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Preface

The physical science studying the climate clearly identifies human activities as the main driver of the observed temperature increase since pre-industrial times (Stocker et al. 2013). Also the changes in the climate that we can witness already today are largely driven by human activities (Cubasch et al. 2013). Although already in 1992 nations came together to recognize the climate change problem and declare their determination to protect the climate system to present and future generations, the increasing rate at which emissions have been growing over the years testifies of little progress in this respect (UNFCCC 1992).[1] With the Paris Agreement in 2015 the goal of protecting the climate became more concrete; stating the parties' aim to limit the increase in the global average temperature to below $2°$C and to pursue additional efforts to limit the increase to $1.5°$C (UNFCCC 2015).

If this target is to be met, all current generations have the important task to decisively reduce their carbon footprint, which represents far-reaching challenges for all economic actors at all administrative and regional levels. Companies are required to develop and take up new technologies, implying structural changes in the economy and, as a consequence, in labor demand. Besides facing new structures in the labor market, households are confronted with challenges involving changes in lifestyle, for instance, by adopting alternative mobility forms or assuming a new role as producers in the energy system. Moreover, local and national governments have the important task to set the appropriate framework to induce emissions reductions and to facilitate international cooperation seeking improvements in the effectiveness of the measures taken to combat climate change. Most of these challenges are directly linked to the reduction in the use of fossil fuel resources, thus mastering them will also have implications for resource suppliers and their economic development.

This doctoral thesis provides an analysis of the economic effects associated with selected aspects of this complex set of challenges. Chapter 1 studies the effects of fossil fuel extraction on development outcomes of a supplier country. Although the repercussions of international climate policy for fossil fuel suppliers seem to be negative a priori, the implications for the

[1] While greenhouse gas (GHG) emissions grew on average by 0.4 Gt carbon dioxide equivalent (CO_2eq) per year between 1970 and 2000, the average annual increase from 2000 to 2010 was 1 GtCO_2eq (IPCC 2014).

majority of the population are less clear, since it becomes a new dimension in the light of a potential resource curse. If the extraction of fossil fuels has predominantly deleterious impacts on the economy and general well-being of the population, a declining global fossil fuel demand would not only have positive consequences for the climate but could also have a positive overall effect on the fossil fuel supplier. If the contrary holds and countries benefit from fossil fuel endowments, a declining fossil fuel demand would indeed represent a challenge for the development of the supplier country. Thus, by analyzing the impact of fossil fuel production on economic outcomes, Chapter 1 addresses a question that provides valuable information for the design of a strategy to adapt to international climate policy and the eventual lapse of financial resources stemming from the extraction of fossil fuels.

This thesis then investigates the economic outcomes occurring in the transition from an economy based on fossil fuel use to an economy relying primarily on renewable energy sources. In particular, Chapter 2 analyzes how companies' GHG emissions have developed in response to policies aiming at reducing fossil fuel use by providing financial incentives to expand renewable energy adoption and to improve energy efficiency. Support schemes for renewable energies are currently the most common policy instruments for climate change mitigation. As of 2013, 127 countries had this type of policy in place, while less than 40 countries have implemented explicit prices on GHG emissions either through an emissions trading system or a tax on emissions (Kossoy et al. 2015; REN21 2013; World Bank 2014). Although the implemented renewables deployment policies have allowed their large scale expansion, an important question concerns their performance as measures to reduce GHG emissions, which is the ultimate goal of the transition to renewable energies.[2] In the long run and with high penetration rates, we can expect to see considerable emissions reductions. However, in the transition phase and due to the interplay of the existing structures of the energy system and the expanding renewable technologies, it is not clear a priori whether emission reductions are indeed achieved. An example of the opposite development can be observed for Germany, where the CO_2 intensity of electricity generation increased between 2000 and 2012 despite an increasing renewable penetration (Umweltbundesamt 2015).

A further consideration, which is generally of much interest in the public debate, concerns the effects of the transition to a low-carbon energy system on the local economy, and in

[2] IPCC (2011) documents that this expansion was made possible by the success of deployment policies in lowering the costs of renewables technologies.

particular on employment. Chapter 3 provides a methodology to study the value added and employment effects of increased investments in renewable energies and energy efficiency measures. Furthermore, it tailors the methodology to make it applicable to subnational regions and quantifies the effects of an intended energy transition in three German districts.

In the following, I provide a short overview of each chapter. Based on municipality data for Colombia, Chapter 1, which is single-authored, analyzes the effect of oil production on economic development and considers the role that local institutions play in this context. Although Colombia is not a major producer of oil, royalties and other income associated with oil production are important income sources for the state at all levels (national, departmental, and municipal). For instance, in 2010 the income associated with oil production represented 14.5% of all income sources for the central government and 13.5% for the subnational governments (Olivera et al. 2013). Therefore, a decline in the global demand for oil can be expected to affect the public coffers. To assess the question of a potential resource curse in Colombia, I combine data on the royalties received by municipalities for hydrocarbons extraction with data on three indicators of the development level of municipalities: school enrollment rates, infant mortality rates, and average results of the nationwide school-leaving examination. Importantly, I examine whether the administrative capacity of the municipality (as an indicator of institutional quality) influences the relationship between hydrocarbons production and development outcomes.

I find that secondary enrollment rates improve with increasing royalties and good institutional quality, while the positive effect is weaker when institutional quality is poor. On the contrary, I find the quality of education to suffer from natural resource abundance. Possible underlying mechanisms behind this negative effect might be labor market forces as well as the change in the students' sample composition. According to the former mechanism, a strong resource sector can increase wages in all sectors, and, therefore, the opportunity costs of education (James 2017). With respect to infant mortality rates, I do not find evidence for resource wealth having an effect on this health outcome, which can be explained by high levels of corruption in the health sector, irrespective of natural resource riches (Lewis 2006). In the light of an eventually declining demand for fossil fuels, these findings suggest that the different levels of government should actively promote the consolidation of other sources of financing so that further improvements in enrollment rates are not at risk.

Chapter 2, which was developed in cooperation with Markus Zimmer, assesses the effectiveness of incentive based policy measures beyond carbon pricing in reducing greenhouse gas emissions of companies.[3] We use emissions data for the headquarters and subsidiaries of the world's largest companies in the manufacturing, mining and quarrying, and utilities sector. On the policy side, we consider national measures grouped in different categories: loans and subsidies to increase the use of renewable energies, feed-in tariffs to increase the use of renewable energies, loans and subsidies for combined heat and power generation, financial incentives for energy audits, and loans and subsidies to improve energy efficiency.

We find that financial incentives and legal requirements to audit energy use reduced companies' emissions, whereas support schemes aimed at promoting the combined generation of heat and power initially increased emissions of non-utility companies. Feed-in tariffs aimed at increasing the use of renewable energy sources for electricity generation increased emissions of utility companies in the first years after policy implementation. This finding can be explained by renewable energies crowding out generation by relatively clean but more expensive fossil fuel power stations. We also find loans and subsidies for energy efficiency improvements to increase emissions in the short term, providing weak evidence for a rebound effect. Our findings highlight the importance of considering the possible interactions between planned policies and the prevailing market structures in order to implement mechanisms to avoid unintended outcomes.

The purpose of Chapter 3, which was developed in cooperation with Marie-Theres von Schickfus and Markus Zimmer, is to analyze the economic effects of an energy transition in a subnational region. The Bavarian Oberland region in Germany intends to cover its energy demand by renewable energies by the year 2035, which requires a significant expansion of renewable technologies for electricity and heat generation, investments in electricity storage capacity, as well as improvements in the energy efficiency of buildings. To analyze the effects of the required investments on regional value added and employment divided in three qualification levels (low-skilled, medium-skilled, and high-skilled employment), we consider the investment and the operation phase of the installations. Moreover, we account for the scarcity of financial resources and factors of production, which is an important contribution to the literature on the economic effects of energy policy. Our analysis is based on an own adaptation of the input-output approach developed by Fisher and Marshall (2011), Benz et al. (2014), and

[3] A previous version was published in the CESifo Working Paper series (Montoya Gómez and Zimmer 2017).

von Schickfus and Zimmer (2018), implemented to improve the suitability of the methodology for an analysis at the subnational level. The implication of considering scarcity of financial resources is that investments in renewable energies crowd out consumption by private households and alternative investments. Moreover, the increased capital in the renewable energy sectors attracts factors of production to these sectors weakening production in other sectors.

Our results show that investments conducive to the regional energy transition increase value added and employment in the Bavarian Oberland region, yet, a large fraction of the regional increase is compensated with a decrease in the rest of the country. Moreover, we find that medium-skilled employment increases more strongly than low and high-skilled employment. This finding shows the importance of medium-skilled employment for the success of the energy transition and, in light of the current shortage of medium skilled labor in Germany (Stippler et al. 2019), it calls for an integrated consideration of labor market developments in energy and climate policy design.

Keywords:	Natural resource curse, economic development, subnational analysis, institutions, education, health, climate policy evaluation, greenhouse gas emissions, cross-country micro panel data, companies, firms, renewable energy, factors of production, input-output analysis, multi-regional input-output table, macroeconomic effects, crowding out effects
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Contents

Preface I

Acknowledgements VII

List of Figures XIII

List of Tables XV

1 Natural Resources, Institutions, and Development: A Within-Country Approach 1

1.1 Introduction . . . 1

1.2 Identification strategy . . . 6

1.2.1 Natural resources and development . . . 6

1.2.2 The role of institutions . . . 10

1.2.3 Potential endogeneity issues and treatment . . . 11

1.3 Data . . . 15

1.4 Results . . . 16

1.5 Robustness tests and extensions . . . 22

1.5.1 Endogeneity of institutions . . . 22

1.5.2 Further robustness tests and extensions . . . 26

1.6 Conclusions . . . 29

References . . . 33

2 Assessing the Effects of Climate Policy on Firms' Greenhouse Gas Emissions 39

2.1 Introduction . . . 39

2.2 Data . . . 43

2.2.1 Data sources and description . . . 43

2.2.2 Descriptive statistics . . . 48

2.3 Identificaiton strategy . . . 54

2.3.1 Explaining emissions . . . 54

2.3.2 Controlling for self-selection . . . 57

2.4 Data analysis 59
2.4.1 Estimation results 59
2.4.2 Sensitivity analysis 64
2.5 Conclusions 67
References 69

3 Economic Effects of Regional Energy System Transformations: An Application to the Bavarian Oberland Region 73
3.1 Introduction 73
3.2 Methodology 77
3.2.1 Disaggregation of the energy sector 77
3.2.2 Construction of the multi-regional IO table 79
3.2.3 Economic effects: extended IO analysis 89
3.3 Data 98
3.3.1 Input-output table 98
3.3.2 Regional data 98
3.3.3 Factors of production 98
3.3.4 Future renewables deployment and investments 99
3.4 Results 101
3.4.1 Effects on value added 102
3.4.2 Effects on employment 104
3.5 Conclusions 107
References 109

Appendix A Appendix to Chapter 2 113

Appendix B Appendix to Chapter 3 117
B.1 Sectors 117
B.2 Scenarios 119
B.3 Additional figures 120

List of Figures

Figure 1.1: Predicted secondary enrollment by royalties and institutions 20

Figure 2.1: Disclosing and non-disclosing company-year pairs by country of incorporation 51
Figure 2.2: Total emissions by country of emissions and country of incorporation (selected countries) 52
Figure 2.3: Development of revenue and emissions (2007–2012) 53
Figure 2.4: Development of average revenue and emissions (2007–2012) 54

Figure 3.1: Installed capacity by scenario, yearly average 100
Figure 3.2: Aggregated effects on value added, by scenario 102
Figure 3.3: Effects on value added, by scenario and region 103
Figure 3.4: Effects on value added for selected sectors, GREEN LARGE scenario 104
Figure 3.5: Aggregated effects on categories of employment in the Oberland region, by scenario 105
Figure 3.6: Effects on employment by category and region, GREEN LARGE scenario . 106
Figure 3.7: Aggregated effects on employment by category, selected sectors and aggregated region, GREEN LARGE scenario 106

Figure B.1: Installed capacity for heat generation by scenario, yearly average 120
Figure B.2: Effects on employment by category and region, BAU SMALL scenario . . 120
Figure B.3: Effects on employment by category and region, BAU LARGE scenario . . 121
Figure B.4: Effects on employment by category and region, GREEN SMALL scenario . 121
Figure B.5: Effects on value added for selected sectors, BAU SMALL scenario 122
Figure B.6: Effects on value added for selected sectors, BAU LARGE scenario 123
Figure B.7: Effects on value added for selected sectors, GREEN SMALL scenario . . . 124
Figure B.8: Aggregated effects on employment by category, selected sectors and aggregated region, BAU SMALL scenario 125
Figure B.9: Aggregated effects on employment by category, selected sectors and aggregated region, BAU LARGE scenario 126

Figure B.10: Aggregated effects on employment by category, selected sectors and aggregated region, GREEN SMALL scenario 127

List of Tables

Table 1.1: Descriptive statistics . . . 17
Table 1.2: Mean comparison HC producers vs. non-producer municipalities . . . 18
Table 1.3: Natural resources and development outcomes . . . 19
Table 1.4: Institutions as omitted variable . . . 22
Table 1.5: Dynamic panel data - Arellano and Bond estimator . . . 23
Table 1.6: First stage estimations of the IV approach . . . 25
Table 1.7: Endogeneity of institutions - IV approach . . . 27
Table 1.8: Alternative controls and sample period . . . 29
Table 1.9: Cumulative and lagged royalties . . . 30
Table 1.10: Other types of transfers . . . 31

Table 2.1: Policy variables . . . 46
Table 2.2: Descriptive statistics . . . 49
Table 2.3: Disclosing vs. non-disclosing companies . . . 50
Table 2.4: Regression results OLS, FD and selection correction . . . 61
Table 2.5: Extended time pattern of policy effects . . . 63
Table 2.6: Sensitivity analysis - single policies . . . 65
Table 2.7: Sensitivity analysis - EUA and electricity prices . . . 66

Table 3.1: Disaggregation of the intersectoral transactions of the energy sector . . . 78
Table 3.2: Technologies, measures and type of investor . . . 100

Table A.1: Sensitivity Analysis - sample composition . . . 113
Table A.2: First stage selection correction . . . 114
Table A.3: Number of surveyed companies per country and selection rule . . . 115

Table B.1: Sector description and numbers . . . 117
Table B.2: Available regional gross value added values . . . 118
Table B.3: Scenario description . . . 119

1 Natural Resources, Institutions, and Development: A Within-Country Approach

1.1 Introduction

The question whether natural resources constitute a curse rather than a blessing has been studied by many scholars in the last two decades. The paradoxical poor economic performance of most natural-resource-rich nations motivated multiple investigations trying to determine the extent to which this observation is the result of a causal link. Sachs and Warner (1997, 2001) can be considered the precursors of the empirical literature on this topic. Since then, countless studies have analyzed the relationship between natural resources and economic growth, income level, and education outcomes, among others, yet there is still no conclusive evidence of the existence of the resource curse (Badeeb et al. 2017; van der Ploeg and Poelhekke 2017). Based on cross-country analyses, Sachs and Warner (1997, 2001) and some following studies conclude that natural resources are negatively associated with economic growth (Sachs and Warner 1997, 2001; Gylfason 2001) and education spending and enrollment (Gylfason 2001), while Alexeev and Conrad (2009) find a positive impact on GDP per capita and growth. Others document an indirect negative effect by increasing corruption (Leite and Weidmann 1999; Papyrakis and Gerlagh 2004) or by harming institutional quality (Isham et al. 2005; Bulte et al. 2005; Sala-i-Martin and Subramanian 2012), finding either no direct (Leite and Weidmann 1999; Bulte et al. 2005) or even a positive impact on growth (Papyrakis and Gerlagh 2004; Sala-i-Martin and Subramanian 2012).

