening of jobs for the entire range of occupations in Germany. I derive the *GOJI* by performing text-mining procedures on the German occupations database BERUFENET, provided by the German Federal Employment Agency. This data is available for 2006 and from 2011 to 2016. I also use employment statistics data to develop employment-weighted occupational, sectoral, and regional *GOJI* aggregates. The creation of the *GOJI* is critical, because it makes possible all further analyses on the greening of jobs. The *GOJI* facilitates a task-based estimation of the greenness and greening of jobs for the entire range of occupations.

Second, to answer the question of how green occupations are, and whether a greening of jobs is taking place, I analyze the distribution of the *GOJI* and present summary statistics of different aggregation levels of occupations, sectors, and regions. Third, to answer the question of whether occupations with larger greenness and/or greening show larger employment and wage growth, I apply the GOJI to an econometric analysis of employment and wage growth. The results of this empirical analysis also clarify the potential of *GOJI* for further econometric analyses.

The paper examines the relationship between the *GOJI* and growth in employment and wages from 2012 to 2016, in terms of both levels (*greenness*) and trends (*greening*). To examine the correlations with employment and wage growth, I apply cross-sectional and panel data regressions. For the econometric analysis, I also create a novel data source by linking the *GOJI* with a project-specific occupational panel based on 2011 to 2016 individual administrative employment data from the Federal Employment Agency.

The descriptive results show a greening of jobs that varies strongly between sectors and regions. The estimation results prove that the total level of greenness of occupations is positively correlated with employment growth, and that the change of greenness is related to a slight increase in wage growth. The econometric application demonstrates the potential of the *GOJI* for further empirical analyses.

This paper is valuable for both researchers and policy-makers. The *GOJI* makes possible detailed scientific studies of the greening of jobs in Germany. Moreover, the descriptive and analytical results will help researchers evaluate environmental policies (e.g., new emission limits) by disentangling important relationships between the greenness and/or greening of jobs and labor market outcomes. The results of the GOJI can also help policy makers evaluate the impact of various green-related policies, present and future, on the labor market. In addition, the results of this paper may help policy makers design training policies that meet the changing demands of the labor market.

The paper is organized as follows: Section 6.2 contains an overview of related literature. Section 6.3 presents the different data sources used in this paper. Section 6.4 covers the econometric analysis of the associations between the greenness and the greening of jobs, and labor market outcomes. Section 6.5 concludes and discusses both practical and policy-making implications.

6.2 Literature review and conceptual framework

6.2.1 Previous descriptive findings on the greenness and greening of jobs

This review of descriptive evidence in the literature on the greenness and greening of jobs discusses findings from both output-oriented and task-based approaches. While the output-oriented approach identifies green jobs by the goods and services produced (e.g., a mechanic who installs wind power plants), the task-based approach identifies green jobs by occupational requirements (e.g., energy consulting as part of the occupational requirements of a chimney sweep). An example of the difference between the two is as follows: While "output-oriented" refers, e.g., to a mechanic who installs wind power plants, and who thus has a green job, "task-based" refers to energy consulting conducted by a chimney sweep, an environmental-related task contributing to the greenness of this particular occupation.

Most studies on green jobs in general still use an output-based definition of green jobs, i.e., employment in the environmental goods and services sector (EGSS). According to the International System of Environmental-Economic Accounting, the EGSS "consists of a heterogeneous set of enterprises which produce environmental goods and services. Historically, the production of environmental goods and services focused on the demand for basic services, such as wastewater treatment and the collection of solid waste. However, with the drive towards cleaner and more resource-efficient processes, products and materials, the activities of the sector have expanded to also include resource management activities" (UN et al. 2017: 25 in connection with UN et al. 2014).[49]

Deschenes (2013), who works with U.S. labor statistics data, finds that thus far green jobs only account for a small percentage of total employment in the U.S. Over the last ten years, this percentage has seen relatively weak growth. Elliott/Lindley (2017) describe the distribution of green jobs in the U.S. in 2010 as varying widely among states: Measured as a percentage of total employment, North Carolina has the largest percentage of green jobs (5.1) and Florida has the smallest (1.6). The spatial distribution of the quantitative development of green jobs is also very heterogeneous, showing both positive and negative changes in values in the percentage of green employment: Maryland with the greatest increase (+0.538) and Minnesota with the largest decrease (-0.184). These findings correspond to those of Weinstein/Partridge (2010), Weinstein et al. (2010) and Vona et al. (2017), all of whom describe large heterogeneity between and within U.S. states.

As for the U.S. sectoral distribution, the manufacturing industry has the largest absolute number of green jobs in the private sector (about 507,000), and the smallest is the financial activities sector (about 500) (Elliot/Lindley 2017). According to Elliott/Lindley (2017), the utilities sector—measured as a percentage of total employment—is the largest

[49] "For detailed information about the concept of measuring green jobs see chap. 5.

provider of green jobs (12 percent) and the financial activities sector the smallest (0.002 percent). Using a detailed (3-digit) industry level, they reveal high heterogeneity within sector aggregates (e.g., manufacturing), with construction as the largest provider of green employment in absolute figures and transit/ground passenger transport as the largest percentage (55 percent). Overall they conclude that those U.S. states and sectors that were relatively green in 2010 became greener in 2011. Elliott/Lindley (2017) use data from the U.S. American Green Goods and Services Survey (GGS), conducted from 2010 to 2012 before being discontinued in 2013, due to public spending cuts.[50]

The challenge of discontinuous green employment data also exists in Germany, in the IAB Establishment Panel survey.[51] In Germany, studies have used two main sources for previous analyses of green jobs in the labor market: the annual IAB Establishment Panel survey, conducted by the Institute for Employment Research, and the statistical data of the Federal Statistical Office. Both take an output-oriented approach to green jobs, i.e., they identify green jobs by EGSS employment. Three survey waves of the IAB Establishment Panel—1999, 2005, and 2012—include questions about environmental goods and services. In this survey, as well as in the entire German labor market data, the observation object is the "establishment."[52] Several studies use the survey data of the IAB Establishment Panel for analyzing employment developments in the EGSS.

Horbach et al. (2009) find a drastic decline in employment in environmental firms dominated by end-of-pipe technologies (e.g., exhaust gas filters) from 1999 to 2005, whereas establishments that produce or trade in clean technologies show positive employment trends. Horbach/Janser (2016) document a far more positive employment situation in the period from 2009 to 2012. They show that environmental establishments have slightly higher employment growth (+0.6 percentage points from 2009 to 2012) than other establishments. A look at the percentages of employees with a university education reveals that environmental establishments employ a larger percentage (13.4) than the total sample of establishments (9.9). Correspondingly, the percentage of innovative establishments is also higher in the group of environmental establishments (53.4) than in the total sample (40.4) (Horbach/Janser 2016).

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[50] For information about the survey, see also Sommers (2013). In 2013, the U.S. Bureau of Labor Statistics (BLS) had to cut its budget as a result of the Balanced Budget and Emergency Deficit Control Act. The BLS decided to stop all "measuring green jobs" products, including data on employment by industry and occupation for businesses that produce green goods and services; data on the occupations and wages of jobs related to green technologies and practices; and green career information publications (sources: www.bls.gov/ggs/ and www.bls.gov/bls/sequester_info.htm, last accessed on Oct. 31, 2018).

[51] The questions changed between 2005 and 2012. Therefore, directly comparing the EGSS data of these two years is not possible. Whether the EGSS question will be included in the questionnaire again remains unclear.

[52] In contrast to the term "company" which is defined by the independent legal form of the organization, the term "establishment" refers to a specific place of work. A company can always comprise several establishments at different locations. I use the terms precisely the way they are used in each respective literature or data source.

Furthermore, Horbach/Janser (2016) identify marked differences between the groups in environmental goods and services: "Environmental remediation, soil conservation" shows the highest employment growth from 2009 to 2012 (+16.8 percent), while "waste management, recycling" has the lowest (+0.6 percent). "Climate protection, renewable energies, energy saving" increased by 6.2 percent, outperforming the average for the entire environmental sector (+4.7 percent). Horbach (2014b) also finds that the environmental sector is disproportionately affected by labor shortages.

The current method for estimating the gross employment effects of environmental protection in Germany is based on Blazejczak/Edler (2015), who apply a demand-driven approach using input-output methods to estimate environmental employment from the production of environmental goods. Using a supply-driven approach based on multiple data sources, one of which is the IAB Establishment Panel, they calculate environmental employment. According to this method, 2.2 million people were working for environmental protection in Germany in 2012 (Edler/Blazejczak 2016). GHK (2009) and Bowen/Kuralbayeva (2015) provide comprehensive literature reviews of a number of studies on green jobs at the national and international levels. Most of these studies are based on different output definitions of green jobs, thereby making any comparison of their results difficult. In addition, Horbach et al. (2015) present an extensive overview of related studies with a focus on employment in a circular economy.[53]

Only a few studies use the task-based approach, usually at the occupational level. Consoli et al. (2016) work with U.S. O*NET data[54], comparing differences between green and non-green occupations in terms of skill contents and human capital. They find that occupations with green tasks require more high-level cognitive skills, interpersonal skills, along with higher levels of education, work experience, and on-the-job training.

Vona et al. (2017), who also work with O*NET data, discover that the proportion of green employment is between two and three percent, and that the green wage premium is about four percent. They also report that green jobs are more regionally concentrated than comparable non-green ones and that the greenest regions are mostly high-tech. Vona et al. (2015) show that green skills (i.e., what I call "green tasks" in this paper) are high-level analytical and technical know-how related to the design, production, management, and monitoring of technology.

Peters (2014), who analyzes roughly 1,000 O*NET occupations using text-mining methods, counts 176 occupations with at least one green task, 70 of which involve

[53] The concept of the circular economy, which is part of the sustainability strategy of the European Union (EC 2015), is an essential element of the green economy. The Ellen MacArthur Foundation (2015: p. 5) defines a circular economy as one that is "restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (see also Ghisellini et al. 2016 and Lieder and Rashid 2016 for extensive literature reviews).

[54] See also Dierdorff et al. (2009) and The National Center for O*NET Development (2010a).

considerable green work. These “green-intense” occupations generally have good working conditions, with predominantly full-time jobs, above-average salaries, and health insurance. Peters reports positive employment prospects for all green jobs, even with the new employment growth lagging behind other sectors. He also finds that green jobs are accessible to disadvantaged workers with limited training and experience and that, while green jobs are mostly male-dominated, they are ethnically diverse.

This literature review reveals the lack of a standard definition for "green tasks.” Those based on U.S. O*NET data work a positive list of tasks that are presumably “green.”—a list developed by the O*NET Green Task Development Project (National Center for O*NET Development 2010a, 2010b). However, the developers of the O*NET do not precisely define what a “green task” is (Dierdorff et al. 2009; National Center for O*NET Development 2010a).

My paper is the first to propose a definition of *green tasks* and implement a new task-based approach to identifying the greenness and greening of jobs. By combining a new indicator with administrative employment data from Germany, I create and analyze a unique dataset, one that facilitates econometric analyses of the relationship between the greenness and greening of jobs and labor market outcomes.

6.2.2 Previous analytical findings and theoretical framework

This subsection provides the theoretical framework for the econometric model and presents related analytical findings from the literature.

The strive towards a greener economy is supposed to have a considerable impact on the labor market. These labor market impacts may be attributable to the interplay among the drivers of a greening economy (e.g., environmental regulation, sustainable consumption), innovation processes (e.g., eco-innovations, technological change), and economic outcomes (e.g., competitiveness, productivity). Porter/Van der Linde (1995) point out that environmental regulations may promote innovation and thus improve competitiveness—as long as the regulations are well designed. Acemoglu et al. (2012, 2016) also stress the high importance of directed technical change, arguing that a combination of both environmental regulation (e.g., carbon taxes) and temporary research subsidies may lead to climate protection and sustainable long-run growth.

These positive expectations about the reconciliation of ecology and economy are in contrast to scientific papers that present a more static model of the economy where regulations inherently lead to a loss of competitiveness–and thus to a decrease in labor demand—or which at least do not find these positive impacts (e.g., Jaffe/Palmer 1997; Becker/Henderson 2000; Greenstone 2002). Another reason for possible low employment effects—particularly for technology-related green jobs—comes from Peters (2014), who points out that the numbers of jobs created for green energy should be small because energy technologies are generally capital-intensive.

Moreover, Deschenes (2013) argues, that drawing a definitive conclusion on the employment potential of green policies is difficult and calls for more careful and detailed empirical studies to learn more about the labor market impacts of green jobs. However, it is challenging to identify green jobs at all and—given the fact that many jobs are not 100 percent green or 100 percent non-green—it is even more challenging to measure the greenness of jobs and its development over time. The application of *GOJI* presented in this paper helps to tackle the problem of measuring the greening of jobs. Furthermore, this paper contributes to the literature about how to analyze the labor market impacts of the greening of jobs.

Besides the changes due to a greening of the economy, I consider also the structural change due to employment polarization and technological progress. (see Autor et al. 2003; Autor 2013; Autor/Dorn 2013; Goos et al 2014; Autor 2015). Employment polarization is defined as the rising employment percentages in the highest and lowest paid occupations due to the shift in labor demand towards non-routine tasks. Due to technological progress, new digital technologies, replace repetitive, routine tasks that are mainly performed by medium-skilled occupations. In contrast, new digital technologies complement non-routine cognitive tasks predominantly used in high-skill occupations (Acemoglu/Autor 2011; Autor et al. 2003; Autor, 2013; Autor/Dorn 2013). Consequently, workers in occupations with a large percentage of routine tasks show a higher risk of being replaced by computer algorithms or robots (Acemoglu/Restrepo 2018; Blien/Ludewig 2017; Dauth et al. 2017; Dengler/Matthes 2018a/b). This structural change has also to be taken into account when analyzing the labor market impacts of the greening of jobs, because it runs parallel to the greening processes and may interact with them. . Therefore, the model that I use also takes into account the task contents and the digital tools usage in occupations.

Looking at analytical findings on green jobs and labor market impacts, Pollack (2012), who works with U.S. data, reports that, in terms of employment, green sectors grew faster between 2000 and 2010 than the economy as a whole. For every percentage-point increase in a sector’s green intensity (i.e., the percentage of employment in green jobs), annual employment growth was 0.034 percentage points stronger. Furthermore, green sectors had a larger proportion of workers without a college degree. For every percentage-point increase in green intensity in a given industry, there was a corresponding 0.28 percentage-point increase in the proportion of jobs in that sector held by workers without a four-year college degree. Pollack also reports that manufacturing plays an important role in the green economy, providing 20.4 percent of green jobs while accounting for only 10.8 percent of total private employment.

However, Elliot/Lindley (2017) relativize these findings, showing that Pollack’s results are largely driven by a limited sample of small industries. They work with a larger sample and put green goods and services into a Cobb-Douglas production function, empirically finding that there is a negative correlation between productivity growth and green employment intensity. Furthermore, for industries that have significantly increased their technology investment and generally grown relatively faster overall, have grown more slowly in the production of environmental protection goods and services. These results largely support those of Becker/Shadbegian (2009), who find no differences between environmental product manufacturers and other manufacturers in terms of wages, employment, production, and exports. Indeed, Becker/Shadbegian (2009) show that the only difference between these two groups of firms is that environmental product manufacturers employ fewer workers in production.

Analyzing the spatial distribution of green jobs, Elliott/Lindley (2017) and Weinstein et al. (2010) reveal a widespread spatial distribution of green jobs in the U.S. in 2010. Analyzing the distribution of green jobs in Ohio, Weinstein/Partridge (2010) show a strong heterogeneity even within U.S. states. Vona et al. (2017) investigate the employment effects of green jobs local U.S. labor markets, revealing that, among others, local subsidies have the strongest impact on the creation of green jobs, whereas direct changes in environmental regulation are a secondary force. As the literature shows the importance of the spatial distribution of green jobs, I also consider regional data in the analytical part of this paper.

In general, eco-innovation appears to be closely linked with the creation of green jobs. For example, Cecere/Mazzanti (2017) investigate the relationship between green jobs and eco-innovations in European small and medium-sized firms, showing that green innovation is highly important for the formation of green jobs. They report that the decision to hire workers for green jobs is primarily driven by the interaction between an eco-management system and product and service innovations. For 2001 and 2008, Gagliardi et al. (2016) also find that the emergence of eco-innovation has considerably contributed to long-run job creation in Germany. This positive influence of eco-innovation is shown both for product innovation (Horbach 2010) and process innovation (Horbach/Rennings 2013). Horbach (2010) finds that this positive effect of eco-product innovation is even greater than in other non-eco-innovation fields. Licht/Peters (2014) confirm that while both environmental and non-environmental product innovations are correlated with employment growth, non-eco product innovations are more likely to increase employment.

Based on cross sectional and panel data analysis, my paper examines the interrelationships between the greenness of jobs and labor market outcomes, hereby contribution to the analytical literature.

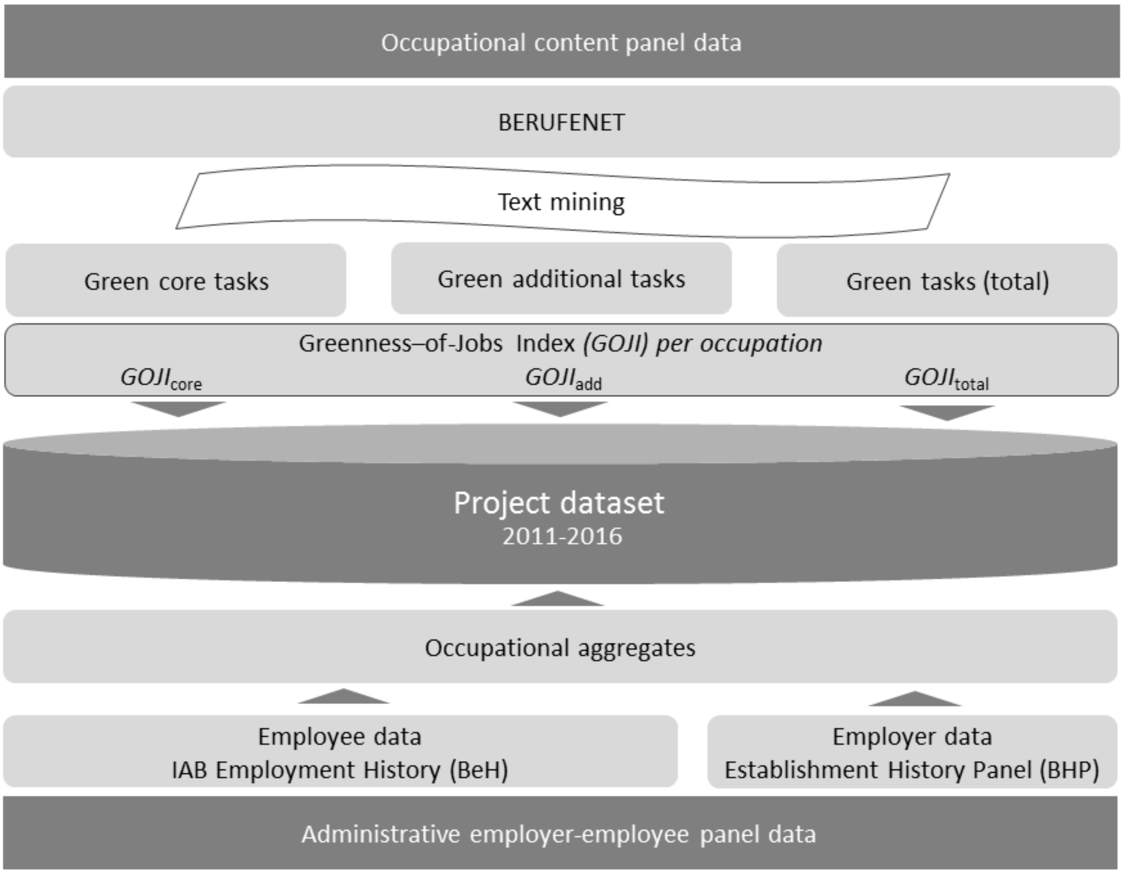
6.3 Data

6.3.1 Overview

I link the Greenness-of-Jobs Index *GOJI* (see chapter 5) with administrative employer-employee data. The occupational aggregates of these micro-data and the *GOJI* form the basis for the econometric analyses. Figure 6-1 provides an overview of the data sources. The BERUFENET is an occupational expert database provided by the Federal

Employment Agency in Germany. This data source and the GOJI have already been introduced in chapter 5. The administrative data sources are described in the remainder of this section.

Figure 6-1: The project dataset



Source: Author's illustration.

6.3.2 Administrative micro data for econometric analyses

The IAB Employment History (Beschäftigten-Historik—BeH) is a research dataset based on administrative data gathered by the Federal Employment Agency. It covers employee biographies from 1975 to the latest available data (here: 2016) of every employee subject to German social insurance contributions[59].

The main source of the BeH are mandatory annual notifications and (de-)registrations of firms to the health insurance institutions. The BeH contains variables about personal characteristics (e.g., age, gender, education, place of residence), individual employment characteristics (e.g., gross wages, tenure, staring/ending date), occupation characteristics (current occupation, occupational status), and some basic employer information (e.g., location, sector, establishment identification number). I apply common imputation

[59] Owing to this restriction, the BeH does not include data about civil servants, people doing military service, self-employed people etc. Detailed information about the BeH can be found in the description of the Sample of Integrated Labour Market Biographies (SIAB) by Antoni et al. (2016).

procedures suggested by Fitzenberger et al. (2005) to improve the BeH education variable and by Gartner (2005) to impute wages above the social security contribution assessment threshold.

The present paper uses the full sample of all BeH employees aggregated at the 5-digit level of the KldB2010 (“occupational panel“). Because the earliest BERUFENET data are from 2006, I set up a BeH panel dataset starting from 2006 to 2016 (the most recent data available). I aggregate the individual employee data at occupational level. This step leads to variables containing information about the composition of persons who work in the specific occupation (e.g., the percentage of female workers in the occupation “chimney sweep”) and information about the median wage wages and wage distribution within every occupation.

The Establishment History Panel (Betriebs-Historik-Panel—BHP) provides a full sample of every German establishment that employs at least one worker liable for social security contributions or at least one marginal part-time worker. It is based on aggregated data of the BeH at establishment level. This yearly panel includes all German establishments that are listed in the BeH on every June 30th. Corresponding to the BeH data, I choose 2006 as the first year of the BHP for my project dataset.