Using reserves as the natural resources variable, Stijns (2005) and Brunnschweiler and Bulte (2008) find no significant evidence that natural resource abundance has been a significant factor determining economic growth. Stijns (2005) also finds a positive association with school attendance, while the correlation with resource dependence, measured by the share of natural capital in national wealth, is negative. These findings illustrate a point that has been criticized and is subject to debate in the resource curse literature: measuring natural resources by dependence or intensity measures is potentially endogenous since this dependence might be the result of economic policies or even of a malfunctioning economy that came about due to reasons different from resource wealth (Brunnschweiler and Bulte 2008; Borge et al. 2015; James 2017). However, using reserves as a measure in cross-country studies does not solve on its own the endogeneity problem either because economic, institutional, and technological factors (that are commonly not controlled for) determine the extent to which countries are prospected, and, therefore, their level of known endowments (Michaels 2011; Borge et al. 2015; Smith 2015). Some recent literature using exogeneous measures like oil discoveries and accounting for the heterogeneity between countries, finds natural resources to increase income per capita (Michaels 2011; Smith 2015). However, Caselli and Michaels (2013) find that oil revenues do increase spending on public goods but do not increase welfare outcomes for the population to the expected extent, if at all.

This paper's contribution to the literature is threefold. First, this study is, to my knowledge, the first to investigate the role of subnational institutions as one important channel in determining the effect of natural resource abundance on economic development. Second, it provides an analysis that relies on an exogenous measure of natural resources. Finally, the within-country panel approach eliminates problems caused by the unobserved heterogeneity between countries present in cross-country studies and allows me to control for unobservable municipality-specific time-invariant factors.

Specifically, the natural resource measure used is yearly hydrocarbon production, proxied by the amount of royalties per capita received by Colombian municipalities.[1] To the extent that there can be differences among Colombian municipalities with respect to technology access and institutions that are relevant for exploration and extraction of natural resources (e.g., openness to international trade), the fixed effects approach takes care of the time-invariant municipality-specific factors, which might be most of the potentially problematic heterogeneity in terms of natural resource extraction, considering the relatively short period of time analyzed. Most past studies are based on cross sections of countries, raising concerns that they do not appropriately account for the heterogeneity of unobserved characteristics. By providing a within-country analysis, the unobserved heterogeneity across countries is not present. While there is still heterogeneity between municipalities, controlling for fixed effects in a panel design allows me to isolate time-invariant characteristics.

[1] Municipalities are the second level of political and administrative subdivisions, after departments.

The resource curse hypothesis has also been tested in within-country settings by a few researchers. The advantage of this approach is that some variables that might be either hard to measure or unobservable, but at the same time influence the effect of natural resources on economic outcomes, do not vary within a country (van der Ploeg 2011; van der Ploeg and Poelhekke 2017). Thus, a number of potentially significant sources of omitted variable biases, including some institutional factors that are commonly proxied or instrumented by latitude, Spanish versus British legal origins, or the fraction of the population speaking English or other Western European languages, can be ruled out.[2] Among the studies assessing the empirical evidence at the within-country level is the one by Beine et al. (2014), who use data from Canadian provinces to investigate whether a labor market mechanism can mitigate the Dutch disease. They find temporary foreign worker programs and interprovincial worker migration to assume this mitigating role. Caselli and Michaels (2013) show that a significant share of oil revenues received by Brazilian municipalities do not improve welfare outcomes for the local population. Based on anecdotal evidence, the authors suggest that oil revenues rather increase illegal practices by local politicians. In contrast, Loaysa et al. (2013) find Peruvian mining districts to have benefited in terms of both extreme poverty reduction and basic needs satisfaction and to exhibit better indicators than non-mining districts. Michaels (2011) finds oil abundance to have had positive effects on infrastructure and per capita income in the southern counties of the U.S. without increasing income inequality.

The observation that some resource-rich countries like Norway, Canada, and Australia seem to not be subject to the resource curse raises the question of what makes them different from other resource rich countries. I argue that one important differential characteristic is the quality of institutions. It seems that countries exhibiting strong and robust institutions are able and willing to design policies that ensure a sustainable and efficient use of the financial resources generated by natural resources. On the other hand, states with weak institutions might not benefit (to a full extent) from natural resources riches because financial resources are lost, for instance, in an inefficient and corrupt system. In other words, “[…] natural resources put the institutional arrangements to a test, so that the resource curse only appears in countries with inferior institutions” (Mehlum et al. 2006, p. 3).

Thus, institutional quality seems to be relevant for determining the direction in which natural resources influence economic performance (Larsen 2005; Mehlum et al. 2006; Bhattacharyya

[2] Studies using these variables include Mehlum et al. (2006) and Brunnschweiler and Bulte (2008).

and Hodler 2014). However, much of the past literature on the impact of natural resources on the economy ignores the role of institutions despite their importance in economic development, as has been emphasized by North, Acemoglu, Johnson, Robinson, and coauthors (Acemoglu et al. 2001; North 1990; Engerman and Sokoloff 2002) and a vast literature derived from these early contributions. Despite its popularity, the concept of institutions is sometimes not properly defined, so that some audiences might find it vague. North (1990) defines them as the “rules of the game in a society” and differentiates between formal institutions, designed by humans, and informal institutions, consisting of conventions, social norms, and codes of behavior. Examples of the first type are the set of laws and the political system. Informal institutions can be, for instance, the way these norms are adopted by individuals.

Admittedly, this paper is not the first to analyze how natural resource abundance influences development within a country, nor the first to investigate the role of institutions. Yet, I am not aware of other studies combining these two aspects, which allows devoting particular attention to the role of local institutions as one important channel through which natural resources can be transformed into a blessing—creating new, positive perspectives for the bulk of the population—or a curse that perpetuates poverty and inequality of income and opportunities.[3] I take advantage of the fact that formal de jure institutional arrangements do not vary within Colombia (which might be the opposite case in other countries, e.g., federal states), and can be treated as a constant. Thus, I can focus the analysis on the role of local de facto institutions. To make clear what is meant by de facto institutions, it is useful to consider that I do not ask whether there are rules on how the public administration of municipalities should be organized, but how the administration is organized. This is a relevant issue because what matters at the end is not what is written on paper but what happens in real life. Specifically, I use an administrative capacity index that has been developed by the Colombian National Planning Department as an indicator to measure the performance of municipalities.

A further contribution consists in providing evidence of the extent to which the results are biased when past criticism of the resource curse literature is not taken into account. Specifically, I show that ignoring the role of institutions and failing to account for the heterogeneity

[3] While Casselli and Michaels (2013) provide suggestive evidence that corruption might be the reason for not finding improvements in living standards of the population despite of the increase in public spending, they do not explicitly look at the role of institutions.

between municipalities (or more generally between observation units) biases the results upwards.

As is the case in a cross-country setting, a casual glance at Colombian regions also suggests a paradoxical pattern of resource-rich regions exhibiting relatively low levels of development. Thus, the aim of the present study is to enrich the literature by analyzing the effect of natural resource abundance on the living standards of the Colombian population. In a recent critical review of the available quantitative evidence on the impact of natural resources on the economy, van der Ploeg and Poelhekke (2017) call for more work on how natural resources influence inequality, among other economic variables. By analyzing the effect on secondary school enrollment, infant mortality rates, and test scores for the nationwide school-leaving examination as an indicator for educational quality, this paper follows van der Ploeg's and Poelhekke's demand since the three measures can be seen as good indicators of the equality of opportunity. Besides being important variables for measuring economic development, secondary enrollment and infant mortality rates are also relevant for the examination of whether royalties were invested in what they were supposed to. It is stipulated by law that resources received as royalties must be invested towards the achievement of several specific targets concerning basic needs of the population, among which are secondary enrollment and infant mortality rates.

In the empirical analysis, where I additionally control for factors like the prevalence of illegal armed groups and GDP per capita as a measure of overall prosperity, I do not find evidence that natural resources are a curse for development in general. On the contrary, I find natural resource abundance to promote improvements in educational attainment. This positive effect can be reinforced when institutions are sufficiently strong, that is, when municipalities have good administrative capacity, or weakened when the quality of institutions is rather low. Thus, making sure that institutions are strong, and strengthening them in case deficiencies are encountered, should be the first step when planning the use of revenues coming from the extraction of natural resources. For educational quality, proxied by the average results of the nationwide school-leaving exams, the picture changes. Here, natural resource abundance has a negative effect on exam result averages, which could be due to the composition of the student population. The bad performance on exams might also have its roots in the labor market, since resource booms can increase wages in all sectors, increasing the opportunity costs of education (James 2017). Not finding evidence for health outcomes can have multiple reasons. I conjecture that corruption in the health sector, which has been found to be a general characteristic of this sector irrespective of natural resources abundance, can be an important explanation for the lack of a diminishing effect of royalties on infant mortality rates.

At this point it is important to mention the main limitations of my analysis and to explain how I deal with them. For the specifications where education-related development outcomes are the dependent variable, there is a concern that institutions might be endogenous. To account for this possibility, I implement a dynamic panel data approach and apply the Arellano-Bond estimator (Arellano and Bond 1991). I explore a further alternative in which institutions are instrumented by the number of crown employees in 1794. This indicator exploits the effect that the colonial state presence might have had on the costs and benefits of investing in later institutional quality, influencing today's institutions (Acemoglu et al. 2015).

As explained above, a within-country design is beneficial for some aspects of the analysis and has been, in fact, claimed by other scholars. Yet, with respect to the external validity of the results, I must be careful when making claims. Nonetheless, I believe that it does raise awareness that local institutions matter, and therefore, even in within-country settings, their role should be taken into account both in academics and in the design of policies aiming to ensure that natural resources are a blessing for the communities.

The paper is organized as follows. The next section presents the identification strategy, Sections 1.3 and 1.4 introduce the data and its sources and present the results, respectively. The robustness of the results is tested in Section 1.5. Section 1.6 concludes.

1.2 Identification strategy

1.2.1 Natural resources and development

Development indicators

Most of the resource curse literature focuses on the effect of natural resources on aggregate economic indicators as GDP per capita and growth. However, from the point of view of economic development, it seems more interesting to investigate the impact of abundant natural resources on the living standards of a country's population, rather than focusing on highly aggregated measures. Although widely used to measure the level of development, GDP measures are not sufficient to reflect people's welfare, especially in societies with high levels of income inequality (Bulte et al. 2005). This paper therefore investigates whether resource wealth has been hindering the development of Colombian resource-rich municipalities. As outcome variables, I use three development indicators: secondary school enrollment, infant mortality rates, and test scores for the nationwide school-leaving examination as an indicator for the quality of education in Colombia. Some studies use spending on education or in general on public goods provision as an outcome variable. However, at least in some countries, reported spending by (local) governments might be problematic as a measure since a fraction of that spending might end in corrupt hands rather than in improving public good provisions, as found by Caselli and Michaels (2013) for Brazilian municipalities. Since there is some evidence that this might also be the case for Colombia, I prefer to avoid using spending figures (El Tiempo 2018; Lewis 2006; Revista Dinero 2017).

Besides being important variables for measuring economic development and public good provision, secondary enrollment and infant mortality rates are also relevant for the examination of whether royalties were invested in what they were supposed to, since it is stipulated by law that resources received in the form of royalties must be invested towards the achievement of several targets concerning basic needs of the population. Among these targets are a maximum infant mortality rate of ten deaths per thousand living births, and 90% coverage rates in basic primary and secondary education. Both at the beginning and at the end of the sample period, less than one percent of the municipalities had achieved these targets. Moreover, concerning infant mortality rates, only eight municipalities had lower rates than the target in the period of analysis, leaving room for improvements.

Natural resources measure

There has been some debate on the appropriate measure of natural resources that enables testing the hypothesis of the resource curse (see, for instance, Sachs and Warner 2001; Stijns 2005; Brunnschweiler 2008; and Borge et al. 2015). First, considering that the motivation for this strand of the literature was the observation that resource-rich countries tend to perform worse than countries without abundant natural resources, the best approach seems to be using the closest possible measure of abundance, which in this case would be natural resource reserves. However, since reserves represent a potential source of revenue that has not yet been realized (and might in fact not be fully realized within the period of analysis), it seems better to use a measure with a more direct link to economic development. This consideration points to a second candidate: production. Rents generated through resource extraction create incentives and unfold economic processes that ultimately result in development outcomes, both positive and negative. As a simple illustrative example, think of natural resource rents being invested in other private productive projects and in the provision of public goods, such as education and infrastructure. One does not have to put in much effort to imagine this process resulting in increased welfare for the whole population. A counterexample can be illustrated by a situation in which the financial resources generated are wasted by corrupt actors, and the clear majority of the population does not benefit from the resource riches of its territories.

Critics of the use of reserves and, implicitly, of the use of production as the resource measure point to its endogeneity to a country's economic performance (Borge et al. 2015; van der Ploeg and Poelhekke 2017). By using royalties per capita to proxy for natural resource wealth, this paper uses a measure that is closely related to production, and, therefore, there is also potential for endogeneity issues associated with royalties. I argue that royalties received by municipalities are exogenous because they are independent of the socioeconomic characteristics of the municipality. A more detailed discussion on the exogeneity of royalties is provided in Section 1.2.3.

Although analyzing the effect of all types of point-source natural resources would be particularly interesting, the natural resource sector in Colombia presents an important characteristic that makes it necessary to restrict the analysis to hydrocarbons (HC). Besides being extracted by a formal sector, coal and other minerals are also extracted by informal or even illegal actors. This would complicate any consideration of these types of resources, since it would be difficult to control for the intensity of informal or illegal mining, and therefore the effect captured by the formal measure might be contaminated. At this point, it is important to mention that municipalities in which extraction of coal and other minerals takes place are excluded from the analysis. That is, the sample of analysis only includes producer municipalities that receive hydrocarbon royalties and municipalities where no natural resource extraction takes place.

Additional explanatory variables

The inclusion of income as a control variable is crucial in order to isolate the effect of the natural resource sector. The possible constellation of municipalities with high levels of production in the resource sector that have poor development indicators, while for low resource production municipalities holds the opposite, does not necessarily mean that natural resources are negatively associated with development. Municipalities exhibiting good development indicators might be in general more prosperous, which might then be reflected in the welfare of the population. I therefore include GDP per capita as an indication of the overall prosperity of the municipality and consider collected taxes per capita as an alternative measure.