The BHP comprises data about establishment size, establishment years, location, sector affiliation, and worker compositions in terms of qualifications, age, gender, and wages. Eberle/Schmucker (2017) provide further information about this comprehensive dataset. Similar to the BEH data, I also aggregate the BHP data at occupational level. At the end of this procedure, I yield percentages of firm characteristics for every occupation (e.g., the average size of establishments that employ “environmental management officer”).

6.4 Econometric analysis

6.4.1 Empirical approach

Two steps are necessary to answer the question whether occupations with larger greenness or greening show larger labor market outcomes: First, cross-sectional data regressions analyze the associations between the ***greenness*** of occupations (level of *GOJI*) and labor market outcomes. Second, panel data regressions (here: yearly data from 2012 to 2016) examine the relation of the ***greening*** of occupations (growth of *GOJI*) labor market outcomes. The estimates should serve as a first example for the application of the *GOJI* in empirical research. In this paper, the labor market outcomes cover both employment and wage growth.

As the question of this paper focuses on occupational labor market outcomes, I define the occupational level as the level of modelling and analysis. In consequence, the results of this paper can only be interpreted at the occupational level, i.e. the interpretation for the individual level is not possible. Otherwise this would lead to an ecological fallacy, i.e. the improper deduction of results from the occupational level to the individual level leads to wrong conclusions (Freedman 2004). This will be taken into account in the discussion of the empirical results.

In any case, the analysis at occupational level is the best option to tackle the research questions of this paper, i.e. to analyze the relationships between changes of occupational contents (greening of occupations) and labor market changes at occupational level (growth of employment and average wages of green(ing) occupations). A similar research design at occupational level is applied by Dengler/Matthes (2018). The main difference in their case is the focus on another current occupational change, the substitutability risks of occupational tasks due to new digital technologies. One variable of interest (employment growth) and some parts of the data source (BERUFENET, Occupational Panel derived by aggregating BeH) overlap clearly. Dengler/Matthes (2018) prove in their article that the occupational level is valuable perspective for analyzing occupational developments, especially for first exploration of new developments based on new data. For both their and my research topic, the analysis of labor market outcomes at the individual level is the obvious next step and remains a promising field for future research.

To estimate the associations between the $GOJI$ and employment and wage growth, I apply employment growth regressions and Mincer-type wage regressions at occupational level. In all models presented below, $Y_{occ\,t}$ represents the specific response variable of the model. Depending on the labor market outcome of interest it covers either $EMP_{occ\,t}$ or $WAGE_{occ\,t}$, where $EMP_{occ\,t}$ is the total of full-time equivalents and $WAGE_{occ\,t}$ the median of daily wages of male full-time workers in order to facilitate the comparison between occupations. The subscript *occ* stands for the occupation at *5*-digit level of KldB2010. ***t*** stands for time and comprises yearly values. The base year t for the cross-sectional analysis is 2012, whereas the years used in the panel data analysis cover 2012-2016. The growth rates $\Delta Y_{occ\,2012-2016}$ are calculated as follows:

$$\Delta Y_{occ\,2012-2016} = (Y_{occ\,2016} - Y_{occ\,2012})/Y_{occ\,2012}$$

$GOJI_{occ\,t}$ represents the variable of interest, i.e., the *GOJI* in three variations: $GOJI_{total}$ is based on both core and additional requirements, $GOJI_{core}$ is based on core requirements and $GOJI_{add}$ is based on additional requirements. As mentioned above, the ***greenness*** of occupations is measured by the level of *GOJI* (here: in 2012) and the ***greening*** of occupations comprises the change of *GOJI* over time (here: 2012-2016).

$X_{occ\,t}$ covers the control variables including the composition of employment, employee, employer, tasks, tools, regional, and sectoral characteristics for each occupation *occ* and year *t*. In models with employment growth as dependent variable, the lagged occupational wage level (represented by the median daily wage of full-time male workers) is also included. For the fixed effects regression I only include those control variables that vary over time. A comprehensive list of all control variables is part of the sample description (Table 6-2).

Greenness of occupations and labor market outcomes: cross-sectional data analysis

As equation 6.1 shows, I estimate the correlation between the greenness of occupations in 2012 and employment and wage growth of the time period from 2012 to 2016 based on OLS regressions. For these regressions, I estimate the following model:

$$\Delta Y_{occ\,2012-2016} = \beta_0 + \beta_1 GOJI_{occ\,2012} + \beta_2 X_{occ\,2012} + \varepsilon_{occ\,2012} \quad (6.1)$$

where $\Delta Y_{occ\,2012-2016}$ is the difference of $Y_{occ\,2016} - Y_{occ\,2012}$. As $Y_{occ\,t}$ represents the specific response variable of the model, the model can be differentiated according to employment and wage growth:

$$\Delta EMP_{occ\,2012-2016} = \beta_0 + \beta_1 GOJI_{occ\,2012} + \beta_2 X_{occ\,2012} + \varepsilon_{occ\,2012} \quad (6.1.1)$$

$$\Delta WAGE_{occ\,2012-2016} = \beta_0 + \beta_1 GOJI_{occ\,2012} + \beta_2 X_{occ\,2012} + \varepsilon_{occ\,2012} \quad (6.1.2)$$

Greening of occupations and labor market outcomes: panel data analysis

The employment effects of the change of greenness (*greening*) are estimated by a fixed effects (FE) estimation (equation 6.2). This approach uses yearly panel data between 2012 and 2016. I estimate

$$Y_{occ\,t} = \beta_0 + \beta_1\, GOJI_{occ\,t} + \beta_2 X_{occ\,t} + \gamma_{occ} + \delta_t + \varepsilon_{occ\,t} \quad (6.2)$$

where γ_{occ} and δ_t comprise the occupation- and time-fixed effects. The error term $\varepsilon_{occ\,t}$ covers the residuals. The panel data model can also be differentiated according to employment and wage growth:

$$EMP_{occ\,t} = \beta_0 + \beta_1\, GOJI_{occ\,t} + \beta_2 X_{occ\,t} + \gamma_{occ} + \delta_t + \varepsilon_{occ\,t} \quad (6.2.1)$$

$$WAGE_{occ\,t} = \beta_0 + \beta_1\, GOJI_{occ\,t} + \beta_2 X_{occ\,t} + \gamma_{occ} + \delta_t + \varepsilon_{occ\,t} \quad (6.2.2)$$

In the fixed effects regression, $EMP_{occ\,t}$ and $WAGE_{occ\,t}$ represent the natural logarithms of these variables.

6.4.2 The sample for econometric analysis

For the econometric analysis in this paper I use an occupational panel dataset for the years 2011 to 2016. As described in detail in the data section, this panel is based on a full sample of public-register data at worker level from the German IAB Employment History (BeH) dataset. To prepare the econometric analysis it is necessary to select a clearly defined sample.

The *non-green* sample group covers the occupations that have already existed since 2012 or longer and had a $GOJI_{total}$ value of 0 in 2012. In contrast, the *green* group comprises those occupations that have also existed since 2012 or longer but had a $GOJI_{total}$ value larger than zero in 2012. I drop all occupations with missing values in the dummy variable *Dgreen2012*.

As Table 6-2 shows, this decision affects 39 of the 5,741 observations, which are dropped from the sample. Hence, the econometric analysis provides no information about the employment effects of new occupations. This might be a worthwhile issue for future research.

Table 6-1: Sample groups—Number of occupations with $GOJI_{total}$ = 0 (Non-green) or $GOJI_{total}$ > 0 (Green) in 2012

		Number of occupations—selection by: Dummy variable Dgreen2012 (Non-green = $GOJI_{total\ 2012}$ = 0; Green = $GOJI_{total\ 2012}$ >0)			
Year	**Non-green (0)**	**Green (1)**	**Sample (0+1)**	**Missing (.)**	**Total**
2012	784	362	1,146	1	1,147
2013	782	361	1,143	9	1,152
2014	777	361	1,138	11	1,149
2015	778	360	1,138	7	1,145
2016	777	360	1,137	11	1,148
Total	3,897	1,804	5,702	(to drop:) 39	5,741

Sources: IAB Employment History (Beschäftigten-Historik—BeH), BERUFENET, own calculations.

Table 6-2 describes the sample by comparing non-green and green occupations in 2012 and 2016, showing all available variables, including the absolute values and the delta values for 2012 to 2016 as percentages. As I restrict the analysis to the base year of 2012, the sample is not refilled if occupations disappear between 2012 and 2016. Consequently, both sample groups decrease slightly in number from 784 to 777 (non-green) and 362 to 360 (green). Both groups may experience greening or degreening between 2012 and 2016 or may just keep the same $GOJI_{total}$ value of 2012. The potential transitions of the $GOJI_{total}$ values and their relations to employment growth are covered by fixed effects regressions, which are presented in the next subsection.

Table 6-3 shows similarities and marked raw differences between characteristics of occupational sample groups: in terms of the number of employees (total of full-time equivalents FTE), in 2016 the non-green group accounts for 77.0 percent (21.037M FTE) of the sample and the green group 23.0 percent (6.290M FTE). In the context of FTE, the group of green occupations shows an overall raw employment growth of 4.5 percent between 2012 and 2016, which is 0.7 percentage points smaller than the employment growth of the non-green group (5.2 percent). The larger difference in headcount growth between the green and the non-green groups (1.9 percentage points less in the non-green group) reflects the percentage of full-time employment: the non-green group has a larger percentage of part-time employees than the green group and the gap between the two groups even increased between 2012 and 2016. Consequently, the raw growth difference between the non-green and green groups is larger when measuring employment per head count.

Looking at wages—for comparison reasons I only use the imputed (and non-inflation adjusted) wages of full-time male workers here—both groups report a raw wage growth between 2012 and 2016, which generally reflects the positive wage development during this time. The workers in the non-green occupation group saw a slightly larger raw wage growth than those in the green occupation group (delta value of median of imputed log wages: 0.1 percentage points). In general, there is a large raw wage gap between the groups: at 116.76 EUR, the median daily wage of male full-time workers in the non-green group in 2016 is about 15.7 percent larger than that of this employee group in green occupations (98.44 EUR). Obviously, this large raw wage gap is driven, among other things, by the larger percentage of highly educated employees, which was 21.0 percent in the non-green group and 11.4 percent in the green group in 2016.

Besides the data on employee numbers and wages, there are plenty of control variables that help to explain the differences between the groups of non-green and green occupations. In terms of the composition of employment characteristics, the green group has a larger percentage of full-time employees and of fixed-term contracts, but also a larger percentage of workers in marginal employment. However, the percentage of temporary agency work is smaller in green occupations than in non-green occupations.

The employee characteristics of occupations also reveal a pronounced heterogeneity between the non-green and green group: green occupations seem to have a good absorption capacity for older employees, as the proportion of this group in the green occupations is about 17 percent higher. In contrast, the non-green occupations employ about 22 percent more employees who are younger than 30. The percentage of middle-aged workers as well as the average tenure are at a similar level. The green occupations are so far relatively male-dominated, because the percentage of female workers is about 50 percent smaller than in the non-green occupations group. The finding is in line with the literature, which also claims that institutional changes should be undertaken in order to motivate women to work in green occupations. This claim is supported by the results of Horbach and Jacob (2018), who find that a large proportion of highly educated women and a gender diverse board of directors is positively linked to the realization of eco-innovations.

There seems to be particularly strong demand—and thus employment opportunities—not only for older workers but also for low-skilled workers in green occupations, as their percentage is substantially larger than it is in the group of non-green occupations. In turn, the latter have a larger percentage of highly educated workers (non-green: 21.0 percent; green: 11.4 percent in 2016). Of course—like any aggregated characteristic—these values vary between each individual occupation.

Looking at the composition of occupational characteristics, the requirement level corresponds to the distribution of the education level: the green group has more unskilled and semi-skilled occupations and specialist occupations, whereas in the non-green group more workers are employed in complex specialist occupations and highly complex occupations. In terms of the average number of tasks and tools, the groups are relatively similar, but the task types vary strongly. Non-green occupations involve larger percentages of non-routine analytical tasks and non-routine interactive tasks, whereas the group of green occupations has a much higher percentage of non-routine manual tasks.

Overall, the group of green occupations has about ten percent fewer routine tasks (cognitive and manual). This indicates that green occupations entail a lower risk of being replaced by computer algorithms and/or robots.

So far, however, the group of green occupations has a far smaller percentage of IT-aided and IT-integrated ("industry 4.0") digital tools. The interactions of the three trends of digitalization, routine biased technological change and the greening of the economy raises several interesting questions that cannot be covered by this paper, but shall be analyzed in more detail in future research.

The composition of employer characteristics in the two groups also reveals pronounced differences and similarities: the largest percentage of small establishments is found in the group of green occupations, whereas the percentage of medium-sized firms is at the same level for green and non-green occupations. The percentage of larger establishments is greater in the group of non-green occupations. The establishment-age composition is similar in both groups, indicating the same trend towards a larger percentage of older establishments. Looking at the differences in establishment size, it is no surprise that workers in green occupations are employed in establishments that pay lower wages (about ten percent less than the average wages in non-green occupations).

The sectoral distributions vary considerably within and between the groups. In general, green occupations are more prevalent in the primary sector and to some extent in the secondary sector. In contrast, the non-green occupations are prevailing in the tertiary sector. Within the group of green occupations, the industries with the largest percentages are manufacturing, construction, as well as administrative and support service activities. The green occupations have higher percentages in in the following industry sections: "agriculture, forestry, and fishing", "electricity, gas, steam, and air conditioning supply", "water supply, sewerage, waste management, and remediation activities", "construction", "transportation and storage", "real estate activities" as well as "administrative and support service activities".

With respect to the regional distribution of occupations, the non-green group is more prevalent in core cities, while the green group has larger percentages in rural districts. The category between these, "urbanized districts", is equally occupied by both groups. The comparison of the distribution across federal states shows that green occupations have a higher percentage of employees in northern and especially eastern Germany. However, the larger percentage of green occupations in the eastern part of Germany decreased between 2006 and 2012. This may be due to the strong drop in the number of jobs in the eastern German solar industry. Besides the eastern German states, there are three western states with higher percentages of green than non-green occupations: Schleswig-Holstein, Lower Saxony, and Rhineland-Palatinate. The other states generally have similar or slightly higher percentages of non-green occupations. Only the city states of Berlin and Hamburg have far higher percentages of non-green occupations.

Finally, the *GOJI* composition delivers some further insights: about two percent of occupations that were non-green in the base year of 2012 have since become green. Additionally, two percent of the occupations that were already green in 2012 became greener between 2012 and 2016.

The occupations with a *GOJI* larger than zero can be also distinguished by their percentages of core tasks and additional tasks as well as by their green tasks categories (links to more than one category are possible). In 2016, 60.2 percent of green occupations have $GOJI_{core}$ (covering only core tasks) larger than zero and 80.2 percent of green occupations have a $GOJI_{add}$ (covering only additional tasks) larger than zero. The green tasks categories of "building", "circular economy", and "mobility and tourism" are the ones with the highest percentages of *green task*-specific $GOJI_{total}$ values larger than zero.

To work out the relationship between the greenness and greening of jobs and employment growth, it is necessary to disentangle the different determinants by applying econometric methods. This last analytical step is described in the next section.

Table 6-2: Sample description: sample size, number of employees, and sample means

	Non-green and green occupations 2012 and 2016 Non-green: $GOJI_{total\ 2012} = 0$; Green: $GOJI_{total\ 2012} > 0$					
	NON-GREEN	GREEN	NON-G.	GREEN	NON-G.	GREEN
	2012	2012	2016	2016	Δ2012-16	Δ2012-16
Variable (Label)	abs.	abs.	abs.	abs.	Δin %	Δin %
Sample size: Number of observations						
Occupations existing in 2012 (N)	784	362	777	360	-	-
Number of employees						
Total full-time equivalents	19.995M	6.020M	21.037M	6.290M	5.2%	4.5%
Total headcount	22.810M	6.978M	24.154M	7.260M	5.9%	4.0%
Wages of full-time male workers						
Imputed log wages of male full-time workers (median)	4.626	4.468	4.697	4.540	1.5%	1.6%
Imputed wages of male full-time workers (median)	108.397	91.444	116.759	98.443	7.7%	7.7%
Employment characteristics						
Normal employment	0.957	0.933	0.964	0.944	0.7%	1.1%
Marginal employment	0.043	0.067	0.036	0.056	-15.7%	-15.7%
Full-time	0.801	0.827	0.788	0.823	-1.7%	-0.5%
Permanent contract	0.888	0.903	0.846	0.864	-4.7%	-4.4%
Fixed-term contract	0.112	0.097	0.154	0.136	37.6%	40.7%
Temporary agency work	0.034	0.025	0.034	0.023	-1.6%	-5.9%
Employee characteristics						
Employee age group: 16 to <30 years	0.198	0.149	0.192	0.149	-3.2%	-0.1%
Employee age group: >=30 to <50 y.	0.523	0.517	0.483	0.471	-7.5%	-9.0%

	Non-green and green occupations 2012 and 2016 Non-green: $GOJI_{total\ 2012} = 0$; *Green:* $GOJI_{total\ 2012} > 0$					
	NON-GREEN	GREEN	NON-G.	GREEN	NON-G.	GREEN
	2012	2012	2016	2016	Δ2012-16	Δ2012-16
Variable (Label)	abs.	abs.	abs.	abs.	Δin %	Δin %
Employee age group: >=50 y.	0.279	0.334	0.325	0.380	16.3%	14.0%
Tenure (average years)	6.458	6.492	6.653	6.637	3.0%	2.2%
Women	0.488	0.230	0.487	0.226	-0.4%	-1.6%
Foreign nationality	0.077	0.095	0.098	0.132	27.0%	38.1%
Education level						
Low education	0.091	0.116	0.106	0.142	16.6%	22.6%
Medium education	0.717	0.778	0.684	0.744	-4.6%	-4.4%
High education	0.192	0.106	0.210	0.114	9.2%	7.9%
Occupational characteristics						
Requirement level						
Unskilled/semi-skilled occupation	0.155	0.172	0.157	0.174	1.2%	0.9%
Specialist occupation	0.572	0.635	0.560	0.627	-2.1%	-1.3%
Complex specialist occupation	0.134	0.116	0.137	0.117	2.5%	0.7%
Highly complex occupation	0.139	0.077	0.146	0.083	4.8%	7.5%
Tasks characteristics						
Tasks complexity / N of tasks	18.554	18.637	19.381	19.040	4.5%	2.2%
Number of core tasks	8.119	8.708	8.340	8.863	2.7%	1.8%
Number of additional tasks	10.435	9.928	11.041	10.178	5.8%	2.5%
Tasks-type: Non-routine analytical	0.269	0.166	0.279	0.172	3.5%	3.9%
Tasks-type: Non-routine interactive	0.150	0.037	0.151	0.037	0.5%	0.5%
Tasks-type: Routine cognitive	0.302	0.251	0.290	0.248	-3.7%	-1.4%
Tasks-type: Routine manual	0.125	0.120	0.125	0.127	-0.4%	5.5%
Tasks-type: Non-routine manual	0.154	0.426	0.155	0.416	1.0%	-2.3%
Tools characteristics						
Tools complexity: N of work tools	7.648	9.314	7.660	9.272	0.2%	-0.5%
Dig. tools percentage (total)	0.343	0.202	0.344	0.206	0.5%	1.8%
Dig. tools percentage 1: IT-aided tools	0.322	0.192	0.323	0.195	0.4%	1.8%
Dig. tools percentage 2: IT-integrated t.	0.021	0.010	0.021	0.010	1.9%	0.3%
plus 27 variables for the *GOJI* composition—see Appendix (Table 6-6)						
Employer characteristics						
Establishment size 1-49	0.383	0.454	0.356	0.423	-7.2%	-6.8%
Establishment size 50-449	0.397	0.370	0.383	0.358	-3.5%	-3.4%
Establishment size >500	0.220	0.176	0.261	0.219	18.9%	24.7%

	Non-green and green occupations 2012 and 2016 Non-green: $GOJI_{total\ 2012} = 0$; Green: $GOJI_{total\ 2012} > 0$					
	NON-GREEN	GREEN	NON-G.	GREEN	NON-G.	GREEN
	2012	2012	2016	2016	Δ2012-16	Δ2012-16
Variable (Label)	abs.	abs.	abs.	abs.	Δin %	Δin %
Establishment age 0-10	0.247	0.246	0.171	0.163	-30.8%	-33.8%
Establishment age 11-20	0.228	0.249	0.223	0.228	-2.3%	-8.5%
Establishment age >20	0.525	0.505	0.606	0.609	15.5%	20.7%
Average daily wage in establishment	99.741	89.901	105.898	94.914	6.2%	5.6%
Avg. age of workers in establishment	41.302	42.481	41.650	42.897	0.8%	1.0%
Sectoral composition						
Basic sectoral composition						
Primary sector	0.006	0.015	0.007	0.014	2.3%	-5.6%
Secondary sector	0.283	0.403	0.275	0.398	-2.9%	-1.3%
Tertiary sector	0.710	0.583	0.718	0.588	1.2%	1.0%
plus 21 variables for sector composition at WZ-1 level (industry sections)— see Appendix (Table 6-6)						
Regional composition						
Regional types						
Core cities	0.380	0.326	0.382	0.328	0.5%	0.8%
Urbanized districts	0.356	0.354	0.355	0.356	-0.2%	0.5%
Rural distr. with features of concentration	0.145	0.170	0.145	0.169	-0.4%	-0.5%
Rural districts-sparsely populated	0.119	0.150	0.118	0.147	-0.6%	-2.4%
Federal states groups						
North	0.156	0.165	0.156	0.168	0.5%	1.8%
West	0.350	0.338	0.346	0.335	-1.0%	-1.1%
East	0.181	0.211	0.180	0.204	-0.5%	-3.1%
South	0.314	0.285	0.317	0.293	1.2%	2.5%
plus 16 variables for the regional composition at NUTS-1 level (fed. states)— see Appendix (Table 6-6)						

Sources: IAB Employment History (Beschäftigten-Historik—BeH), BERUFENET, own calculations.