Considering the existence of the Colombian armed conflict is a further important factor mainly for two reasons. First, natural resources have been found to be associated with internal conflicts (Collier and Hoeffler 2004; Arezki and Gylfason 2013; Berman et al. 2017), thus ignoring the existence of the Colombian conflict can lead to a biased estimation of the coefficient of the resource measure, since the presence and the intensity of conflict can also affect development measures. Second, since predation on public financial resources is often a source of finance for the conflict's illegal actors (guerrilla and paramilitary groups) and predation is especially notorious in natural resource-rich regions (Dube and Vargas 2013), including a measure of conflict accounts for the effect of predation in reducing the available resources that can be invested in welfare-improving projects.[4] Therefore, considering these indications, I include the number of attacks by illegal armed groups in each municipality as a measure of the intensity of their presence. Summarizing, the starting point of the empirical analysis is represented by the following relationship:

$$D_{it} = \beta_r R_{it} + \beta_g G_{it} + \beta_c C_{it} + \boldsymbol{\beta_t} \mathbf{d_t} + \mu_i + \upsilon_{it}, \tag{1.1}$$

where D_{it} stands for the various development indicators of municipality i in year t, R represents the natural resource variable, G is GDP per capita and C represents the intensity of the armed conflict. $\mathbf{d}$ is a vector of year specific dummy variables capturing common shocks, while μ_i and υ_{it} represent time-invariant and time-variant unobserved factors of each municipality, respectively. The estimation of this and all equations presented in the next subsections is done for the different development indicators.

The problem in drawing conclusions from estimation results of Equation (1.1) is that they are probably biased. The reason is that the important role that institutions play in the effect of natural resources on economic development is not taken into account.

[4] Predation consists, for instance, in extortions or in forcing government officials to allocate expensive contracts to specific firms from which the illegal armed groups later claim financial participation (Dube and Vargas 2013).

1.2.2 The role of institutions

Following a vast literature that finds institutions to be a significant factor contributing to the observed differences in today's economic development levels (Acemoglu et al. 2001, 2002, 2014; Nunn 2008; Dell 2010), I include a measure of institutional quality in the analysis. Moreover, the observation that some resource-rich countries have a good economic performance, while others do not, raises the question whether institutional quality is a mediating factor for these differences. Thus, the econometric specification also includes an interaction term between natural resources and institutional quality to investigate the extent to which natural resource wealth has a different effect depending on the quality of institutions. These inclusions lead to the following specification:

$$D_{it} = \beta_r R_{it} + \beta_i I_{it} + \beta_{ri}(R_{it} \times I_{it}) + \boldsymbol{\beta}_{\mathbf{x}}\mathbf{X_{it}} + \mu_i + \epsilon_{it}, \tag{1.2}$$

where and $\mathbf{X}$ is a vector containing the control variables introduced in Equation (1.1): GDP per capita, conflict intensity, and year dummies. I_{it} represents institutional quality in municipality i and ϵ_{it} is the new error term, containing time-variant unobserved factors. Specifically, institutional quality is measured by the administrative capacity index, which is constructed as part of a broader measure of municipality performance. Some of the indicators considered by the index are the stability of the managerial staff in the municipality and the implementation of the so-called standard model of internal control. The relevance of administrative capacity for development and especially for handling financial resources towards development is supported by the acknowledgement in development assistance of the role of capacity development in recipient countries (Vallejo and When 2016). Moreover, with respect to the stability of the managerial staff as one of the indicators included in the index and considering that clientelism would generate a high fluctuation in staff, the administrative capacity index serves as an indication of the degree of meritocracy prevailing in the recruitment of government officials. This is, in turn, recognized as a factor limiting corruption and fostering effective bureaucracies (Dahlström et al. 2012; Charron et al. 2016).

Comparing results from estimating Equations (1.1) and (1.2) will provide some indications of whether it was in fact necessary to include institutions in the analysis. My hypothesis, based on the literature, is that the magnitude of the coefficient on natural resources will be lower when including the institutions measure. A remaining concern is that institutions might be endogenous, at least when the outcome variable is related to education. The next subsection explores in detail this issue and its possible solutions.

1.2.3 Potential endogeneity issues and treatment

Institutions

The first type of endogeneity that might come to mind when talking about institutions and economic development is related to the possibility that more developed regions (be it countries or municipalities) have strong preferences for better institutions and can afford them, so there is a simultaneity problem in trying to estimate the impact of institutions on economic development (see for instance Acemoglu et al. 2001). Controlling for GDP per capita partially addresses this problem, and the fixed-effects design implemented in my regressions also contributes to addressing this type of endogeneity by eliminating time-invariant factors that can be associated both with the level of development and the quality of institutions.[5]

However, endogeneity remains a concern due to the development indicators selected. Specifically, it seems plausible that more and better education plays a role in shaping later administrative capacity, for instance by increasing the likelihood of people to report misconduct of government officials (Botero at al. 2013) or by improving the pool of potential candidates to fill vacancies in the municipal administration. Looking at the data shows an unconditional correlation of 0.11 to 0.13 between secondary enrollment and later administrative capacity, giving some indication that education does not necessarily have a strong effect on later administrative capacity, at least not in the short period of time analyzed here. Nevertheless, I further analyze the potential endogeneity and implement two strategies to address these concerns.

The first strategy consists in implementing a dynamic panel data approach by including the lagged dependent variable as a regressor and following Arellano and Bond (1991) in correcting

[5] Acemoglu, Gallego, and Robinson (2014, AGR) criticize the approach of considering country-fixed-effects as a remedy for omitted variable biases used by Gennaioli et al. (2013) in an analysis where the observation units are subnational regions. The argument of AGR is that, as documented and exploited by a growing number of studies (including this paper), institutions vary greatly within countries, so that the approach is insufficient. Since my analysis takes place at the municipal level, and I control for fixed effects at the same level, AGR's criticism does not apply; using fixed effects is sufficient to avoid identification problems caused by constant unobserved municipality-specific factors.

the resulting endogeneity. The model to be estimated can be specified as

$$D_{it} = \sum_{j=1}^{p} \alpha_j D_{i,t-j} + \alpha_r R_{it} + \alpha_i I_{it} + \alpha_{ri}(R_{it} \times I_{it}) + \boldsymbol{\alpha_x X_{it}} + \mu_i + \omega_{it}, \tag{1.3}$$

where p is a parameter to be estimated. This approach relies on first differencing the equation to eliminate the unobserved time-invariant unobservable μ_i, and on instrumenting the differenced lagged dependent variable using its second and subsequent lags to solve the endogeneity generated by the first differencing. For these instruments to work, the serial correlation of the differenced error term, ω_{it}, cannot be of an order greater than 2, which will be tested in the results section.

The second strategy consists of an instrumental variable approach. Following Acemoglu et al. (2015), who instrument for contemporary state capacity in Colombian municipalities using colonial state presence indicators, I exploit a historically determined source of variation to instrument for contemporary institutional quality, namely, the number of colonial crown employees in 1794. Acemoglu et al. (2015) use this measure to instrument for state capacity today (measured by the number of notary offices, schools, and jails, among others) and advocate for the validity of the instrument pointing to the effect that colonial state presence likely had on the cost and benefits of maintaining and building a later state presence. In relation to municipal administrative capacity, state presence serves as an indication of the ability of the national government to supervise and control the activities of subnational entities, as well as to support improvements in their administrative capacity. Moreover, the authors argue that the location decisions of colonial officials were largely influenced by factors that do not have any relevant effect on public goods provisions today. So, for instance, state presence in the eighteenth century was determined by the location of gold mines, which were depleted during colonial times, or by their importance for the Spanish military.

An important limitation of colonial state presence as an instrument is that it is time invariant, so that a fixed-effects specification cannot be maintained. Thus, the following set of equations, where Equations (1.4) and (1.5) represent the first stage and Equation (1.6) the second stage equation, is estimated:

$$I_{it} = \gamma_r R_{it} + \gamma_z Z_i + \gamma_{rz}(R_{it} \times Z_i) + \boldsymbol{\gamma_x}\mathbf{X_{it}} + \boldsymbol{\gamma_s}\mathbf{S_i} + \nu_{it}^{I} \tag{1.4}$$

$$R_{it} \times I_{it} = \delta_r R_{it} + \delta_z Z_i + \delta_{rz}(R_{it} \times Z_i) + \boldsymbol{\gamma_x}\mathbf{X_{it}} + \boldsymbol{\delta_s}\mathbf{S_i} + \nu_{it}^{RI} \tag{1.5}$$

$$D_{it} = \lambda_r R_{it} + \lambda_i \hat{I}_{it} + \lambda_{ri}(\widehat{R_{it} \times I_{it}}) + \boldsymbol{\gamma_x}\mathbf{X_{it}} + \boldsymbol{\lambda_s}\mathbf{S_i} + \nu_{it}. \tag{1.6}$$

In (1.4) and (1.5) Z_i is the instrument for the administrative capacity index, that is, the number of crown employees in 1794. In Equation (1.6) $\hat{I}$ is the predicted administrative capacity index, and $\widehat{R \times I}$ the predicted interaction term. The error term is denoted by ν and the superscripts I and RI indicate that the parameter is from the institutions or interaction term equation, respectively. Note that ν contains both time-variant and time-invariant unobserved factors, since, as explained above, it is not possible to use the fixed-effects design of Equation (1.2) because the instrument does not vary with time. Instead, I include the vector $\mathbf{S}$, which is a set of geographic control variables, accounting for the fact that geographic characteristics are often claimed to be significant determinants of economic development (see, e.g., Sachs 2001). Partly following Acemoglu et al. (2012) the geographic characteristics that will be considered are distance to the capital city of the department and to the national capital Bogota, longitude, latitude, elevation above sea level, share of cultivable land per capita, density of primary, secondary, and tertiary rivers, annual rainfall, and the share of mountainous land. Despite the inclusions of additional control variables in the IV specifications, there is still some probability that there are unobservable characteristics that I cannot control for. So, the results of the IV regressions should be interpreted with caution.

Natural resources measure

Recent literature has criticized the use of reserves and production measures for their endogeneity to the level of income and development in a country. However, I argue that my measure for natural resource abundance is exogenous, because both hydrocarbon production and royalties are determined by factors that cannot be influenced by the municipality itself or by someone else based on the municipalities' characteristics. On the production side, the first factor for determining whether hydrocarbons are extracted in a municipality is the availability of the resources—clearly an exogenous geological condition. Second, the extent to which the resources have been discovered, which depends on exploration activities, is not determined by the municipality either, but by international companies or by Ecopetrol, 80% of which belongs to the Colombian state. One can argue, as has been done in the recent literature analyzing the effects of natural resources on the economy, that the extent to which a country has been prospected depends on the available technology in the country and this, in turn, on other economic factors, including the degree of openness to international trade or other institutions facilitating or hindering exploration and production (see, for instance, Borge et al. 2015; Smith 2015).[6] While this argument is relevant for a cross-country analysis or an analysis within a (federal) state, where these factors differ between the subnational units, it is not the case for the analysis within highly centralized countries like Colombia. A third factor influencing production is the price of the resource, which is determined in international markets in which Colombia is not a major player and its municipalities even less so. Finally, an aspect that provides additional confidence about the exogeneity of hydrocarbon production is the use of municipality fixed effects, which allows for controlling for time-invariant factors influencing the propensity to discover and extract natural resources.

With respect to the factors influencing the amount of royalties a municipality receives, these are determined by specific rules that apply to all producing municipalities. First, the amount of royalties paid by companies for the exploitation of natural resources is set by the Colombian state. It is determined by a function of production and the international oil price, and is uniform for all production sites. Specifically, there are no differences by company or municipality (DNP 2007). Second, during the period of my analysis, the producing municipalities received a fixed share of the royalties that were paid to the Colombian state, irrespective of the municipalities' characteristics (other than the amount of production). This changed with a new royalties law, which came into effect in 2012 and is one reason to limit the analysis.

One issue that might be problematic about the distribution of royalties is the fact that not only producing municipalities, but also departments (the first level of political and administrative subdivision), other subnational institutions, and municipalities hosting ports and transporting infrastructure receive a share of the royalty payments. If these other recipients of royalties invest in public goods provision, it will be more difficult for me to find an effect of natural resources on public good provision by the municipalities.

[6] A further mechanism potentially influencing exploration consists in the national government preferring exploration in specific regions, where it wants its political power to increase or with intent to please political allies. However, there is no evidence of this kind of favoritism in the hydrocarbon sector.

1.3 Data

Most of the data was obtained from the Center for Economic Studies (CEDE) at the Universidad de los Andes in Bogota, but their origin is from different institutions. Two of the indicators of the municipalities' development level—secondary school enrollment and infant mortality rate—are originally collected by the National Administrative Department of Statistics (DANE), while test scores of the nationwide school-leaving examination are from the Colombian Institute for the Evaluation of Education (ICFES), which also runs the examinations.

I use the information on the yearly amount of royalties received by each municipality published by the National Planning Department (Departamento Nacional de Planeación) and collected by CEDE. Municipal GDP per capita and tax revenue are also obtained from CEDE. These three variables are converted to real values with 2005 as the base year. They are calculated using GDP data from the Colombian central bank (Banco de la República).

The institutional quality indicator—the administrative capacity index—originates in the National Planning Department (DNP). It is constructed every year as part of a broader measure of municipality performance. The Panel Violence and Conflict by CEDE reports yearly data on the presence of guerrilla and paramilitary groups as well as on their actions. From this dataset, I use the number of attacks against the civilian population. Some of the geographic characteristics—altitude above the sea level, longitude, latitude, and distance to the department capital and to Bogota—are also obtained from CEDE. The share of mountain land, the annual mean rainfall, the share of land suitable for agriculture, as well as the density of primary, secondary, and tertiary rivers are from the published data set used by Acemoglu et al. (2015). From this data set I also obtain the number of crown employees in 1794.

Table 1.1 presents descriptive statistics of all variables and the units in which they are expressed. We see a large variation in the development indicators, especially in secondary enrollment and infant mortality rates. Important for the relevance of this study is the observation that most municipalities do not reach the targets of 90% coverage in secondary education and fewer than 10 infant deaths per 1,000 living births, indicating that there is ample scope for improvement. The administrative capacity index also exhibits sufficient variation, and, although in theory the index range goes from 0 to 100, none of the observations take the value of 0. Therefore, all regressions will include this variable centered at its sample mean, which is a common approach in such cases to ensure a more sensible interpretation of the coefficient on royalties (Wooldridge 2009).[7] In Table 1.1 we also see that the average number of colonial crown employees is rather low, which is likely because there were no crown employees in more than 75% of the municipalities.

The sample period is based on data availability and covers the years 2005 to 2009, since the administrative capacity index is available only from 2005, and municipal GDP per capita is available only until 2009. Out of 1,119 municipalities, the sample analyzed includes 751 municipalities, of which approximately 10% (76 municipalities) received royalties from oil and gas production. However, some specifications include fewer municipalities due to data availability. About 150 of the remaining municipalities were excluded because of being producers of coal, gold, or other types of minerals, and the rest because of missing data.

A comparison of the two groups of producer and non-producer municipalities can be seen in Table 1.2. Here it is clear that the difference between the means of the development outcomes is statistically significant, yet especially exam results do not differ by a lot. Interestingly, hydrocarbon municipalities perform better on average in terms of educational indicators, pointing rather to a resource blessing than to a resource curse, though in terms of infant mortality rates, there are initial indications of a resource curse. On average, none of the institutions measurements differ significantly, while for the other controls in the fixed-effects specification (GDP per capita and conflict intensity), more pronounced and significant differences can be detected.