6.4.3 Estimation results

Table 6-4 presents the coefficients of greenness (OLS, Column 1 and 2) and greening (FE, Column 3 and 4) of occupations with employment growth as dependent variable. The variables of interest are $GOJI_{total\ 2012}$ (Column 1) or $GOJI_{core\ 2012}$ and $GOJI_{add\ 2012}$ (Column 2), respectively. The coefficient for $GOJI_{total\ 2012}$ in Column (1) is 0.238 and highly significant at the 1 percent level. The regression results reported in Column (2) contain $GOJI_{core\ 2012}$ and $GOJI_{add\ 2012}$, but in this case only the coefficient of 0.246 for $GOJI_{add\ 2012}$ is significantly different from zero (at 1 percent level). The GOJI covers continuous values between 0 and 1 that can be interpreted as percentage values. The results in Columns (1) and (2) indicate that if the $GOJI_{total}$ or $GOJI_{add}$ value rises by one percentage point, the employment growth is related with an increase of 0.238 or 0.246 percentage points respectively. It is obvious that the positive relation of $GOJI_{total}$ and employment growth is largely driven by the proportion related to green additional tasks, represented by the coefficient of $GOJI_{add}$.

Column (3) and (4) of Table 6-4 report the results of the fixed effects estimation using yearly panel data from 2012 to 2016. The coefficients of the GOJI variations indicate the associations between the growth of GOJI (*greening*) and the employment growth. According to Table 6-4, the FE estimation gives negative, but statistically insignificant coefficients of $GOJI_{total}$ (Column 3) and $GOJI_{core}$ /$GOJI_{add}$ (Column 4). Since institutional changes at the occupational level are often slow, the observation period available so far might be too short for delivering representative findings about the greening of jobs on employment growth. The development of data material for further years might improve this situation. This remains an open point for future research.

To sum up, the level of greenness—measured by OLS estimation—is associated with a positive and highly significant growth in employment, whereas the growth of greenness over time (greening of jobs)—measured by FE estimation— points to a negative correlation but is statistically not significant.

Table 6-3: *GOJI* and employment growth: Estimation results

Dependent variables:	GREENNESS 2012 (level) OLS Full-time equivalents (pp, delta 2012-2016)		GREENING 2012-2016 (growth) FE Full-time equivalents (log, yearly panel 2012-2016)	
	(1)	(2)	(3)	(4)
$GOJI_{total}$ Green tasks total	0.238*** (2.60)		-0.230 (-1.58)	
$GOJI_{core}$ Green core tasks		-0.005 (-0.06)		-0.058 (-1.31)
$GOJI_{add}$ Green additional tasks		0.246*** (2.72)		-0.102 (-1.05)
Constant	0.430 (1.63)	0.429 (1.60)	13.24*** (22.60)	13.25*** (22.59)
Control variables of occupational characteristics are included (employee, employer, employment, tasks, tools, (lagged) wage, regional, and sectoral characteristics). The FE regression also contains time dummies for the years 2013-2016. Full regression results: see Appendix (Table 6-7).				
N	1146	1146	5699	5699
R^2	0.491	0.492	0.613	0.613

Note: Robust standard errors. t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01. Full regression results: see Appendix, Table 6-7. Source: IAB Employment History (Beschäftigten-Historik—BeH), BERUFENET, own calculations.

Turning to the wage development, the OLS estimations in Table 6-5 report a statistically insignificant coefficient for $GOJI_{total}$ (Column 1), but show significant results for $GOJI_{core}$ and $GOJI_{add}$. Interestingly, $GOJI_{core}$ returns a positive value of 0.069, whereas $GOJI_{add}$ returns a negative value -0.083. In other words, a $GOJI_{core}$ in 2012 that is larger by 1 percentage point is associated with a slight increase of wage growth by 0.07 percentage points. Contrary, a $GOJI_{add}$ in 2012 larger by 1 percentage point is related with a slight decrease of wage growth by 0.08 percentage points. The difference between $GOJI_{core}$ and $GOJI_{add}$ might be explained by variations in productivity related to those tasks or occupations respectively. As there is no data available about related productivity so far, the analysis of the exact reasons for the wage differences between core and additional requirements is also left to future research.

Table 6-4: *GOJI* and wage growth: Estimation results

	GREENNESS 2012 (level)		GREENING 2012-2016 (growth)	
Dependent variables:	OLS Daily Wage (pp, delta 2012-2016)		FE Daily Wage (log, yearly panel 2012-2016)	
	(1)	(2)	(3)	(4)
$GOJI_{total}$ Green tasks total	-0.009 (-0.17)		0.098** (2.01)	
$GOJI_{core}$ Green core tasks		0.069** (2.03)		0.001 (0.01)
$GOJI_{add}$ Green additional tasks		-0.083* (-1.93)		0.062 (1.35)
Constant	0.018 (0.11)	0.014 (0.09)	5.747*** (11.38)	5.733*** (11.28)
Control variables of occupational characteristics are included (employee, employer, employment, tasks, tools, regional, and sectoral characteristics). The FE regression also contains time dummies for the years 2013-2016. Full regression results: see Appendix (Table 6-8).				
N	1137	1137	5702	5702
R^2	0.452	0.456	0.694	0.694

Note: Robust standard errors. t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01. Full regression results: see Appendix, Table 6-8. Source: IAB Employment History (Beschäftigten-Historik—BeH), BERUFENET, own calculations.

Looking at the greening of occupations, Table 6-5 reports in Column (3) a positive $GOJI_{total}$ coefficient of 0.098 that is statistically significant at the five percent level, whereas the FE estimation results in Column (4) show coefficients of $GOJI_{core}$ and $GOJI_{add}$ that are positive, but not significantly different from zero. It can therefore be stated that growth of the $GOJI_{total}$ by 1 percentage point between 2012 and 2016 is accompanied by a wage growth of 0.098 percent in this period.

One possible explanation for the relatively small coefficients in the field of labor market outcomes might be the short time period from 2012 to 2016, which might be not long enough to identify larger effects. Furthermore in some fields of activity the argument put forward by Peters (2014) might play a role. He states that the numbers of jobs created on account of green energy should be rather small because energy technologies are generally capital-intensive. This might also rule for other technology-intensive field of activity, too. But this interesting aspect will also be reserved for future research. As already mentioned above, the results of this paper can only be interpreted at the professional level and not at the individual or establishment level. Otherwise this would lead to an ecological fallacy.

The results presented show that there is obviously a large potential of the new index and also a need for further empirical analyses at individual level.

From a methodical point of view, the empirical results suggests that the set of $GOJI_{core}$ and $GOJI_{add}$ should be applied to measure wage developments related to the greenness of jobs, whereas $GOJI_{total}$ might be the better choice to measure the relation between the greening of occupations and employment growth.

6.5 Conclusions

This paper describes and analyzes the greenness and greening of jobs and its relationships to labor market outcomes. In other words, it contributes to the literature by analyzing the associations between the Greenness-of-Jobs index *GOJI* and employment as well as wage growth by applying econometric analyses.

In order to analyze these relationships, OLS and FE regressions are applied. The econometric analysis uses a novel data source, linking the *GOJI* with occupation panel data based on a full sample of individual employment data from 2011 to 2016.

The estimation results show a small positive and statistically highly significant association between the total greenness of occupations (level of $GOJI_{total}$) and employment growth. The coefficient of $GOJI_{total}$ may be interpreted such that one percentage point higher $GOJI_{total}$ value is accompanied by a 0.22 percent increase in employment growth. When differentiating between the two sub-indices $GOJI_{core}$ and $GOJI_{add}$, the results show that the positive correlation between the greenness-of-jobs and employment growth is mainly driven by the percentages of green additional tasks.

The OLS analysis of greenness and wage growth reveals the importance of differentiating between core and additional requirements. A $GOJI_{core}$ in 2012 that is larger by 1 percent is associated with a slight increase of wage growth by 0.07. Contrary, a $GOJI_{add}$ in 2012 larger by 1 percent is related with a slight decrease of wage growth by 0.08 percent. The reasons for this mixed effects should be analyzed in future research. In terms of the relationship between greening of occupations and wage growth, the results from FE estimation are clearer: an increase of $GOJI_{total}$ by 1 percent between 2012 and 2016 is accompanied by wage growth of 0.10 percentage points.

The econometric results also demonstrate the potential of the new index for empirical studies in general. For example, the *GOJI* can be applied to examine the impact of environmental regulation on the greenness of jobs, the effects of a firm’s greenness composition on productivity, or the interplay between local economic development and the regional greenness of jobs.

The practical and political implications of the results of this paper are as follows:

The general message of the econometric results is that the greenness of jobs is related to a moderate increase of employment growth and the greening of jobs is associated with a moderate increase of wage growth. Only the level of $GOJI_{add}$ is conjoined with a slight slowdown of wage growth. An in-depth analysis of this phenomenon is an interesting issue for future research.

The economic significance of the results is relatively small in the short time period observed. This is not bad news at all, because the overall results of this paper show that green transitions and labor market outcomes can even positively interrelate with each other.

Nevertheless, there is still a need to prevent threats of individuals to lose their employability through these transitions. Hence, the most important objective for labor market policy should be to support the green adaptation of occupations, employees, and employers to the changing needs of the labor market. This includes both continuous structural reforms of occupational contents and institutions as well as the use of existing active labor market policy instruments such as the promotion of further training, retraining and life-long learning.

6.6 Appendix of chapter 6

Table 6-5: Extension for sample description: Sectoral composition and regional composition of non-green occupations and green occupations 2012 and 2016

	Selection by $GOJI_{total}$ in 2012 (Non-green: $GOJI_{total\ 2012}$=0; *Green:* $GOJI_{total\ 2012}$> 0)					
	NON-GREEN	GREEN	NON-G.	GREEN	NON-G.	GREEN
	2012	2012	2016	2016	Δ2012-16	Δ2012-16
Variable (Label)	abs.	abs.	abs.	abs.	Δin %	Δin %
Sectoral composition						
Agriculture, forestry and fishing	0.006	0.015	0.007	0.014	2.3%	-5.6%
Mining and quarrying	0.003	0.003	0.002	0.003	-24.0%	-12.0%
Manufacturing	0.244	0.199	0.237	0.196	-3.0%	-1.4%
Electricity, gas, steam and air conditioning supply	0.007	0.012	0.006	0.011	-6.8%	-7.8%
Water supply, sewerage, waste management and remediation	0.005	0.021	0.005	0.021	-0.5%	0.3%
Construction	0.025	0.168	0.025	0.167	0.5%	-0.6%
Wholesale and retail trade, repair of motor vehicles and motorcycles	0.161	0.089	0.156	0.084	-3.3%	-5.5%
Transportation and storage	0.034	0.123	0.035	0.128	2.3%	3.8%
Accommodation and food service	0.042	0.018	0.043	0.018	2.4%	5.4%
Information and communication	0.039	0.007	0.040	0.006	4.0%	-15.0%
Financial and insurance activities	0.041	0.003	0.039	0.003	-5.8%	-7.9%
Real estate activities	0.006	0.019	0.006	0.020	0.1%	1.7%
Professional, scientific and technical activities	0.067	0.044	0.072	0.046	8.3%	6.1%
Administrative and support service activities	0.056	0.139	0.056	0.145	-0.1%	4.1%
Public administration and defense, compulsory social security	0.052	0.052	0.053	0.052	1.2%	-1.0%
Education	0.036	0.021	0.038	0.021	5.8%	-0.5%
Human health and social work	0.136	0.036	0.143	0.036	4.7%	-0.4%
Arts, entertainment and recreation	0.011	0.006	0.011	0.006	0.8%	-3.3%

	Selection by *GOJI_{total}* in 2012 (Non-green: *GOJI_{total 2012}*=0; *Green: GOJI_{total 2012}*> 0)					
	NON-GREEN	GREEN	NON-G.	GREEN	NON-G.	GREEN
	2012	2012	2016	2016	Δ2012-16	Δ2012-16
Variable (Label)	abs.	abs.	abs.	abs.	Δin %	Δin %
Other service activities	0.028	0.023	0.026	0.022	-7.1%	-4.2%
Activities of households as employers, undiff. goods & services	0.001	0.001	0.001	0.001	2.4%	-10.6%
Activities of extraterritorial organizations and bodies	0.001	0.001	0.001	0.001	-27.1%	-29.1%
Regional composition						
Schleswig Holstein	0.028	0.033	0.028	0.034	-0.5%	2.0%
Hamburg	0.031	0.025	0.031	0.025	0.7%	1.6%
Lower Saxony	0.086	0.098	0.087	0.100	0.8%	2.0%
Bremen	0.010	0.009	0.010	0.010	-0.3%	0.6%
North Rhine-Westphalia	0.214	0.205	0.212	0.202	-1.0%	-1.8%
Hesse	0.080	0.074	0.080	0.075	-0.6%	1.6%
Rhineland-Palatinate	0.043	0.046	0.042	0.046	-1.0%	-0.9%
Baden-Württemberg	0.144	0.129	0.145	0.132	0.5%	2.4%
Bavaria	0.169	0.156	0.172	0.161	1.7%	2.7%
Saarland	0.013	0.013	0.012	0.012	-3.6%	-5.9%
Berlin	0.041	0.037	0.044	0.038	5.6%	2.8%
Brandenburg	0.025	0.033	0.024	0.032	-2.2%	-4.4%
Mecklenburg Western Pomerania	0.017	0.022	0.017	0.021	-2.6%	-4.1%
Saxony	0.048	0.056	0.048	0.055	-0.9%	-2.6%
Saxony-Anhalt	0.024	0.032	0.023	0.030	-4.6%	-5.9%
Thuringia	0.025	0.030	0.025	0.028	-2.6%	-6.3%
Goji composition						
goji0_0	0.000	0.072	0.002	0.072	N/A	-1.0%
goji0_1	0.000	0.053	0.000	0.056	N/A	5.6%
goji0_2	0.000	0.074	0.002	0.069	N/A	-7.0%
goji1_0	0.000	0.004	0.000	0.003	N/A	-18.9%
goji2_0	0.000	0.018	0.000	0.018	N/A	2.2%
goji3_0	0.000	0.015	0.000	0.015	N/A	4.8%
goji4_0	0.000	0.004	0.000	0.003	N/A	-7.4%
goji5_0	0.000	0.001	0.000	0.002	N/A	40.7%
goji6_0	0.000	0.007	0.000	0.007	N/A	-7.6%
goji7_0	0.000	0.017	0.000	0.016	N/A	-5.7%
goji8_0	0.000	0.007	0.000	0.007	N/A	2.9%
D1goji0_0	0.000	1.000	0.059	0.996	N/A	-0.4%
D1goji0_1	0.000	0.579	0.018	0.602	N/A	4.0%
D1goji0_2	0.000	0.816	0.057	0.802	N/A	-1.8%
D1goji1_0	0.000	0.117	0.004	0.115	N/A	-1.4%
D1goji2_0	0.000	0.265	0.015	0.283	N/A	6.8%
D1goji3_0	0.000	0.284	0.007	0.315	N/A	11.0%
D1goji4_0	0.000	0.081	0.030	0.079	N/A	-2.4%
D1goji5_0	0.000	0.062	0.012	0.103	N/A	67.9%
D1goji6_0	0.000	0.139	0.013	0.162	N/A	17.3%
D1goji7_0	0.000	0.332	0.001	0.314	N/A	-5.4%
D1goji8_0	0.000	0.166	0.019	0.178	N/A	7.3%
Dnongreensteady	0.939	0.000	0.940	0.000	0.1%	N/A

Variable (Label)	Selection by $GOJI_{total}$ in 2012 (Non-green: $GOJI_{total\ 2012}$=0; Green: $GOJI_{total\ 2012}$> 0) NON-GREEN 2012 abs.	GREEN 2012 abs.	NON-G. 2016 abs.	GREEN 2016 abs.	NON-G. Δ2012-16 Δin %	GREEN Δ2012-16 Δin %
Dgreensteady	0.000	0.905	0.000	0.906	N/A	0.1%
Dgreening	0.019	0.020	0.019	0.020	3.8%	0.6%
Ddegreening	0.000	0.071	0.000	0.069	N/A	-1.7%
Dblsgreenenhanced	0.019	0.020	0.019	0.020	3.8%	0.6%

Source: IAB Employment History (Beschäftigten-Historik—BeH), own calculations.

Table 6-6: GOJI and employment growth: Full estimation results

Dependent variables:	**GREENNESS 2012 (level)** **OLS** **Full-time equivalents** **(pp, delta 2012-2016)**		**GREENING 2012-2016 (growth)** **FE** **Full-time equivalents** **(log, yearly panel 2012-2016)**	
	(1)	**(2)**	**(3)**	**(4)**
$GOJI_{total}$ Green tasks total	0.238*** (2.60)		-0.230 (-1.58)	
$GOJI_{core}$ Green core tasks		-0.005 (-0.06)		-0.058 (-1.31)
$GOJI_{add}$ Green additional tasks		0.246*** (2.72)		-0.102 (-1.05)
Imputed log wages of male full-time workers—median (lagged)	0.007 (0.17)	0.008 (0.17)	-0.030 (-1.00)	-0.030 (-1.00)
Employment age group 16 - <30 years	0.082 (0.60)	0.096 (0.69)	0.536*** (2.71)	0.534*** (2.69)
Employment age group >= 50 years	-0.387*** (-2.79)	-0.376*** (-2.71)	-1.565*** (-8.36)	-1.561*** (-8.31)
Tenure	-0.023*** (-3.67)	-0.024*** (-3.73)	-0.059*** (-5.70)	-0.059*** (-5.73)
Women	-0.130*** (-3.90)	-0.128*** (-3.83)	0.324 (1.26)	0.322 (1.24)
Foreign nationality	-0.098 (-0.65)	-0.075 (-0.49)	0.084 (0.34)	0.089 (0.36)
Low education	0.216 (1.32)	0.208 (1.27)	-0.580** (-2.13)	-0.586** (-2.15)
High education	0.030 (0.72)	0.028 (0.67)	-0.250 (-1.05)	-0.248 (-1.04)
Establishment size 1-49	-0.206*** (-4.92)	-0.211*** (-4.96)	0.716*** (4.10)	0.719*** (4.12)
Establishment size >500	-0.223*** (-4.33)	-0.226*** (-4.31)	0.383*** (2.81)	0.385*** (2.82)
Establishment age 0-10 years	0.124 (0.86)	0.105 (0.74)	-0.187** (-2.30)	-0.189** (-2.31)
Establishment age > 20 years	0.115 (1.05)	0.105 (0.96)	0.131*** (2.95)	0.130*** (2.99)
Marginal Employment	-0.290* (-1.95)	-0.283* (-1.91)	0.640 (1.51)	0.639 (1.51)
Part-time work	0.163** (2.08)	0.164** (2.09)	0.555** (2.08)	0.557** (2.09)

Dependent variables:	GREENNESS 2012 (level) OLS Full-time equivalents (pp, delta 2012-2016)		GREENING 2012-2016 (growth) FE Full-time equivalents (log, yearly panel 2012-2016)	
	(1)	(2)	(3)	(4)
Fixed-term contract	-0.261*** (-2.67)	-0.279*** (-2.89)	0.068 (0.35)	0.072 (0.37)
Unskilled/semi-skilled occupation	0.027 (1.32)	0.031 (1.47)	N/A	N/A
Complex specialist occupation	-0.020 (-1.19)	-0.021 (-1.24)	N/A	N/A
Highly complex occupation	-0.034 (-1.25)	-0.035 (-1.29)	N/A	N/A
Tasks complexity (Number of tasks$_{total}$)	-0.0024** (-2.48)	-0.002** (-2.32)	-0.001 (-0.91)	-0.001 (-0.91)
Percentage of non-routine analytical tasks	0.239*** (6.41)	0.241*** (6.42)	0.161** (2.24)	0.159** (2.21)
Percentage of non-routine interactive tasks	0.147*** (3.04)	0.148*** (3.08)	0.065 (0.75)	0.063 (0.72)
Percentage of routine cognitive tasks	0.101*** (3.17)	0.100*** (3.09)	0.010* (1.90)	0.097* (1.86)
Percentage of non-routine manual tasks	0.131*** (3.98)	0.133*** (4.01)	0.186*** (4.27)	0.185*** (4.25)
Tools complexity (Number of tools$_{total}$)	0.001 (1.00)	0.001 (1.03)	N/A	N/A
$dtox_{IT\text{-}add}$: percentage of IT-aided digital tools	-0.027 (-0.39)	-0.021 (-0.29)	N/A	N/A
$dtox_{IT\text{-}int}$: percentage of IT-integrated digital tools	0.108 (0.71)	0.097 (0.65)	N/A	N/A
Mining and quarrying	-0.302** (-2.44)	-0.294** (-2.39)	0.595 (0.75)	0.555 (0.70)
Manufacturing	-0.033 (-0.62)	-0.026 (-0.50)	-0.790 (-1.52)	-0.804 (-1.54)
Electricity, gas, steam, and air conditioning supply	-0.014 (-0.14)	-0.038 (-0.38)	-2.382** (-2.23)	-2.382** (-2.22)
Water supply, sewerage, waste management, and remediation activities	-0.274*** (-2.89)	-0.192** (-2.15)	-1.723 (-1.38)	-1.736 (-1.39)
Construction	-0.141*** (-2.76)	-0.139*** (-2.74)	-0.950 (-1.50)	-0.977 (-1.54)
Wholesale and retail trade, repair of motor vehicles, and motorcycles	-0.141*** (-2.63)	-0.136** (-2.54)	-0.766 (-1.31)	-0.782 (-1.33)
Transportation and storage	-0.109 (-1.62)	-0.110 (-1.63)	-0.492 (-0.89)	-0.510 (-0.91)
Accommodation and food service activities	-0.147** (-2.45)	-0.149** (-2.52)	-0.480 (-0.60)	-0.496 (-0.62)
Information and communication	-0.142* (-1.68)	-0.140* (-1.67)	-0.862* (-1.65)	-0.878* (-1.67)
Financial and insurance activities	-0.179*** (-2.83)	-0.176*** (-2.81)	-2.170*** (-3.08)	-2.190*** (-3.09)
Real estate activities	0.209** (2.40)	0.205** (2.41)	-0.698 (-0.95)	-0.711 (-0.97)
Professional, scientific, and technical activities	-0.056 (-0.75)	-0.054 (-0.71)	-0.742 (-1.43)	-0.758 (-1.45)