1.4 Results

Table 1.3 summarizes the results of estimating Equation (1.2), that is, of the regressions assessing the effects of hydrocarbon royalties on development and the role of institutions in that relationship. Columns (1) and (2) present the result for secondary enrollment, first using OLS and then fixed-effects estimation. Comparing these two sets of results highlights the importance of taking into account the heterogeneity across municipalities both for obtaining unbiased royalties' coefficients as well as for their precision. Also, for most of the other outcome variables and coefficients, fixed-effects estimations result in more precise coefficient estimates. Looking more closely at column (2), I find that one million Colombian Pesos (COP)

[7] Otherwise, the coefficient on royalties would capture the effect of royalties on development when the administrative capacity index is zero, which does not occur in the sample, making that an irrelevant analysis.

Table 1.1 : Descriptive statistics

	Mean	Std.Dev	Median	Min	Max
Development indicators:					
Secondary enrollment rate (%)	50.85	14.91	51.94	0.00	98.40
Infant mortality rate (per 1,000 living births)	22.13	7.45	20.61	7.65	61.35
Exam results	47.95	2.89	47.96	36.65	65.29
Natural resources and institutions:					
HC Royalties (million COP p.c.)	0.03	0.17	0.00	0.00	3.00
Administrative capacity index	54.20	22.15	54.14	0.12	100.00
Number of colonial crown employees in 1794	1.56	27.02	0.00	0.00	715.00
Economic and conflict controls:					
GDP (million COP p.c.)	7.63	8.07	6.23	0.22	128.52
Conflict intensity (attacks per 100,000 inhab.)	5.67	13.92	0.00	0.00	224.38
Tax revenue (million COP p.c.)	0.07	0.08	0.04	0.00	0.88
Transfers (million COP p.c.)	0.06	0.08	0.04	0.00	1.98
Geographic controls:					
Elevation (mts above sea level)	1,213.14	869.74	1,291.00	2.00	3,087.00
Latitude	5.45	2.53	5.30	-4.22	11.74
Longitude	-74.70	1.51	-74.75	-78.30	-67.47
Lineal distance to department capital (km)	75.96	52.41	65.42	0.00	376.12
Lineal distance to Bogota (km)	299.81	189.23	261.98	0.00	1,270.85
Density of primary rivers (mts/sq km)	35.62	271.90	0.00	0.00	6,467.87
Density of secondary rivers (mts/sq km)	27.26	69.88	0.00	0.00	865.63
Density of tertiary rivers (mts/sq km)	19.44	63.71	0.00	0.00	1,007.79
Rainfall (mm/year)	1,828.21	887.67	1,600.00	160.00	5,910.00
Share of agriculture-suitable land	0.51	0.33	0.50	0.00	1.00
Share of mountain land	0.70	0.39	1.00	0.00	1.00
Observations	3,755				
Number of municipalities	751				
Number of hydrocarbon municipalities	76				

in hydrocarbon royalties per capita lead to a 4.25 percentage points increase in secondary enrollment in municipalities with average administrative capacity, as indicated by the uninteracted coefficient.[8] Evaluated at the average amount of royalties received by hydrocarbon municipalities (0.29 million Colombian Pesos, COP), this corresponds to an increment of 1.2 percentage points. The statistical insignificance of the coefficient on administrative capacity implies that secondary enrollment in municipalities that do not receive royalties from hydrocarbon extraction is not affected by institutions. However, the quality of institutions does play a role when hydrocarbon royalties are positive, as indicated by the significant interaction term. Since the institutions measure also takes negative values, the interpretation of the overall

[8] One million COP is equivalent to approximately 300 USD.

Table 1.2 : Mean comparison HC producers vs. non-producer municipalities

	Non-Producers	Producers	Difference
Secondary enrollment rate (%)	50.57	53.26	2.69***
	[15]	[14]	(.8)
Infant mortality rate (per 1,000 living births)	21.98	23.49	1.51***
	[7.3]	[8.8]	(.4)
Exam results	47.92	48.22	0.30*
	[3]	[2.2]	(.16)
Administrative capacity index	54.08	55.28	1.20
	[22]	[20]	(1.2)
Number of colonial crown employees in 1794	1.65	0.77	-0.88
	[28]	[2.7]	(1.5)
GDP (million COP p.c.)	7.44	9.35	1.92***
	[8]	[8.7]	(.43)
Conflict intensity (attacks per 100,000 inhab.)	4.98	11.74	6.76***
	[13]	[20]	(.74)
Observations	3,371	384	3,755

Notes: The *Difference* column presents the absolute difference between the means of both groups and the results of the *t*-test for the equality of means. Standard deviation in brackets. Standard error in parenthesis. ***/**/* indicate significance at the 1%/5%/10% level.

effects for hydrocarbon royalties and administrative capacity is more challenging and is better illustrated graphically. Figure 1.1 shows the marginal effect of hydrocarbon royalties and administrative capacity for the combination of several values of these two variables, while other covariates are fixed at their mean. We see that for lower institution scores, secondary enrollment rates do not improve as fast with increasing royalties as for higher institution scores. So, for instance, a municipality with a (centered) administrative capacity score of 30 and 0.5 million COP per capita royalties, has a predicted secondary enrollment rate of approximately 52%. Increasing per capita royalties by half a million COP leads to a predicted secondary enrollment rate of approximately 56%. By contrast, the same increase in per capita royalties (for 0.5 to 1 million COP), while having an institutions score of -30, leads to a change of the enrollment rate from 50% to 52%, that is, 2 percentage points or half as much as in the first case. Thus, bad institutional quality weakens the positive effect of natural resource revenues on this measure of development and public good provision, and good institutional quality reinforces their positive effect.

Moving to the next development indicator, I do not find hydrocarbon royalties to influence infant mortality rates, at least not in a significant way (column (4) of Table 1.3). This finding is surprising and worrying since royalties are supposed to be invested towards bringing infant mortality rates down to less than ten deaths per thousand living births. Possible reasons

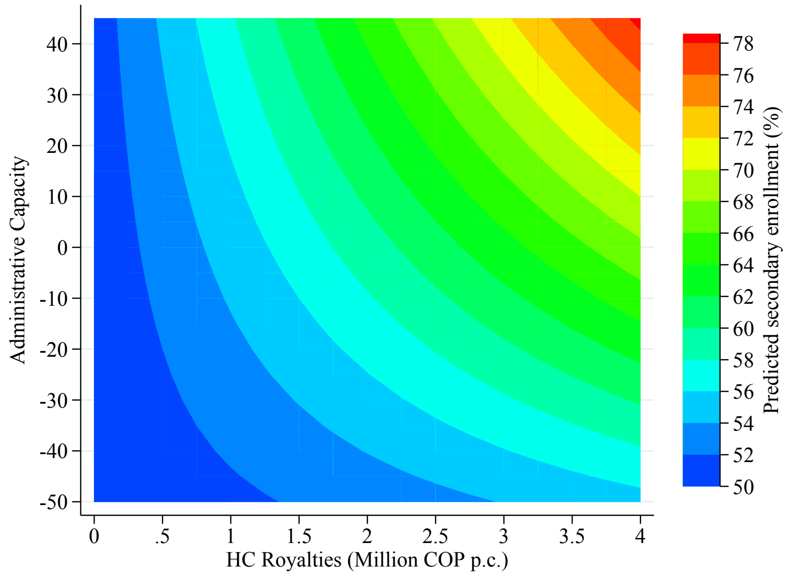
Table 1.3 : Natural resources and development outcomes

	(1) OLS Sec. Enroll.	(2) FE Sec. Enroll.	(3) OLS IMR	(4) FE IMR	(5) OLS Exam Results	(6) FE Exam Results
HC Royalties	1.768	4.245^{***}	0.712	0.120	0.097	-0.684^{***}
	(2.783)	(0.876)	(2.229)	(0.117)	(0.453)	(0.164)
HC Royalties × Ad. Capacity	0.031	0.060^{**}	0.053	0.003	0.008	0.007
	(0.059)	(0.027)	(0.034)	(0.003)	(0.011)	(0.005)
Ad. Capacity	0.046^{***}	0.006	-0.047^{***}	-0.002^{**}	0.011^{***}	0.002
	(0.016)	(0.006)	(0.008)	(0.001)	(0.004)	(0.002)
GDP	0.384^{***}	0.406	−0.078	−0.032	0.034	0.078
	(0.138)	(0.288)	(0.052)	(0.028)	(0.022)	(0.061)
Conflict intensity	−0.025	−0.002	−0.004	0.000	0.003	0.008^{**}
	(0.028)	(0.007)	(0.012)	(0.001)	(0.005)	(0.004)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Geographic controls	Yes	No	Yes	No	Yes	No
Observations	3,460	3,725	3,490	3,755	3,445	3,690
Nr. of municipalities	692	745	698	751	689	738
R^2	0.262	0.277	0.317	0.639	0.267	0.020
F-statistic	33.978	66.276	53.731	149.430	16.896	7.213

Notes: OLS regressions include a full set of region dummies and other geographic controls (latitude, longitude, elevation above sea level, distance to the department capital and to Bogota, share of cultivable land per capita, density of primary rivers, density of secondary rivers, density of tertiary rivers, annual rainfall, share of mountain land). All regressions include year-fixed effects, regressions in columns (2), (4) and (6) include municipality-fixed effects. Royalties and GDP are measured in millions of COP per capita. Robust standard errors clustered by municipality in parenthesis. ***/**/* indicate significance at the 1%/5%/10% level.

for the lack of improvement in this respect are the inefficient use of the income generated by natural resource abundance or even corruption that impedes natural resource riches from materializing in better living conditions for the population. Support for the inefficiency mechanism, also known as the paradox of plenty, is found in Borge et al. (2015), who find evidence for its existence in Norwegian municipalities receiving payments for hydropower generation. In fact, my findings also indicate that improvements in the administrative capacity of municipalities, which can arguably translate to more efficient use of resources, help reduce infant mortality rates, if only by 0.002 per thousand points for a one-point increase in the institutions' measure. It is intriguing, however, that according to my findings, the paradox of plenty would be especially salient in the health sector. Considering that there is enough (anecdotal) evidence suggesting that the health system is particularly prone to corruption in Colombia—e.g., by billing services or medicines that were never provided (see, for instance, El Tiempo 2018; Lewis 2006; Revista Dinero 2017)—provides support for the hypothesis that

Figure 1.1 : Predicted secondary enrollment by royalties and institutions



corruption is very likely part of the explanation for the missing effect of royalties on infant mortality rates.

Column (6) in Table 1.3 presents results for the average test scores of the nationwide school-leaving examination. According to that, a one million increase in hydrocarbon royalties leads to a decrease of almost 0.7 points in the test score average, which is equivalent to a decrease of about 0.2 points for the mean royalties. The effect is found to not depend on the quality of institutions, as indicated by the insignificant interaction term. At first, the finding of a negative effect might seem contradictory to the increasing secondary enrollment rates, yet there are several possible explanations reconciling both results. First, it is possible that higher attendance rates also imply an increasingly mixed quality of students. While able and motivated students might be the first to enroll and attend school, increasing enrollment brings in less motivated students who perform worse and decrease the average exam results. Thus, when considered in isolation, the finding of higher royalties leading to lower average test scores suggests a negative development in the education sector. However, combining this result with higher enrollment rates allows a more optimistic reading.

A second explanation considers possible tradeoffs between quantity and quality. In that respect, in their eagerness to improve enrollment rates, municipality officials might not pay much attention to the quality of education or deliberately choose to improve enrollment rates at the expense of quality via higher student-teacher ratios or the employment of poorly qualified teachers in order to keep costs low. While these are possible more direct mechanisms for this effect to come about, there are also potential mechanisms through the labor market. Natural resource booms and their spillover effects in other economic sectors can increase the demand for skilled and unskilled labor, increasing local wages and, hence, incentives for the youth to work and not attend school (James 2017). Students in Colombian resource-rich municipalities might, thus, start working prematurely, which leads them to pay less attention to school and perform worse on final exams. Similarly, increasing opportunity costs of further education, like apprenticeships or university study, might discourage the youth from pursuing further qualification. Therefore, the incentives to put effort into preparing for final exams decrease, accordingly affecting performance. To a certain extent, my results are in line with James (2017), who found evidence of high-school graduation rates to fall in U.S. resource-rich states as a result of booming resource sectors.

With respect to the control variables GDP and conflict intensity, Table 1.3 shows that, in general, the coefficients have the expected signs. That is, GDP is positively associated to enrollment rates and exam results, and negatively correlated to infant mortality rates. However, the coefficient is always insignificant in the fixed effects specifications, what might be the consequence of GDP not varying much over time during the period of analysis. Similarly, in all but one specifications, the correlation between conflict intensity and the development outcomes is statistically insignificant. Although there is an indication of a positive association between conflict and exam results, the low magnitude of the coefficient points to an economically insignificant association.

The importance of accounting for the role of institutions becomes salient by comparing the results in Table 1.4 with the fixed effects column of the respective development indicator in Table 1.3. For each of the dependent variables, the first column presents the results of the estimation of Equation (1.1), that is, completely omitting institutions, with the result that the effect of natural resources on secondary enrollment is overestimated. The second column corresponds to a model including the institutions measure but not its interaction with royalties, that is, neglecting the possibility that institutions could play a role in the way resources affect development. By including the measure for administrative capacity, the royalties' coefficient becomes slightly smaller, but it is still larger than the coefficient estimated using a model that also includes the interaction term. Thus, when institutions are not included in the analysis, their positive effect on the development measure is loaded into the natural resource measure, biasing the results. Importantly, the model in column (2) requires that the effect of increasing royalties on secondary enrollment is constant at each value of the institutional quality measure, yet, as we saw in column (2) of Table 1.3 the effect of royalties on secondary enrollment depends on institutional quality.

A similar pattern can be observed for exam results (see columns (5) and (6) of Table 1.4). By also capturing the positive effect of institutions, the coefficient on hydrocarbon royalties is biased upwards, so that it is less negative. Including administrative capacity but not its interaction with royalties the degree of the bias is reduced, yet, the coefficient on royalties is still biased towards zero.

Table 1.4 : Institutions as omitted variable

	(1) FE Sec. Enroll.	(2) FE Sec. Enroll.	(3) FE IMR	(4) FE IMR	(5) FE Exam Results	(6) FE Exam Results
HC Royalties	4.764^{***}	4.754^{***}	0.145	0.148	-0.615^{***}	-0.630^{***}
	(1.020)	(1.032)	(0.140)	(0.142)	(0.141)	(0.143)
Ad. Capacity		0.007		-0.002^{**}		0.002
		(0.006)		(0.001)		(0.002)
GDP	0.303	0.311	-0.033	-0.034	-0.002	0.063
	(0.288)	(0.288)	(0.028)	(0.028)	(0.088)	(0.062)
Conflict intensity	-0.003	-0.003	0.000	0.000	0.007^{*}	0.007^{**}
	(0.007)	(0.007)	(0.001)	(0.001)	(0.004)	(0.004)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,725	3,725	3,725	3,725	3,709	3,660
Nr. of municipalities	745	745	745	745	745	732
R^2	0.275	0.276	0.640	0.640	0.015	0.021
F-statistic	83.431	73.313	189.455	167.073	7.906	8.069

Notes: All regressions include year and municipality-fixed effects. Royalties and GDP are measured in millions of COP per capita. Robust standard errors clustered by municipality in parenthesis. ***/**/* indicate significance at the 1%/5%/10% level.