Dependent variables:	GREENNESS 2012 (level) OLS Full-time equivalents (pp, delta 2012-2016)		GREENING 2012-2016 (growth) FE Full-time equivalents (log, yearly panel 2012-2016)	
	(1)	(2)	(3)	(4)
Administrative and support service activities	-0.167*** (-2.73)	-0.168*** (-2.70)	-0.824* (-1.65)	-0.843* (-1.67)
Public administration and defense, compuls. social security	0.003 (0.05)	0.006 (0.11)	-1.068** (-1.98)	-1.080** (-2.00)
Education	0.071 (1.08)	0.078 (1.18)	-1.849*** (-3.16)	-1.867*** (-3.17)
Human health and social work activities	-0.009 (-0.17)	-0.005 (-0.09)	0.030 (0.05)	0.019 (0.03)
Arts, entertainment, and recreation	-0.143** (-2.10)	-0.136** (-2.00)	-2.038*** (-2.95)	-2.056*** (-2.96)
Other service activities	-0.092 (-1.42)	-0.090 (-1.39)	-2.389*** (-3.45)	-2.391*** (-3.45)
Activities of households as employers, undifferentiated goods and services	0.175 (0.70)	0.164 (0.66)	-0.409 (-0.25)	-0.421 (-0.26)
Activities of extraterritorial organizations and bodies	1.656 (1.63)	1.601 (1.56)	2.343 (0.91)	2.396 (0.93)
Urbanized districts	-0.043 (-0.46)	-0.077 (-0.82)	-1.168*** (-5.55)	-1.166*** (-5.53)
Rural districts with features of concentration	-0.167 (-1.35)	-0.181 (-1.46)	-1.365*** (-3.92)	-1.364*** (-3.90)
Rural districts-sparsely populated	0.0093 (0.07)	0.023 (0.18)	-2.217*** (-5.76)	-2.221*** (-5.76)
Western fed. states: North Rhine-Westphalia, Hesse, Rhineland-Palatinate, Saarland	-0.213* (-1.81)	-0.197* (-1.66)	0.455* (1.95)	0.456* (1.95)
Eastern fed. states: Berlin, Brandenburg, Mecklenburg Western Pomerania, Saxony,	-0.066 (-0.63)	-0.062 (-0.59)	0.189 (0.73)	0.198 (0.76)
Southern fed states: Baden-Wuertemberg, Bavaria	0.073 (0.72)	0.093 (0.91)	0.306 (1.13)	0.310 (1.15)
Dummy 2013	N/A	N/A	0.039*** (8.15)	0.039*** (8.09)
Dummy 2014	N/A	N/A	0.080*** (8.96)	0.080*** (8.88)
Dummy 2015	N/A	N/A	0.102*** (8.14)	0.102*** (8.06)
Dummy 2016	N/A	N/A	0.125*** (7.81)	0.124*** (7.73)
Constant	0.430 (1.63)	0.429 (1.60)	13.24*** (22.60)	13.25*** (22.59)
N	1146	1146	5699	5699
R^2	0.491	0.492	0.613	0.613

Note: t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01. *Reference groups:* Employee age group: >=30-<50 years; Medium education; Establishment size 50-499; Establishment age 11-20 years; Specialist occupation; Percentage of routine manual tasks; Agriculture, forestry, and fishing; Core cities; Dummy 2012. *Source:* IAB Employment History (Beschäftigten-Historik—BeH), own calculations.

Table 6-7: *GOJI* and wage growth: Full estimation results

Dependent variables:	GREENNESS 2012 (level) OLS - Daily Wage (pp, delta 2012-2016)		GREENING 2012-2016 (growth) FE - Daily Wage (log, yearly panel 2012-2016)	
	(1)	(2)	(3)	(4)
$GOJI_{total}$ Green tasks total	-0.009 (-0.17)		0.098** (2.01)	
$GOJI_{core}$ Green core tasks		0.069** (2.03)		0.001 (0.01)
$GOJI_{add}$ Green additional tasks		-0.083* (-1.93)		0.062 (1.35)
Employment age group 16 - <30 years	-0.109* (-1.77)	-0.119** (-1.97)	0.179 (1.46)	0.181 (1.48)
Employment age group >= 50 years	-0.097 (-1.48)	-0.105* (-1.66)	0.123 (1.24)	0.122 (1.24)
Tenure	0.008*** (3.13)	0.008*** (3.21)	0.005 (0.90)	0.005 (0.91)
Women	-0.062*** (-3.77)	-0.064*** (-3.92)	0.047 (0.27)	0.047 (0.27)
Foreign nationality	0.082 (0.94)	0.071 (0.82)	-0.318** (-2.35)	-0.320** (-2.37)
Low education	-0.008 (-0.10)	0.001 (0.02)	-0.223 (-1.32)	-0.220 (-1.31)
High education	0.001 (0.08)	0.001 (0.07)	0.235** (2.41)	0.234** (2.40)
Establishment size 1-49	0.051** (2.25)	0.055** (2.42)	-0.417*** (-4.01)	-0.418*** (-3.99)
Establishment size >500	0.018 (0.76)	0.022 (0.93)	0.086 (1.34)	0.086 (1.32)
Establishment age 0-10 years	0.137* (1.76)	0.147* (1.96)	-0.066 (-1.20)	-0.065 (-1.18)
Establishment age > 20 years	0.085 (1.52)	0.092* (1.74)	-0.066** (-2.22)	-0.065** (-2.19)
Marginal Employment	0.056 (0.84)	0.050 (0.75)	-0.254 (-1.22)	-0.252 (-1.21)
Part-time work	0.106*** (2.77)	0.108*** (2.82)	0.495*** (3.50)	0.494*** (3.49)
Fixed-term contract	0.014 (0.36)	0.022 (0.58)	-0.152** (-2.12)	-0.154** (-2.15)
Unskilled/semi-skilled occupation	-0.040*** (-3.67)	-0.042*** (-3.79)	N/A	N/A
Complex specialist occupation	-0.006 (-0.85)	-0.006 (-0.78)	N/A	N/A
Highly complex occupation	0.002 (0.13)	0.002 (0.21)	N/A	N/A
Tasks complexity (Number of $tasks_{total}$)	0.000 (0.78)	0.000 (0.58)	0.000 (0.83)	0.000 (0.86)
Percentage of non-routine analytical tasks	0.049** (2.37)	0.049** (2.39)	-0.111 (-0.99)	-0.108 (-0.95)
Percentage of non-routine interactive tasks	0.087*** (3.68)	0.087*** (3.72)	-0.187** (-2.07)	-0.186** (-2.06)
Percentage of routine cognitive tasks	0.055*** (3.14)	0.057*** (3.31)	-0.129 (-1.49)	-0.128 (-1.47)
Percentage of non-routine manual tasks	0.058*** (3.06)	0.057*** (3.06)	-0.013 (-0.32)	-0.014 (-0.37)

Dependent variables:	GREENNESS 2012 (level) OLS - Daily Wage (pp, delta 2012-2016) (1)	(2)	GREENING 2012-2016 (growth) FE - Daily Wage (log, yearly panel 2012-2016) (3)	(4)
Tools complexity (Number of tools$_{total}$)	0.000 (0.14)	0.000 (0.16)	N/A	N/A
$dtox_{IT\text{-}add}$: percentage of IT-aided digital tools	0.006 (0.17)	0.002 (0.08)	N/A	N/A
$dtox_{IT\text{-}int}$: percentage of IT-integrated digital tools	-0.027 (-0.34)	-0.021 (-0.26)	N/A	N/A
Mining and quarrying	-0.054 (-1.45)	-0.060 (-1.59)	-0.218 (-0.47)	-0.193 (-0.41)
Manufacturing	-0.082*** (-3.21)	-0.084*** (-3.22)	0.164 (0.52)	0.179 (0.56)
Electricity, gas, steam, and air conditioning supply	-0.090** (-2.02)	-0.075* (-1.68)	0.329 (0.85)	0.336 (0.86)
Water supply, sewerage, waste management, and remediation activities	-0.036 (-1.07)	-0.061* (-1.82)	0.192 (0.46)	0.201 (0.48)
Construction	-0.112*** (-5.04)	-0.110*** (-4.88)	-0.213 (-0.62)	-0.193 (-0.56)
Wholesale and retail trade, repair of motor vehicles, and motorcycles	-0.129*** (-4.90)	-0.130*** (-4.90)	0.048 (0.14)	0.065 (0.19)
Transportation and storage	-0.150*** (-4.46)	-0.149*** (-4.46)	-0.678* (-1.94)	-0.659* (-1.86)
Accommodation and food service activities	-0.050* (-1.81)	-0.048* (-1.77)	0.010 (0.02)	0.0228 (0.04)
Information and communication	-0.155*** (-3.98)	-0.154*** (-3.97)	0.007 (0.02)	0.021 (0.07)
Financial and insurance activities	-0.107*** (-4.09)	-0.107*** (-4.07)	-0.293 (-0.78)	-0.276 (-0.73)
Real estate activities	-0.211*** (-3.73)	-0.202*** (-3.78)	-0.005 (-0.01)	0.02 (0.05)
Professional, scientific, and technical activities	-0.124*** (-3.97)	-0.124*** (-3.93)	-0.111 (-0.36)	-0.096 (-0.31)
Administrative and support service activities	-0.125*** (-4.13)	-0.122*** (-4.09)	-0.172 (-0.55)	-0.156 (-0.49)
Public administration & defense, compulsory social security	-0.088*** (-3.26)	-0.088*** (-3.28)	-0.587* (-1.75)	-0.577* (-1.70)
Education	-0.120*** (-3.60)	-0.122*** (-3.63)	-0.572 (-1.58)	-0.557 (-1.52)
Human health and social work activities	-0.094*** (-3.11)	-0.094*** (-3.11)	-0.725* (-1.86)	-0.715* (-1.82)
Arts, entertainment, and recreation	-0.073** (-2.04)	-0.075** (-2.10)	-1.000** (-2.10)	-0.984** (-2.06)
Other service activities	-0.048 (-1.57)	-0.048 (-1.55)	-0.625 (-1.55)	-0.622 (-1.54)
Activities of households as employers, undifferentiated goods and services	0.076 (0.30)	0.079 (0.31)	0.116 (0.14)	0.132 (0.16)
Activities of extraterritorial organizations and bodies	-1.170 (-1.42)	-1.146 (-1.40)	-1.583 (-0.70)	-1.555 (-0.69)
Urbanized districts	0.0028 (0.06)	0.025 (0.53)	-0.186** (-2.01)	-0.186** (-2.01)

Dependent variables:	GREENNESS 2012 (level) OLS - Daily Wage (pp, delta 2012-2016)		GREENING 2012-2016 (growth) FE - Daily Wage (log, yearly panel 2012-2016)	
	(1)	(2)	(3)	(4)
Rural districts with features of concentration	0.00751 (0.12)	0.0186 (0.31)	0.151 (0.83)	0.152 (0.83)
Rural districts-sparsely populated	0.084 (1.03)	0.072 (0.87)	-0.542*** (-2.81)	-0.541*** (-2.81)
Hamburg	0.181 (0.94)	0.184 (0.97)	-0.426 (-0.94)	-0.428 (-0.95)
Lower Saxony	-0.034 (-0.19)	-0.029 (-0.17)	-0.898** (-2.09)	-0.897** (-2.09)
Bremen	-0.078 (-0.25)	-0.083 (-0.27)	-0.921** (-2.05)	-0.927** (-2.07)
North Rhine-Westphalia	-0.056 (-0.35)	-0.062 (-0.39)	-0.849** (-2.28)	-0.848** (-2.29)
Hesse	0.044 (0.25)	0.034 (0.20)	-0.479 (-1.27)	-0.480 (-1.27)
Rhineland-Palatinate	-0.051 (-0.31)	-0.060 (-0.37)	-0.747** (-2.05)	-0.748** (-2.06)
Baden-Wuerttemberg	-0.055 (-0.34)	-0.071 (-0.44)	-0.572 (-1.50)	-0.575 (-1.51)
Bavaria	-0.016 (-0.10)	-0.026 (-0.17)	-0.676* (-1.84)	-0.679* (-1.85)
Saarland	-0.261 (-0.89)	-0.298 (-1.01)	-0.230 (-0.29)	-0.230 (-0.29)
Berlin	0.462** (2.29)	0.462** (2.30)	-1.425*** (-3.39)	-1.432*** (-3.42)
Brandenburg	-0.150 (-0.75)	-0.167 (-0.85)	-0.565 (-1.19)	-0.560 (-1.18)
Mecklenburg Western Pomerania	-0.312 (-1.30)	-0.299 (-1.24)	-0.824 (-1.27)	-0.816 (-1.26)
Saxony	0.100 (0.58)	0.094 (0.56)	-1.153*** (-3.03)	-1.154*** (-3.04)
Saxony-Anhalt	0.044 (0.19)	0.048 (0.21)	-1.389*** (-2.84)	-1.399*** (-2.87)
Thuringia	-0.275 (-1.40)	-0.254 (-1.31)	-1.196** (-2.23)	-1.201** (-2.24)
Dummy 2013	N/A	N/A	0.019*** (7.57)	0.019*** (7.59)
Dummy 2014	N/A	N/A	0.042*** (10.23)	0.042*** (10.25)
Dummy 2015	N/A	N/A	0.059*** (9.66)	0.059*** (9.67)
Dummy 2016	N/A	N/A	0.057*** (6.99)	0.057*** (7.02)
Constant	0.0181 (0.11)	0.0145 (0.09)	5.747*** (11.38)	5.733*** (11.28)
N	1137	1137	5702	5702
R^2	0.452	0.456	0.694	0.694

Note: t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01. Reference groups: Employee age group: >=30-<50 years; Medium education; Establishment size 50-499; Establishment age 11-20 years; Specialist occupation; Percentage of routine manual tasks; Agriculture, forestry, and fishing; Core cities; Schleswig Holstein; Dummy 2012. Source: IAB Employment History (Beschäftigten-Historik—BeH), own calculations.

7 Summary and conclusions

This dissertation presents new insights about the relationship between environmental sustainability and the labor market. It introduces new approaches to analyze the environmental sector and to measure the greenness of occupations in the whole economy. Based on these approaches, I contribute new insights on the associations between environmental sustainability and direct labor market outcomes such as employment growth and wages.

The key research goal of this doctoral thesis was to analyze the associations between the transitions towards environmental sustainability and labor market outcomes. The second goal—and also an important prerequisite for answering the first question—was to identify the methodological question of how to identify environmental protection activities and related employers, employees or occupational changes in administrative labor market data. To follow these research goals, I provide five related but mutually independent chapters, comprising a framework chapter and four empirical studies of the relationship between environmental sustainability and the labor market.

Chapter 2 introduces the overall topic of "Environmental sustainability and the labor market," including a detailed literature review. Chapters 3 to 6 provide four studies with different perspectives on the research subject: While chapter 3 examines sector-specific wage differentials in the context of renewable energy value chains, chapter 4 addresses the entire field of the environmental goods and services sector (EGSS) and analyzes the role of innovation and agglomeration for employment growth in the EGSS. The two following chapters cover the economy as a whole: Chapter 5 presents the new occupational Greenness-of-Jobs Index (*GOJI*), comprising comprehensive descriptive evidence at occupational, sectoral and regional level. Applying the GOJI for the first time in econometric analyses, chapter 6 investigates the greening of occupations and its correlations with employment and wages.

In the remainder of this last chapter, I briefly summarize the main results of the empirical studies before deriving overall conclusions and discussing possible policy implications from these findings.

The hidden winners of renewable energy promotion: Insights into sector-specific wage differentials

In the first study, I start with one single but very essential subfield of the EGSS, the renewable energies, with a focus on sector specific wage-differentials. My coauthors Manfred Antoni, Florian Lehmer and I develop a novel data set by linking company-level information from the German Renewable Energy Federation with administrative establishment-level data from the Institute for Employment Research. The descriptive evidence shows significant differences between renewable energy establishments and their sector peers with regard to wages and several other characteristics. Our estimates provide evidence that it is mostly human capital and other establishment-level characteristics that explain the wage differential between manufacturers and energy providers. However, we find a persistent 'renewable energy wage premium' of more than ten percent in construction/installation activities and architectural/engineering services. We interpret this premium as a positive indirect effect of the promotion of renewable energies for the benefit of employees in renewable energy establishments within these two sectors.

The role of innovation and agglomeration for employment growth in the environmental sector

The second study covers the entire EGSS, analyzing the role of innovation and agglomeration for employment growth in that sector. This work, written together with Jens Horbach, is based on linked employment and regional data for Germany. The descriptive results show that the environmental sector is characterized by disproportionately high employment growth. The application of a generalized linear mixed model reveals that especially innovation and industry agglomeration foster employment growth in establishments in the environmental sector. Establishments with no green products or services exhibit a smaller increase in employment, even if they are also innovative.

The GOJI and the greening of jobs in Germany: First evidence from a text mining based index and employment register data

Chapters 5 and 6 deal with the economy as a whole and examine the greening of occupations and its correlation with employment and wages. The key element of these two single-author papers is the new task-based Greenness-of-Jobs index (*GOJI*). The *GOJI* is derived by performing text mining algorithms on yearly data from BERUFENET, an occupational data base provided by the German Federal Employment Agency, covering 2006 and the period from 2011 to 2016. The descriptive results of the paper show that there is a notable greening of jobs which varies strongly between sectors and regions. Based on employment register data from 2011 to 2016, the econometric analysis reveals that the overall level of the greenness of occupations is positively correlated with employment growth. Furthermore, increasing greenness is related to a slight rise in wage growth.

Overall conclusions and policy implications

The research questions and data sources used in this thesis vary widely. Therefore, I am careful with generalizable conclusions. Every empirical study of this thesis shows to some extent positive raw labor market outcomes. However, every study also shows that the characteristics of employers, employees and occupations explain a large share of the positive raw employment outcomes. The "non-green" comparison groups mostly show similar positive trends in the observed time range. In most cases, the green and non-green groups show relatively similar developments in terms of employment and wage growth.

Nevertheless, considering the overall net outcomes of the studies presented, i.e. after controlling for the relevant observables, the empirical findings indicate mostly small, but positive direct labor market correlations with transitions towards environmental sustainability. In some sectors, there are even larger differences, e.g. renewable energy establishments in the construction/installation activities have a net wage differential of about ten percent.

Reflecting the overall results of the studies presented, I propose the following policy implications: Policy-makers should be always aware that a change in environmental policies, such as the reform of feed-in tariffs, can also have an impact on the quantity and quality of jobs. The inclusion of indicators about the quantity and quality of work in the policy assessment would be an appropriate measure to take into account this important social impact of environmental or climate policy. Requirements for the quality of work could be coupled with the evaluation of policy or public tenders, e.g., for energy services. This might promote the positive effects of environmental policies on the labor market.

When policy makers draft or change environmental policies, they should consider the whole value chain, and not only, e.g., producers of a specific technology. The government should improve the availability of open data on the extent of environmental regulation at establishment level. This is necessary to evaluate labor market impacts of environmental policies in more detail. As has already been done in in labor market policy, political decision-makers planning regulations to promote environmental sustainability should already take into account in the planning process how the effects on the labor market can be investigated.

The overall results of this dissertation support the view that environmental or climate policy may yield a dual benefit. Besides positive environmental effects, the environmental sector—or green jobs in general—may also lead to a higher employment growth compared to the rest of the economy. However, this potential employment effect highly depends on the sector or environmental subfields that are supported and, on the innovativeness of the establishments. The results of chapter 4 suggest that if environmental policies aim to realize this potential dual benefit, they should primarily support establishments which are active in innovative environmental fields. Of course this is only one of several crucial dimensions, but according to our findings, it may increase positive employment impacts and thus may help to maximize the dual benefit of environmental sustainability. Furthermore, the promotion of eco-innovation activities, the development and expansion of regional networks and clusters as well as knowledge spillovers between environmental establishments seems to be a promising groundwork for future employment growth in this field.

The descriptive analysis of the *GOJI* distribution revealed a large heterogeneity between occupational aggregates, industries, and regions. This heterogeneity should be kept in mind especially before policy implications are drawn. If the promotion of green jobs is a policy target, the results of this paper suggest that it is more advisable to promote the transformation of existing occupations rather than to design new occupations, though this may be necessary in individual cases. Furthermore, the large heterogeneity of the distribution of the *GOJI* demands a precise alignment of policy instruments.

As shown in the studies, it is possible to identify the actors of greening processes and to measure the greenness and greening of jobs in labor market microdata. The greenness of jobs may even be identified using existing administrative data without expensive surveys and new data sources. This approach might therefore be an efficient way to officially measure the green transitions of employment in Germany. If similar data sources exist in other countries, this approach can be adopted or used for international comparisons. Methodologically, the combination of text mining, index development and aggregation has the potential to be applied to other societal transition processes, e.g., the ongoing digitalization.

The economic significance of the analysis of GOJI and employment outcomes is relatively small in the short time period observed. This is not bad news at all, because the overall results of this paper show that green transitions and labor market outcomes can even positively interrelate with each other.

Nevertheless, there is still a need to prevent threats of individuals to lose their employability through these transitions. Hence, the most important objective for labor market policy should be to support the green adaptation of occupations, employees, and employers to the changing needs of the labor market. This includes both continuous structural reforms of occupational contents and institutions as well as the use of existing active labor market policy instruments such as the promotion of further training, retraining and life-long learning.

The applied data strategies have proven their applicability to empirical questions. Therefore, this dissertation should be seen more as a starting point for future research. The results of every empirical study presented in chapters 3 to 6 can be the basis for numerous follow-up questions. For example, it is a promising field for future research to apply the approaches presented in this dissertation to use the GOJI for evaluating labor market effects of environmental and/or climate policies at worker level.

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Antoni, M.; Janser, M.; Lehmer, F. (2015): The hidden winners of renewable energy promotion: Insights into sector-specific wage differentials. In: *Energy Policy*, 86, 595-613, DOI: https://doi.org/10.1016/j.enpol.2015.07.027.
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Eine Vorversion des Papiers ist als IAB Discussion Paper 16/2015 verfügbar.

Kapitel 5: Eine Vorversion des Kapitels ist Teil des folgenden Diskussionspapiers:

Janser, M. (2018): The greening of jobs in Germany: First evidence from a text mining based index and employment register data. *IAB-Discussion Paper* 14/2018. Nuremberg: IAB. URL: https://iab.de/183/section.aspx/Publikation/k180516302.

Kapitel 6: Eine Vorversion des Kapitels ist Teil des folgenden Diskussionspapiers:

Janser, M. (2018): The greening of jobs in Germany: First evidence from a text mining based index and employment register data. *IAB-Discussion Paper* 14/2018. Nuremberg: IAB. URL: https://iab.de/183/section.aspx/Publikation/k180516302.

Nürnberg, den 5. November 2018 Markus Janser