1.5 Robustness tests and extensions

1.5.1 Endogeneity of institutions

In this subsection I explore the possibility that the institutions measure is endogenous and implement two alternative strategies to address this concern. First, recalling the type of endogeneity I am considering leads ones attention to an approach that allows preserving and exploiting the panel structure of the data. The consideration was that past education might affect contemporaneous administrative capacity, and thus, since past education is contained in the error term, the institutions measure could be endogenous. Therefore, explicitly including past education in the model appears to be a promising approach to follow. As explained in Section 1.2.3, this requires employing a dynamic panel data estimator that allows one to control for the unobserved time-invariant municipality-specific factors while solving the inconsistency generated by the correlation between the differenced lagged dependent variable and the error term.

Table 1.5 : Dynamic panel data - Arellano and Bond estimator

	Fixed effects		Arellano and Bond	
	(1) Sec. Enroll.	(2) Exam Results	(3) Sec. Enroll.	(4) Exam Results
HC Royalties	4.245^{***}	-0.684^{***}	2.799^{***}	-0.464
	(0.876)	(0.164)	(0.778)	(0.334)
HC Royalties $\times$ Ad. Capacity	0.060^{**}	0.007	-0.013	0.012^{*}
	(0.027)	(0.005)	(0.015)	(0.007)
Ad. Capacity	0.006	0.002	0.014^{**}	-0.001
	(0.006)	(0.002)	(0.006)	(0.002)
GDP	0.406	0.078	0.149	0.041
	(0.288)	(0.061)	(0.182)	(0.079)
Conflict intensity	-0.002	0.008^{**}	0.007	0.005
	(0.007)	(0.004)	(0.006)	(0.003)
Lagged dep. variable			0.212^{***}	0.165^{***}
			(0.048)	(0.037)
Year FE	Yes	Yes	Yes	Yes
Observations	3,725	3,690	2,980	2,950
Nr. of municipalities	745	738	745	738
R^2	0.277	0.020		
F-statistic	66.276	7.213		
Chi-square			796.519	71.244
p-value serial cor. test			0.008	0.311

Notes: All regressions include municipalities and year-fixed effects. Royalties and GDP are measured in millions of COP per capita. Robust standard errors clustered by municipality in parenthesis. ***/**/* indicate significance at the 1%/5%/10% level.

I employ the Arellano-Bond estimator to estimate the models of education outcomes and present the results in Table 1.5, columns (3) and (4). The first and second columns present the results of the fixed-effects estimation in Table 1.3 to facilitate comparison. According to the estimates in column (3), royalties are found to have a positive and highly statistically significant effect on enrollment rates, yet the coefficient is much lower than in the fixed-effects models, implying that increasing royalties by one million COP per capita leads to an increase in enrollment rates by 2.8 percentage points. Moreover, the insignificance of the interaction term implies that the effect of royalties on the secondary enrollment rate does not depend on administrative capacity, that is, it is found to be constant for all values of the adminsitrative capacity index. The results also indicate that an increase of one point in the administrative capacity index leads to a 0.014 percentage point increase in secondary enrollment rates, which is admitedly a rather small effect. This result should still be interpreted with caution since an important model assumption is not satisfied. At the bottom of Table 1.5, the p-value of the test on serial correlation in the first differenced error terms indicates that the null hypothesis of no autocorrelation of order 2 is rejected, providing evidence of model misspecification.

With respect to the satisfaction of model assumptions, the picture changes for the model for exam results. There we see that the hypothesis of no autocorrelation of order 2 cannot be rejected, so that the model is correctly specified. As in the fixed effects model, the main effect of royalties on the results of the school-leaving examination is negative, though in this case the estimate is lower in absolute terms and statistically insignificant. Although only significant at the 10% level, the coefficient of the interaction term indicates that the effect of natural resource abundance depends on the quality of institutions.

Not only to further explore the endogeneity of institutions but also given that the specification for secondary enrollment do not satisfy the requirements of the Arellano-Bond estimator, I follow an alternative approach and present it in the following the results of the IV estimations. Here, I perform again the analysis for the three development indicators. Since I cannot preserve the fixed-effects framework, I induce an additional type of endogeneity that could be ruled out in the baseline specifications, namely endogeneity due to the correlation of unobserved time-invariant factors with the measure of institutional quality. An example is that more developed municipalities have stronger preferences for strong institutions. Thus, the endogeneity concerns apply not only to the education indicators but also to infant mortality rates. Table 1.6 corresponds to the estimations of the first stages, that is, of Equations (1.4) and (1.5). Since the first stages for the secondary enrollment and the infant mortality rate models are identical, they are presented together in columns (1) and (2). The first stage for the exam results regression are presented in columns (3) and (4), yet, as can be seen, the differences between columns (1) and (3) and columns (2) and (4) are negligible, so that the analysis of the first stages in columns (1) and (2) also hold for the first stages of the exam results model. The lower panel shows the F-statistic of the weak identification test and its p-value. According to these values, the null hypothesis that administrative capacity and its interaction with royalties are weakly identified can be rejected, though the F-statistic on the identification of the interaction term is much lower. As expected, municipalities with more colonial crown employees have, on average, a higher administrative capacity index today. Specifically, the magnitude of the coefficient implies that a further colonial crown employee is associated with a 0.01 points higher administrative capacity index, which is a plausible effect since one would expect rather low than very large effects. The coefficient on the effect of crown employees on the interaction term is significant at the 10% level and the magnitude is much lower, consistent with the result previously discussed. The other instrument, the interaction term between the number of crown employees and royalties, is statistically insignificant in both first stage regressions, indicating that the effects of the number of crown employees and royalties on administrative capacity and its interaction term with royalties are independent from each other.

Table 1.6 : First stage estimations of the IV approach

	Sec. Enroll. and IMR		Exam Results	
	(1)	(2)	(3)	(4)
	Ad. Capacity	RoyaltiesX Ad.Cap	Ad. Capacity	RoyaltiesX Ad.Cap
Nr. of crown employees	0.0113***	-0.0004*	0.0113***	-0.0004*
	(0.0025)	(0.0002)	(0.0025)	(0.0002)
HC Royalties	4.8575**	6.4828**	4.8792**	6.4793**
	(1.9725)	(2.9349)	(1.9715)	(2.9349)
HC Royalties $\times$ Nr. of crown employees	-0.5382	0.5259	-0.5436	0.5269
	(1.2274)	(1.1601)	(1.2282)	(1.1598)
GDP	0.0801	0.0338	0.0794	0.0339
	(0.0549)	(0.0222)	(0.0547)	(0.0223)
Conflict intensity	-0.0059	-0.0102	-0.0079	-0.0105
	(0.0160)	(0.0074)	(0.0161)	(0.0075)
Year FE	Yes	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes	Yes
Observations	3,460	3,460	3,449	3,449
Nr. of municipalities	692	692	692	692
F-statistic weak identification	18.992	8.415	18.910	8.463
p-value F-stat. weak id.	0.000	0.004	0.000	0.004

Notes: All regressions include year-fixed effects, a full set of region dummies and other geographic controls (latitude, longitude, elevation above sea level, distance to the department capital and to Bogota, share of cultivable land per capita, density of primary rivers, density of secondary rivers, density of tertiary rivers, annual rainfall, share of mountain land). Royalties and GDP are measured in millions of COP per capita. Robust standard errors clustered by municipality in parenthesis. ***/**/* indicate significance at the 1%/5%/10% level.

Table 1.7 presents the results of the second stage of the IV estimations. The first important observation is that, contrary to weak identification tests on the single endogenous regressors reported together with the first stages, the joint weak identification test for which the results are presented at the bottom of Table 1.7 indicate that overall the models are weakly identified. Weak identification can and does have consequences for the precision of the estimates, as we can see in their large standard errors. I perform endogeneity tests for each specification to see whether there is statistical support for the worry of endogeneity, and I find that there is not strong enough evidence that administrative capacity is endogenous. From the high p-value for the endogeneity test in the secondary enrollment and exam-results estimations, we see that it is not possible to reject the null hypothesis that administrative capacity and its interaction with royalties are exogenous. Already in the analysis in Section 1.2.3, there were no unambiguous indications of the potential endogeneity of institutions, and, according to the endogeneity test, endogeneity can be discarded. In the model where infant mortality is the dependent variable, the null hypothesis cannot be rejected at the 10% level, providing weak statistical support for the endogeneity concern. Nevertheless, endogeneity in this case is likely coming from time-invariant unobservable factors influencing both the institutions' measure and development (proxied here by infant mortality rates) and can be solved by the fixed effects estimation implemented in the baseline approach. Thus, from the estimation results in Table 1.7, I cannot draw conclusions on the influence of natural resource abundance on development: first, since these models do not account for heterogeneity across municipalities, which was found to be significant comparing the results of the OLS and FE estimations in Table 1.3; second, due to lacking support for the hypothesis of endogeneity, and finally, because the weak instruments do not allow even a moderately precise estimation.

1.5.2 Further robustness tests and extensions

In this section I present the results of alternative specifications to test the robustness of the presented results. A first robustness test consists of including tax revenue per capita instead of GDP per capita. The rationale for including GDP per capita was to control for overall municipality prosperity. Tax revenues will take on this role, specifically considering other sources of financial resources available to the municipality to invest in public goods. At the same time, they also provide some information about the administrative capacity of the municipality. Besley and Persson (2009) establish a link between state capacity and the ability to tax citizens. Moreover, this link is usually the motivation in the development literature to use tax revenue as a proxy for state capacity. However, it is inferior to the administrative capacity index as an institutions measure because over 70% of the tax revenues received by

Table 1.7 : Endogeneity of institutions - IV approach

	(1) IV Sec. Enroll.	(2) IV IMR	(3) IV Exam Results
HC Royalties	-3.318	20.463	-5.130
	(29.189)	(46.876)	(13.509)
HC Royalties × Ad. Capacity	1.334	-2.577	0.462
	(4.133)	(6.158)	(1.885)
Ad. Capacity	-0.686	-0.492	0.495^{***}
	(0.493)	(0.345)	(0.161)
GDP	0.397^{*}	0.046	-0.019
	(0.232)	(0.232)	(0.074)
Conflict intensity	-0.016	-0.035	0.012
	(0.051)	(0.064)	(0.022)
Year FE	Yes	Yes	Yes
Geographic controls	Yes	Yes	Yes
Observations	3,460	3,460	3,449
Nr. of municipalities	692	692	692
F-statistic	30.438	34.324	5.034
F-stat. weak id. test	1.175	1.175	1.168
p-value *F*-stat. weak id.	0.309	0.309	0.312
p-value endogeneity test	0.485	0.061	0.409

Notes: All regressions include year-fixed effects, a full set of region dummies and other geographic controls (latitude, longitude, elevation above sea level, distance to the department capital and to Bogota, share of cultivable land per capita, density of primary rivers, density of secondary rivers, density of tertiary rivers, annual rainfall, share of mountain land). Royalties and GDP are measured in in millions of COP per capita. Robust standard errors clustered by municipality in parenthesis. ***/**/* indicate significance at the 1%/5%/10% level.

the municipalities are regulated by national legislation, providing limited information about the municipalities' state capacity.[9] Columns (1), (3), and (5) in Table 1.8 show the results for each of the development indicators. We see that in both education equations, the coefficients on royalties remain quite stable, especially in their significance but also in their magnitude. The estimate of the interaction between royalties and administrative capacity in column (1) is a bit lower and significant only at the 10% significance level, which might be explained by tax revenues and administrative capacity capturing similar aspects of institutional quality. The estimate of the effect of administrative capacity on infant mortality rates even remains unchanged. Puzzling is the positive and significant coefficient on tax revenue, indicating

[9] For the two major municipal taxes, making up about 70% of the total, the national congress sets a range of the tax rates to be charged, the lower bound being always greater than zero (Observatorio Fiscal de la Universidad Javeriana 2018). This means that, although municipalities can set the specific rate, they all need to build the necessary capacity for tax raising.

that an increase of one million COP per capita increases the infant mortality rate by one per thousand living births.

A test of the sensitivity to basing the analysis in a longer time period is provided in columns (2), (4), and (6) of Table 1.8. To do so it is necessary to use tax revenue instead of GDP and to omit the institutions measure, which has only been available since 2005. This specification allows extending the sample to cover the period from 1996 to 2010 in the case of secondary enrollment, from 2005 to 2010 for the infant mortality rate analysis, and from 2000 to 2010 for exam results. According to the estimations, an increase of one million COP per capita royalties leads to a 4 percentage point increase in secondary enrollment rates, which is only 0.25 percentage points less than in the baseline specification. Thus, even considering that the coefficient on royalties is biased due to omitting the institutions measure and its interaction with the natural resource measure, one can argue that the results for secondary enrollment are quite robust to prolonging the sample period. On the contrary, the coefficient on royalties in the exam results specification becomes much smaller and loses its statistical significance. However, as we learned from the analysis of the results presented in column (5) of Table 1.4, omitting the institutions measure biases the coefficient on royalties towards zero. Therefore, we can conclude that the omission of institutions might explain at least a fraction of the drop in the magnitude of the coefficient. The counterintuitive finding of tax revenue increasing infant mortality rates survives, becomes even larger, and its statistical significance improves.

Table 1.9 presents in columns (1), (3), and (5) the results of replacing the natural resource measure by its first lag. For both education outcomes, the absolute magnitude of the coefficient on royalties is lower than in the baseline specification, but not dramatically so. A further difference from the baseline is the significant coefficient of the interaction between administrative capacity and hydrocarbon royalties in the exam-results regression. According to this, above average administrative capacity can mitigate to a certain extent the negative effect of natural resource abundance on exam results. Columns (2), (4), and (6) in Table 1.9 show the results of considering the royalties received in the last four years as the resource measure. This specification takes into account that it might take some time until the royalties received materialize into development outcomes. Although the magnitude of the coefficients decreases, the qualitative results remain.

An extension of the analysis consists in evaluating whether the results hold for all types of transfers from the national government and other intermediate levels of government,

Table 1.8 : Alternative controls and sample period

	(1) FE Sec. Enroll.	(2) FE Sec. Enroll.	(3) FE IMR	(4) FE IMR	(5) FE Exam Results	(6) FE Exam Results
HC Royalties	4.367***	3.983***	0.017	0.102	−0.569***	−0.113
	(1.021)	(1.227)	(0.109)	(0.071)	(0.203)	(0.264)
HC Royalties × Ad. Capacity	0.047*		0.003		0.006	
	(0.027)		(0.003)		(0.006)	
Ad. Capacity	0.006		−0.002**		0.002	
	(0.006)		(0.001)		(0.002)	
Tax revenue	−0.800	0.679	1.079**	1.121***	−1.153	−2.810**
	(6.559)	(6.543)	(0.508)	(0.418)	(1.454)	(1.235)
Conflict intensity	−0.001	−0.008	0.000	0.001	0.008**	0.001
	(0.007)	(0.008)	(0.001)	(0.002)	(0.004)	(0.001)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,725	9,570	3,755	4,926	3,690	7,425
Nr. of municipalities	745	638	751	821	738	675
R^2	0.276	0.363	0.640	0.641	0.020	0.019
F-statistic	66.484	84.930	152.396	184.267	7.196	5.812

Notes: All regressions include municipalities and year-fixed effects. Royalties and tax revenue are measured in millions of COP per capita. Robust standard errors clustered by municipality in parenthesis. ***/**/* indicate significance at the 1%/5%/10% level.

or whether they are specific to hydrocarbon royalties. Table 1.10 presents the results of such an analysis. Unlike royalties, other transfers are found to reduce infant mortality rates when administrative capacity lies above average values, as indicated by the highly significant coefficient on the interaction term. Since the administrative capacity index is centered at its sample average, the coefficient also means that, when administrative capacity is below average, transfers increase infant mortality rates. For the education outcomes, I find no significant evidence for other types of transfers having an impact on the respective outcome variable.

1.6 Conclusions

This study investigates the impact of natural resources on local development. I focused the analysis on Colombian municipalities, which are the second level of administrative subdivisions, after departments. Importantly, the assessment considers the role that local institutions play in this context. My analysis shows that there is no straightforward *yes* or *no* answer to the question whether natural resources constitute a curse or a blessing. As is often the case

Table 1.9 : Cumulative and lagged royalties

	(1) FE Sec. Enroll.	(2) FE Sec. Enroll.	(3) FE IMR	(4) FE IMR	(5) FE Exam Results	(6) FE Exam Results
HC Royalties (*t*-1)	3.510***		0.156		−0.607***	
	(0.964)		(0.160)		(0.211)	
HC Royalties (*t*-1) x Ad. Cap.	0.068**		0.003		0.010**	
	(0.028)		(0.003)		(0.004)	
Cum. HC Royalties		1.905***		0.116		−0.300**
		(0.582)		(0.086)		(0.140)
Cum. HC Royalties x Ad. Cap.		0.018**		0.000		0.003*
		(0.008)		(0.001)		(0.001)
Ad. Capacity	0.006	0.007	−0.002**	−0.002**	0.002	0.002
	(0.006)	(0.006)	(0.001)	(0.001)	(0.002)	(0.002)
GDP	0.371	0.332	−0.035	−0.040	0.090	0.100*
	(0.289)	(0.303)	(0.028)	(0.028)	(0.061)	(0.059)
Conflict intensity	0.001	0.001	0.000	0.000	0.007*	0.007**
	(0.008)	(0.008)	(0.001)	(0.001)	(0.004)	(0.004)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,725	3,725	3,755	3,755	3,690	3,690
Nr. of municipalities	745	745	751	751	738	738
R^2	0.276	0.277	0.639	0.640	0.020	0.020
F-statistic	66.264	65.569	149.198	148.954	8.579	5.891

Notes: All regressions include year and municipality-fixed effects. Royalties and GDP are measured in millions of COP per capita. Robust standard errors clustered by municipality in parenthesis. ***/**/* indicate significance at the 1%/5%/10% level.

in economics, the answer starts with "It depends". In this paper I find that, first, it depends on what is the outcome measure. Second, it depends on the quality of institutions. In sum and putting it in a positive narrative: I find natural resource abundance to be a blessing for education attainment in Colombian municipalities. This positive effect can be reinforced when institutions are sufficiently strong, that is, when municipalities have good administrative capacity, or the effect can be weakened when the quality of institutions is rather low. Thus, making sure that institutions are strong, and strengthening them in case deficiencies are encountered, should be the first step when planning the distribution and use of revenue coming from the extraction of natural resources. Measuring the capacity of local governments, as done by the administrative capacity index, is clearly an important step that needs to be followed by explicit capacity-building efforts.

For education quality, proxied by the average results of the nationwide school-leaving exams, the picture is less clear. Here, natural resource abundance has a negative effect on average exam results, which could have its roots in the labor market and in the quality of education that

Table 1.10 : Other types of transfers

	(1) FE Sec. Enroll.	(2) FE IMR	(3) FE Exam Results
Transfers	15.279	-0.661	-0.284
	(10.008)	(0.572)	(1.557)
Transfers × Ad. Capacity	0.124	-0.036^{***}	-0.013
	(0.102)	(0.012)	(0.035)
Ad. Capacity	-0.001	0.001	0.003
	(0.008)	(0.001)	(0.002)
GDP	0.230	-0.038	0.068
	(0.266)	(0.028)	(0.064)
Conflict intensity	-0.004	0.000	0.008^{**}
	(0.007)	(0.001)	(0.004)
Year FE	Yes	Yes	Yes
Observations	3,725	3,755	3,690
Nr. of municipalities	745	751	738
R^2	0.277	0.643	0.019
F-statistic	68.583	156.746	5.575

Notes: All regressions include year and municipality-fixed effects. Transfers and GDP are measured in millions of COP per capita. Robust standard errors clustered by municipality in parenthesis. ***/**/* indicate significance at the 1%/5%/10% level.

students receive, but it can also be explained by an increasingly mixed pool of students. All mechanisms might be part of the explanation. Thus, further research is needed to disentangle the effects and design appropriate policies leading to a better-educated society. Not finding evidence for health outcomes can have multiple reasons. I conjecture that corruption in the health sector can be an important explanation for the lack of effect of royalties on infant mortality rates, although financial resources streaming from royalties are supposed to be invested in reducing this indicator.

I explore the possibility that the measure for institutions is endogenous, although it is not clear a priori, whether the endogeneity concern is indeed justified. With the strategies followed, I am not able to entirely address a potential endogeneity, yet statistical tests provide support for the exogeneity assumption. All in all, based on these and further estimations considering alternative specifications, I do not find clear evidence of a resource curse in Colombian municipalities. On the contrary, secondary enrollment rates are positively affected by natural resource abundance, and even when the estimated effect on results of the school-leaving examination are negative, it is possible that the drop in the average is at least partly explained by characteristics of the newly enrolled students.

One interesting extension of this investigation would be to analyze the effects that dependence on royalty payments have on development outcomes. This would consider the royalties received by the municipality in relation to all income sources including taxes and other transfers. In such an analysis, it would be important to account for the endogeneity of natural resource dependence. A further research question in this context consists of an ex-post analysis of the new royalty law, which came into force in 2012 and redistributes royalty payments also to non-mining municipalities and departments. It would be interesting to assess what kind of effect this change has both in the mining municipalities—which now receive fewer resources—and in the non-mining ones—which suddenly receive new resources.

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2 Assessing the Effects of Climate Policy on Firms' Greenhouse Gas Emissions

2.1 Introduction

Growing concern over global warming has resulted in an increasing number of national policies designed to slow or halt climate change over the past two decades. Yet in the light of the fact that the climate is a global public good, there are concerns that these unilateral efforts are not sufficiently ambitious to effectively limiting greenhouse gas (GHG) emissions. Aside from the potential catastrophic consequences of climate change in the long run, ineffective policies can have a detrimental effect in the more immediate future because every policy implementation requires effort and resources that could have been put to different use. For this reason, it is important to assess the effectiveness of implemented climate policies so as to learn from past experiences and improve instruments found ineffective at reducing emissions.

Our study analyzes the effect of climate policy at the microeconomic level by examining companies' emissions. We focus our analysis on financial support schemes for renewables expansion and for energy efficiency improvements since these are the most frequently implemented instruments for climate change mitigation. As of 2013, 127 countries had support schemes for renewable energies in place (REN21 2013). In contrast, and despite of being considered the most efficient policy instruments, less than 40 countries have implemented explicit prices on GHG emissions either through an emissions trading system (ETS) or a tax on emissions (Kossoy et al. 2015; Somanathan et al. 2014; World Bank 2014a).

We assess several policy types simultaneously to obtain a direct comparison of the measures. To the best of our knowledge, no study has yet compared the effectiveness of different climate policy measures using company-level data from several countries. Previous research has addressed only two of these dimensions, typically focusing on either a single instrument or a single country. As a consequence, the resulting estimates are inherent to very specific contexts and lack cross-instrument or cross-country consistency and comparability. Besides having an important contribution to the generalizability of the results, this consistency and comparability are essential for policy advice.[1] In contrast to the existing literature, our cross-country, cross-policy panel approach enables us to identify climate policy measures that have proven to be effective in different contexts. Consequently, our research fills an important gap in the process of formulating policy recommendations for the choice and sensible combination of climate policy instruments.

The literature related to this study relies on three types of assessments that can be categorized as follows: the analysis of individual policies, meta-analysis as well as similar approaches to identify the emergence of conclusive evidence, and investigations of environmental regulation as a conglomerate of single measures. Abrell et al. (2011), Martin et al., (2014) and Martin et al. (2016) provide ex-post analyses of specific policies. The effects of the Climate Change Levy (CCL) and Climate Change Agreements (CCA) in the UK, for example, have been scrutinized in studies by Ekins and Etheridge (2006) and, more recently, by Martin et al. (2014). Using panel data in relation to the economic characteristics of plants and detailed information on their energy use, Martin et al. (2014) found the CCL to have reduced energy consumption and energy intensity of manufacturing plants in the UK for the period 2001–2004. Although it is important to analyze single measures in order to improve policies, approaches that compare policy instruments in different countries provide information on whether the lessons learned can be applied in other countries and on which types of policy are generally more effective.

Press (2007) highlights the usefulness of such an international assessment for policy-makers, yet it remains rare in the literature and has been approached mainly by the second category of studies. Harrington et al. (2004), for instance, provides 12 detailed case studies assessing, among other things, the effectiveness of command-and-control versus economic incentive instruments to tackle environmental problems. Analysis of the case studies did not allow the authors to clearly identify the comparative effectiveness of these instruments. The experience of Harrington et al. (2004) illustrates the difficulties in comparing case studies. Although a case study analysis would appear to be a promising method of assessing policies in different countries, the results of the comparison may be far from unambiguous. Also in the second category and with similar conclusions, Haug et al. (2010) conducted a meta-analysis of over 250 studies evaluating climate policies in European countries, finding too divergent results

[1] The evaluation of multi-instrument combinations in multi-country settings is of particular interest for specific target groups such as integrated assessment modelers or transdisciplinary policy projects employing multi-agent based firm modeling, whose requirements motivated our research.

to being able to draw conclusions on the effectiveness of climate policies. In this paper, we employ an econometric approach capable of simultaneously assessing different policy types and control for relevant country and company characteristics, enabling us to single out the effect of each policy type on corporate emissions, while allowing comparability across policies.

The third strand of the related literature investigates the effects of environmental regulation (as a conglomerate of single measures) on pollutant emissions. While Cole et al.'s (2005) analysis for the UK was performed at industry level, Féres and Reynaud (2012) studied the response of plants' emissions in the Brazilian state of São Paulo, with both of them finding a negative effect of regulation on emissions. Similarly, Cheng et al. (2017) and Zhao et al. (2015) assessed the effects of environmental regulation in China, distinguishing between command-and-control policies, market-based instruments, and (in the case of Zhao et al. (2015)) government subsidies. Using province-level data, the former study found that command-and-control regulation reduces emissions, while the latter did not identify any effect of this type of policy using plant-level data. The picture for market-based instruments is different. Cheng et al. (2017) established a weak impact on emissions reductions, whereas Zhao et al.'s (2015) results revealed a positive effect on emissions reductions. Thus, these studies provide a comprehensive picture of the effects of climate or environmental regulation as a whole on emissions, nevertheless they do not allow to single out the effects of single policies types and the results are very specific to the jurisdictions for which they are conducted.

Summing up, this paper contributes mainly in two ways to the existing literature. The first contribution consists in the novel combination of analyzing company-level emissions and multiple climate policy instruments in a cross-country panel setting. This combination expands the literature in three dimensions. First, we study the effect of climate policy at the microeconomic level by examining firms' emissions. Second, we assess several policy types simultaneously to obtain a direct comparison of the measures' effectiveness. Finally, our cross-country approach makes it possible to give a general answer to the question of whether climate policy has been effective in reducing greenhouse gas emissions. Related to this, the second contribution of our work is to provide a foundation for further research on paths for national climate policies in a global context.

For our analysis, we use company-level emissions data collected through surveys conducted by the Carbon Disclosure Project (CDP) and policy measures collected in the Policies and Measures Database of the International Energy Agency. The policies analyzed consist of financial incentives to increase the use of renewable energy sources (RES) in electricity generation, the use of combined heat and power generation technologies (CHP), and energy efficiency (EE) improvement measures. Our analysis focuses on the largest global manufacturing, mining and quarrying, and utility companies and their operations in 39 OECD and BRICS countries. The final sample covers emissions by about 4,700 observations for the period 2007–2012. Total emissions in the sample comprised 23% of the total emissions of OECD and BRICS countries in 2007.[2]

The assessment is based on econometric regressions, where companies' emissions are explained by a set of variables indicating the number of policy measures introduced in the respective country. Moreover, in order to separate business-as-usual emissions from the policy effect, companies' economic activity is considered by including their revenues as a control variable. Other characteristics, including company size, are also considered as determinants of emissions. By first differentiating the equations, we also control for time invariant observed characteristics (e.g., industry sector, and home country) as well as time invariant unobserved heterogeneity. However, the voluntary nature of emissions disclosures to CDP raises concerns about the representativeness of the data. If companies self-select into disclosure and non-disclosure based on the level of their emissions, the sample will be biased, as will the results. We therefore test and correct for sample selection in various ways, including a two-step procedure largely following Semykina and Wooldridge (2010). The results suggest that self-selection is not a pressing issue in our sample.

We find financial incentives and legal requirements for auditing companies' energy use to reduce their emissions. Moreover, our finding point to an initial increase in emissions by companies in non-utility sectors following the introduction of support schemes for combined heat and power generation. Three years after implementation this effect is already reversed, providing support for our hypothesis that emissions by non-utility companies increase because they start generating electricity and heat motivated by CHP support schemes.[3] According to our last result, feed-in tariffs aiming at increasing the use of renewable energy sources for electricity generation increase utilities' emissions. This might be due to renewable generation

2 BRICS countries are: Brazil, Russia, India, China, and South Africa.
Own calculations based on WRI (2016), CDP waves 2008–2013, and UNFCCC (2016)

3 Note that this result does not necessarily translate into an overall emissions increase since utility companies then need to generate less electricity, lowering their emissions.

crowding out generation by relatively clean fossil fuel plants of traditional utility companies, leading to a more CO_2-intensive generation by these companies on average.

The rest of this paper is organized as follows. Section 2.2 describes emissions data, policies, and other company and country data used for the analysis, as well as their sources and descriptive statics. Section 2.3 introduces the model for identifying the effect of climate policy on companies' emissions, and includes a discussion of endogeneity-related econometric issues and how they are addressed in this study. The results of the regressions analysis is presented in Section 2.4 and Section 2.5 contains concluding remarks and suggests several possible extensions of the analysis.

2.2 Data

2.2.1 Data sources and description

Emissions and participation data

It is vitally important when investigating the effects of national climate policy on corporate emissions that companies provide a country break-down of their GHG emissions and not only the company's global total. Emission figures of companies at the country level for the period from 2003 to 2012 were obtained from the Carbon Disclosure Project (CDP).[4] Emissions, expressed as metric tons of CO_2-equivalent (CO_2e), consist of so-called scope-1 emissions, that is, direct emissions from sources that are controlled or owned by the company (Greenhouse Gas Protocol 2014) and that are predominantly attributed to the combustion of fossil fuels. Scope-1 emissions do not include indirect emissions from the generation of purchased or acquired electricity, steam, heat or cooling consumed by the reporting company. The time period of the analysis was selected on the basis of the availability and quality of emissions data. Thus, since there is a great deal of information missing from the CDP waves of 2003 to 2007, only post-2008 waves were included in the analysis.

[4] CDP is a not-for-profit organization that collects information provided voluntarily on corporate emissions, energy use, and attitudes toward climate change from the largest companies in the world as well as from the largest companies in selected regions or countries. Table A.3 in the Appendix shows, as an example, the number of companies per country and region that were asked to report on climate change via CDP in 2013.

CDP's datasets also provide information on the industry sector, the company's country of incorporation, the company's International Security Identification Number (ISIN), and the CDP's account numbers. The latter were used to map CDP data across years, since responses to each CDP wave are in separate workbooks. Since account numbers were not available in the pre-2010 workbooks, company names were used to match companies to account numbers from later CDP waves.

In the data preparation process, a number of assumptions were made in order to allow comparability of the data. First, as some companies' reporting periods do not always coincide with calendar years, it was necessary to decide on a rule for assigning their emissions to a specific year. It makes sense to assign emissions to the year that coincides closest with the actual emissions period. For instance, emissions that were reported for the period between August 1 of year *t* and July 31 of year *t+1* were assigned to calendar year *t+1*.

CDP questionnaires allow the reporting of emissions for more than one year, which has two consequences for data availability and completeness. On the one hand, even if companies do not report emissions for one year, for example, due to a lack of information, they are still able to do so in a future CDP wave when information becomes available. On the other hand, it was noticed that companies reported emissions for the same year in different CDP waves, indicating that companies corrected their calculations as more information became available to them. After merging all CDP waves, this phenomenon resulted in "duplicate" observations with respect to the company, country, and year. Assuming that the more recently disclosed information was correct, any older observations were eliminated from the dataset.

There were three issues with CDP data that might have an impact on the analysis. First, the voluntary nature of CDP surveys raises the concern that companies might self-select into disclosure and non-disclosure, depending on the level of their emissions. The consequence for this study would be that the sample on which the analysis is based would not be representative, leading to a biased analysis. To control for self-selection, it is necessary that the same information set is available for respondents and non-respondents, with the exception of emissions. Thus, CDP, at our request, provided an additional dataset containing basic information (name, identification number, and sector) for all companies invited to participate in their surveys and the response status of each (i.e., either participated or not).

Second, the group of companies asked to report their emissions was not chosen randomly, but based on company size. This could be another source of selection bias, although in this case it would be generated by the sampling methodology and not by the companies' decisions. Fortunately, this potential problem was easily addressed by including the variable on which selection is based as an explanatory variable in the model, as will be shown in Section 2.3.1.

Third, the fact that emissions at the country level were obtained by asking companies to provide a country breakdown of their total global emissions indicates that disclosure decisions were not made in the individual countries where emissions were released but, for example, at the company's headquarters. This could affect the estimation, since in the process of correcting for self-selection, companies reporting emissions for several countries will be more heavily weighted than those reporting for only one country or those not disclosing at all. Thus, disclosing companies are more heavily weighted than non-disclosing ones, since the latter show up only once per year and the former several times, depending on the number of subsidiaries for which the companies are reporting. [5] To eliminate this bias, we used data from Bureau van Dijk's Orbis dataset indicating the countries where a company has subsidiary and the number of subsidiaries a company has in each country. Since the sample only consists of large and stock-listed companies, the typical ownership structure is complex and the spectrum of industries in which each of the ultimate parent companies is involved can be wide. A pre-analysis performed in collaboration with Bureau van Dijk resulted in the inclusion of only those subsidiaries for which the company in our initial dataset is a majority owner. Moreover, only subsidiaries whose two-digit NACE code coincided with the two-digit NACE code of the parent company were used for the analysis. Ownership relations as of the end of 2012 were assumed for the entire sample period.

Policy measures

Data on policy measures implemented in different countries were from three databases of the International Energy Agency (IEA 2015a): the Addressing Climate Change Database, the IEA/IRENA Global Renewable Energy Policies and Measures Database, and the Energy Efficiency Database. The policies were sorted by goal and similarity of the policy types. Table 2.1 provides a description of the types of policy in the different groups. Both policy types

[5] Moreover, companies do not necessarily report GHG emission levels for all countries where they have subsidiaries, leading to a similar source of bias as the mentioned above when correcting for self-selection.

aiming at the expansion of renewable energy sources consist in subsidies in a broad sense, yet they differ in that *RES loans and subsidies* are granted in relation to the investment costs or the installed capacity, while policies in the category *RES feed-in tariffs* are paid per actual amount of electricity generated.

Table 2.1 : Policy variables

Category	**Target**	**Description**
RES loans and subsidies	Increase the use of renewable energy sources for electricity generation	Loans at reduced or market interest rates, grants, subsidies, and tax relief
RES feed-in tariffs	Increase the use of renewable energy sources for electricity generation	Feed-in tariffs
CHP	Expansion of combined generation of heat and power	Grants, subsidies, and loans
Energy audits	Auditing the energy use of companies	Financial incentives or legal requirements
EE loans and subsidies	Increasing energy efficiency	Loans at reduced or market interest rates, grants, subsidies, and tax relief

Notes: Own compilation based on IEA Policies and Measures Databases.

For every year and country, the final dataset contains the cumulative sum of policy measures of every type implemented in 39 OECD and BRICS countries since 1970. Although it is clear that specific design and implementation details are important determinants of a policy's effectiveness, this count variable approach, together with a dummy variable approach, is one of the few means available for achieving comparability across countries given the current scarcity of data. In the empirical analysis, various possibilities of aggregating and averaging of policies were tested; the results remain robust.[6] Thus, we used the most basic approach as its interpretation is straight forward and consistent with the derivation of the estimation equation. During the data collection process, it was assumed that a type of policy was not implemented in a certain country if for that country none of the databases consulted listed a policy measure that could be assigned to that category. Although this is a plausible assumption, there remains the possibility that a policy measure existed but was not listed in the databases. Thus, we consider countries for which there are few policies in the databases as suspects of having poor data availability. [7]

[6] The alternative approaches followed in this context consisted in summing or averaging the number of policies implemented over the last 3, 4, 5 or 6 years.

[7] These countries are Belgium, Brazil, Chile, Slovenia, and Iceland.

Additional company and country data

Revenue data was available only for the companies that responded to the CDP survey (i.e., this information was not available for companies that chose not to participate). However, to control for self-selection, revenue data were needed for non-respondents and the Thomson Reuters' Thomson.One Banker dataset was used to this end. Since some companies' fiscal years differ from calendar years, revenue data were assigned to a calendar year using the same rule as for emissions data. Thus, revenues of companies whose fiscal year ended between August 1 of year *t* and July 31 of year *t+1* were assigned to calendar year *t+1*.[8] Market capitalization figures were retrieved as of December 31 of the year before each CDP wave.

Because companies, and also the Thomson.One Banker dataset, report financial data in the respective country's currency, these figures were converted to USD using the official exchange rates calculated as an annual average and reported by the World Bank in its World Development Indicators dataset (World Bank 2014b). The resulting revenues and market capitalization figures are expressed in million USD. To obtain real figures and to be consistent in terms of basis year and currency, revenues and market capitalization data were deflated using the GDP deflator of the U.S. Bureau of Economic Analysis with 2009 as base year (US BEA 2013).

Ideally, revenue information should correspond to the company's activity in each country, allowing the calculation of emission intensities for each subsidiary, that is, how many tons of CO_2e per USD revenue they emit. However, only figures for the entire company were available and so a weighting procedure was implemented to proxy for specific country revenues. The weighting factor for each company-country pair was calculated by dividing the number of subsidiaries a company has in each country by that company's total number of subsidiaries. Subsequently, the company's worldwide revenue was multiplied by the corresponding company-country weighting factor. This assumption is strong and various alternative specifications that are possible with the available data were tested. Fortunately, results are robust also in comparison to a small subsample with full revenue information.

Other data needed to control and correct for potential self-selection were extracted from Thomson Reuters' ASSET4 Environmental, Social and Corporate Governance (ASSET4 ESG)

[8] Revenue and emissions reporting periods coincide for the respective company both prior to and after the assignment of the periods to a calender year.

Dataset. ASSET4 gathers publicly available information from corporate social responsibility reports, company websites, annual reports, and NGOs on over 250 performance indicators (Thomson Reuters 2012). The extracted variable indicates whether a company monitors the protection of human rights in its facilities or those of its suppliers.

Data on industry electricity prices and prices for emissions certificates of the European Union Emissions Trading System (EU ETS), used in the sensitivity analysis, were obtained from IEA (2010 and 2015b) and the ICE ECX platform, respectively. Information on subsidiaries' participation in the EU Emissions Trading System (EU ETS) was obtained by matching the ISIN numbers and subsidiary countries with the dataset resulting from the Ownership Links and Enhanced EUTL Dataset Project (Jaraite et al. 2013). This dataset identifies the ultimate owners of the installations covered by the EU ETS.

Matching process and resulting sample

Emissions, financial data, and ASSET4 indicators were merged using CDP account numbers and years. Subsequently, policy and other country-specific data were matched to company data by country and year. For expositional reasons, the combination of country of emissions and company will be referred to as a subsidiary below.

Since financial and ASSET4 data were not available for all observations, the initial sample of over 100,000 observations was reduced to a final balanced sample of about 34,000 observations. More details on the data are provided below.

2.2.2 Descriptive statistics

Summary statistics are set out in Table 2.2. The *Subsidiary level* panel reveals that the average subsidiary in the sample had a yearly revenue of one billion USD and emitted around 1.3 Mt CO_2e a year. Disclosing emissions is the dependent variable in the first-stage regression of the selection-correction procedure and takes the value 1 whenever subsidiary emissions were disclosed in two consecutive years. Its mean tells us that out of 34,045 observations, we have the CO_2e emissions levels for 14% of the final sample, corresponding to 4,788 observations. The *Corporate level* panel of Table 2.2 shows descriptive statistics for the whole corporation. The revenues of the average company in our sample amounted to around 15 billion USD and its market capitalization value was 14.4 billion USD. The statistic for the human rights monitoring variable indicates that 21% of the corporations in the sample monitored human rights on their premises.

With respect to the policy variables, we see that *RES loans and subsidies* was the policy type most frequently implemented, while *Energy audits* were the least frequently implemented. The average cumulative number of policies of the type *RES loans and subsidies* was around 15, followed by *EE loans and subsidies* with almost 5 instruments of this type. Table 2.2 also shows that none of the policy types was in place in the whole set of countries. Moreover, there is significant variation across all policy variables.

Table 2.2 : Descriptive statistics

	Mean	Std.Dev	Min	Max
Subsidiary level:				
Disclosing emissions	0.14	0.35	0	1
Metric tons CO2e	1,337,436.39	6,726,845.33	.7	156,300,000
Weighted revenues, million USD	1,118.39	4,483.90	.0036	179,271
Policy variables:				
RES loans and subsidies	15.45	11.07	0	41
RES feed-in tariffs	2.03	2.31	0	9
CHP	1.06	1.57	0	6
EE loans and subsidies	4.87	7.74	0	28
Energy audits	0.25	0.57	0	2
Corporate level:				
Revenues, million USD	15,317.23	27,361.92	.021	266,998
Market capitalization, million USD	14,408.64	26,166.60	.0003	475,892
Human Rights Monitoring	0.21	0.41	0	1
Observations	34,045			
Uncensored Observations	4,788			

Notes: Summary statistics for the Corporate level panel were calculated considering one observation per company and year, corresponding to a total of 1,049 company-year pairs.

Since sample selection is a possibility, it is interesting to see whether disclosing firms differed significantly from non-disclosing firms. This analysis took place at the corporation level because the decision to report emissions to CDP is most probably made at corporate headquarters. Sample statistics of company data were drawn for both groups, making sure only one observation per year and per corporation entered the calculation. These are presented in the *Corporate level* panel of Table 2.3. Disclosing firms were on average 1.5 times as large and generate 1.5 times the revenue of their counterparts. Thirty-seven percent of the disclosing companies monitored human rights protection on their premises; only 15% of the non-disclosing companies did so. Additionally, two-group mean comparison tests were applied to the revenue, market capitalization, and human rights monitoring variables. With a p-value below 0.001, the results indicate that in all three cases the hypothesis that the averages for the disclosing and non-disclosing group are equal can be rejected. Thus, firms with higher revenues, those that are larger, and those that monitor human rights are more likely to report their emissions. Moreover, the mean comparison test applied to weighted revenues (see *Subsidiary level* panel of Table 2.3) indicates that subsidiaries for which emissions were disclosed by their parent company were larger in terms of revenue than subsidiaries for which no emissions data were available.

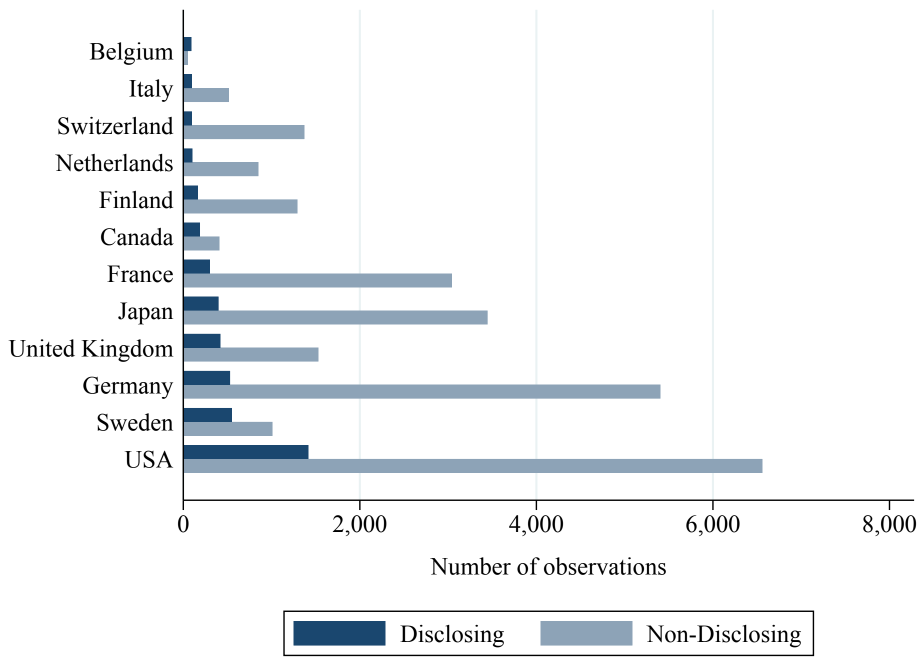
Table 2.3 : Disclosing vs. non-disclosing companies

	Not disclosing	Disclosing	Difference
Corporate level:			
Revenues, million USD	13,252	20,525	7,273***
	[26,023]	[29,865]	(1,038)
Market capitalization, million USD	12,545	19,108	6,563***
	[26,475]	[24,770]	(993)
Human Rights Monitoring	.15	.37	.22***
	[.36]	[.48]	(.015)
Observations	2,413	957	3,370
Subsidiary level:			
Weighted revenues, million USD	956	2,112	1,156***
	[4,146]	[6,066]	(70)
Observations	29,257	4,788	34,045

Notes: The Mean Diff. column reports the significance levels of a two-group mean comparison test with unequal variances, *** p<0.01, ** p<0.05, * p<0.1. Standard deviation in brackets, standard error in parentheses. Statistics for the *Corporate level* panel were calculated considering one observation per company and year.

Figure 2.1 illustrates the disclosure behavior of companies registered in selected countries. Most of the observations in the sample were attributable to companies registered in the USA, followed by German and Japanese companies. Moreover, companies from these countries comprised around 50% of the disclosing company-year pairs. The figure also shows how in all cases the number of censored observations was much higher than the number of observations for which emissions were disclosed. Figure 2.2 allows a closer look at the disclosing companies and their emissions in each country. Out of the 6,400 Mt CO_2e released by the companies in the sample between 2007 and 2012, emissions of close to 1,800 Mt CO_2e occurred in the USA, over 900 Mt in Germany, and around 500 Mt in both the UK, Canada and Japan. Although it is tempting to make sweeping statements as to how dirty or clean companies are in different countries, the number of subsidiaries differs dramatically. While in the USA 1,800 Mt CO_2e were released by about 640 observations, in Brazil 186 observations were responsible for the 70 Mt emitted in that country during the sample period.

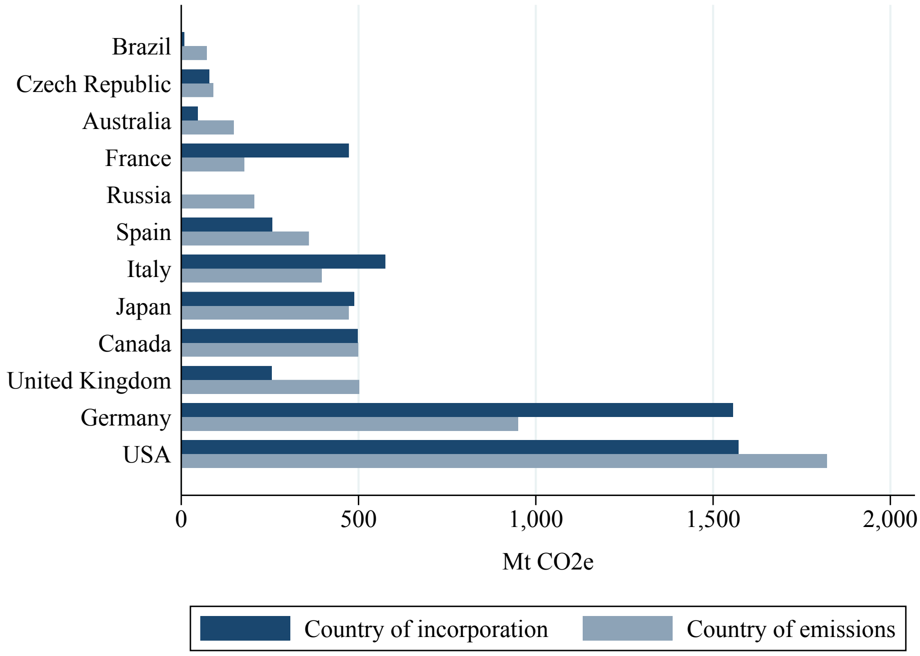
Figure 2.1 : Disclosing and non-disclosing company-year pairs by country of incorporation



Notes: The countries shown in the figure were selected according to the number of disclosing subsidiaries. Own calculations based on CDP waves 2008–2013.

Figure 2.2 also shows emissions released in each country and emissions that can be attributed to companies incorporated in the same country. For instance, German companies emitted around 1,500 Mt CO_2e across all OECD and BRICS countries —as indicated by the dark blue bar— while emissions amounting to 900 Mt CO_2e were released in Germany by subsidiaries of companies incorporated in Germany or any other country. The difference between the two bars for each country might be viewed as a kind of emissions balance: for example, German, French, and Italian companies emitted more in OECD and BRICS countries than was emitted in their territories, while the opposite holds for the USA, the UK, and Spain. However, we should bear in mind the general reporting behavior of companies by country of incorporation (Figure 2.1) —Germany and France are among the countries with the largest number of reporting companies, which means that the emissions balance interpretation of Figure 2.2 should be made with some caution.

Figure 2.2 : Total emissions by country of emissions and country of incorporation (selected countries)

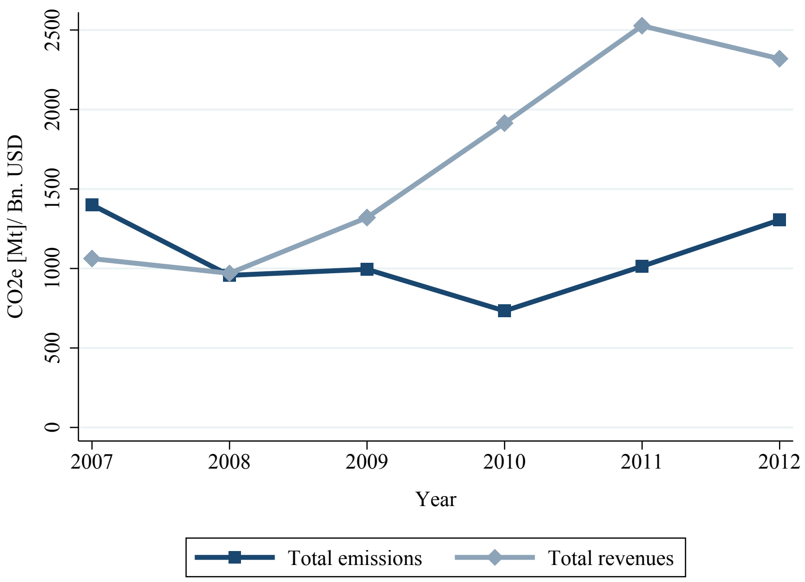


Notes: The countries shown in the figure were selected according to the level of emissions released by companies located in their territory. Own calculations based on CDP waves 2008–2013.

To gain insight into the development of emissions and revenues, total figures per year were calculated by adding up reported emissions across subsidiaries on the one hand, and revenue figures across reporting companies on the other. Figure 2.3 plots these totals. There is an overall upward trend in total revenues, with an acceleration in 2011 followed by a slight decrease between 2011 and 2012. In contrast, total emissions initially decrease and then start increasing in 2011. This pattern of acceleration of total emissions is likely due to the increased number of companies for which emissions data is available as the end of the sample period approaches. The figure is informative in the sense that it provides insight into the overall development of emissions and revenues of companies in the sample, but it can be misleading as the number of disclosing firms varies every year. Total revenues and emissions were thus divided by the number of subsidiaries to calculate the averages and avoid confusing a larger number of reporting companies with increases in emissions or revenues. The resulting plot, presented in Figure 2.4, shows fairly constant average revenues, except for the year 2009, during which companies experienced a fall in revenue, probably due to the outbreak of the financial crisis in 2008 and its expansion to the real economy. This is also one factor contributing to considerable emissions decline in 2009 and 2010. Specially the drop in 2009 and the slight increase after 2010 is a pattern that is not unique to our sample of firms, but can be observed for the total emissions of OECD countries when looking at additional data by UNFCCC (2016). The significant drop in average emissions can also be partly explained by changes in the composition of the sample. With smaller firms both in terms of revenues and emissions starting to report, average emissions drop. These changes in the composition of the sample do not, however, represent any concern for the analysis presented in Section 2.4, as we find when performing the analysis only considering subsidiaries for which emissions data is available every year of the sample.[9]

The different trends observed for average emissions and revenue during the sample period point to a decoupling of these two outcomes of production and indicate that the observed emissions reductions cannot be attributed solely to deceleration of the economy or the changes in sample composition. Whether this apparent decoupling is the result of climate policy will be analyzed in the following section.

Figure 2.3 : Development of revenue and emissions (2007–2012)



Notes: Total revenue was calculated using weighted revenue figures. Own calculations based on CDP waves 2008–2013, Thomson.One Banker, and Orbis.

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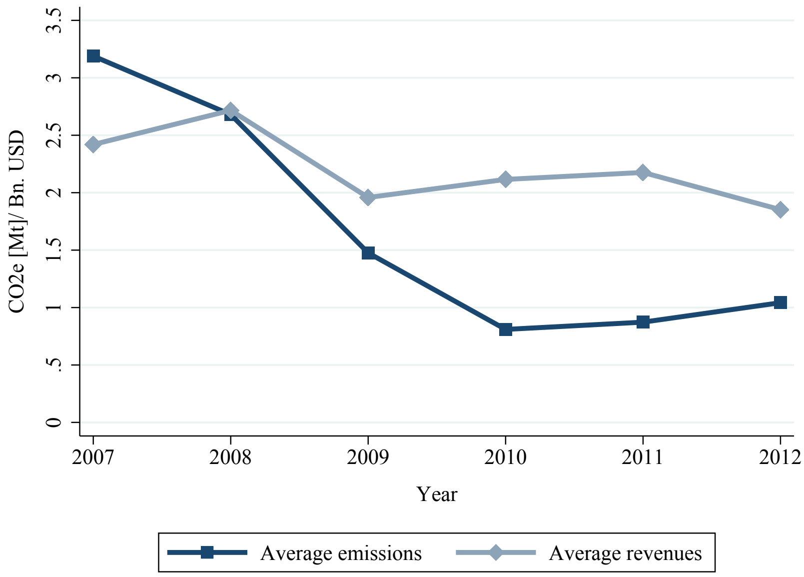
[9] Table A.1 in the Appendix shows the results of the mentioned regression in the second column and our preferred specification in the first column, to facilitate comparison. While the estimated coefficients remain fairly unchanged, we see a lower statistical significance of the coefficients, which is probably due to the reduction in the number of observations by about 25%.

Figure 2.4 : Development of average revenue and emissions (2007–2012)



Notes: Average revenue were calculated using weighted revenue figures. Own calculations based on CDP waves 2008–2013, Thomson.One Banker, and Orbis.

2.3 Identificaiton strategy

2.3.1 Explaining emissions

The analysis of the effectiveness of climate policy on companies' emissions involves much more than simply noting upward or downward trends in emissions; it requires the consideration of factors that might explain this development in the absence of regulation. For example, changes in production level are one of the most obvious reasons for changes in emissions and, indeed, have been found by other authors to be a significant predictor of emissions (Abrell et al. 2011). In general, an expansion of production is accompanied by higher emission levels, and vice versa. Therefore, to control for changes in production level, changes in companies' revenues are included as an explanatory variable.

Company size is also found to be an important determinant of emissions, possibly because larger companies have better access to environmentally efficient technology (Blackman 2010; Féres and Reynaud 2012). In this study, market capitalization figures are used as a proxy for company size. Another reason for taking market capitalization into consideration is that CDP uses this figure as a criterion for participation in its surveys; hence including it in the model as an exogenous explanatory variable prevents selection generated by sampling methodology from becoming an issue. This means that, arguably, we are dealing with exogenous sample selection, which does not affect the estimation (Wooldridge 2009).

We could consider the direct and indirect effect of informal regulation on pollution, which is shown in some studies to be non-negligible (Cole et al. 2005; Féres and Reynaud 2012).[10] However, community pressure on both polluters and regulators is likely to be limited in the special case of GHG, as the local effect of emission by companies located in a specific area is so small that it is hardly perceivable by the community. In fact, Cole et al. (2005) found that informal regulation has very little influence on CO_2 emissions; thus this type of regulation is not considered in the present analysis.

The relationship between changes in emissions and the above-discussed determinant factors can be expressed as:

$$ln(E_{it}) = \boldsymbol{\beta_p}\mathbf{POL_{ct}} + \beta_r ln(R_{it}) + \beta_m ln(M_{it}) + \mu_{it}^E \quad (2.1)$$

where E_{it} is GHG emissions of subsidiary i in year t, R_{it} represents deflated revenues, and M_{it} is deflated market capitalization. $\mathbf{POL_{ct}}$ is a vector of variables capturing the different policy measures in country c with which firms are confronted, that is, the variables of interest. Each policy variable counts the number of measures implemented in the period from 1970 to the respective year t. The error term is represented by μ_{it}^E.

Equation (2.1) represents the relationship of interest, yet estimating it with ordinary least squares (OLS) could lead to biased estimates due to three potential sources of endogeneity: unobserved heterogeneity, measurement error and self-selection. Each aspect is discussed below.

The first potential source of bias, the one arising from unobserved heterogeneity, is addressed by analyzing the first differences of the logarithms of emissions, revenue, and market capitalization. This goes beyond controlling for firm characteristics and takes account of unobserved subsidiary effects. Finally, we include a full set of year dummies, which is particularly impor-

[10] Informal regulation consists in communities exercising pressure on companies, for instance, by lobbying the firm directly, by ensuring media coverage of misconduct or lobbying local authorities to regulate the firm (Cole et al. 2005).

tant considering that the period of analysis includes the turbulent years following the 2008 financial crisis.

Second, it seems likely that at least some of the companies do not report their real emissions, either because they do not have complete information or because, for various reasons, they deliberately choose to exaggerate or underreport. For example, they might report inflated emission figures if they expect climate policies based on past emissions to be implemented in the near term. This would be the case for an emissions trading system that allocates allowances based on companies' historical emissions, so that over-reporting emissions would grant companies access to more allowances in the future. However, this is unlikely to be the chief consideration when disclosing emissions to CDP, simply because it is not an official data source on which regulation is based. On the other hand, underreporting would make companies appear cleaner, not only to communities and customers, but also to investors. Since the expected implementation of certain policy measures might affect the profit prospects of the companies concerned, investors should, in theory, consider a company's emissions level in their risk assessments and be less interested in "dirty" companies. Thus, it seems more reasonable that measurement error would go in the direction of companies underreporting their emissions. If the degree of underreporting remains constant over the years, it will be canceled out by first differencing emissions and, therefore it will not have any consequences for the estimated effect of the policies.

The third source of endogeneity arises from the fact that our emissions data are taken from a survey in which many companies did not participate, and some of those that did participate did not provide information on their emissions, resulting in a non-random sample. As this issue is the main methodological challenge for the present study, the following subsection is dedicated to analyzing the selection problem and discussing the measures taken to address it.

With respect to the policy variables, an important implication of the fact that the measures of the *RES loans and subsidies*, or *RES Feed-in tariffs* types are aimed at increasing the use of RES for electricity generation is that presumably they more strongly influence the emitting behavior of companies in the *Utilities* sector than of manufacturing companies. A similar consideration applies to grants, loans, and subsidies for combined heat and power. Since *CHP*-type policies target electricity and heat generation, their effect on utilities' GHG emissions is expected to differ from their effect on other sectors' emissions. To take these factors into consideration, the above-mentioned policy variables enters the analysis interacting with the dummy variable identifying utility companies.

Thus the policy vector in (2.1) should be:

$$\mathbf{POL_{ct}} = \begin{pmatrix} reslosu_{ct} \\ ut_{it} \times reslosu_{ct} \\ resfit_{ct} \\ ut_{it} \times resfit_{ct} \\ chp_{ct} \\ ut_{it} \times chp_{ct} \\ eelosu_{ct} \\ indaud_{ct} \end{pmatrix}$$

where $reslosu_{ct}$, $resfit_{ct}$, chp_{ct}, $indaud_{ct}$, and $eelosu_{ct}$ represent the policies described in Table 2.1 and ut_{it} is the dummy variable identifying companies in the utilities sector.[11]

Thus, the relationship of interest expressed by (2.1) becomes:

$$\Delta ln(E_{it}) = \boldsymbol{\beta_{\mathrm{p}}} \mathbf{\Delta POL_{ct}} + \beta_r \Delta ln(R_{it}) + \beta_m \Delta ln(M_{it}) + \beta_t \Delta \xi_t + \upsilon_{it}^E \tag{2.2}$$

where ξ_t represents the unobserved year effects.

2.3.2 Controlling for self-selection

The self-selection problem arises because data on a key variable are missing as a result of the outcome of another variable, namely disclosure (Wooldridge 2002). If firms made their disclosure decision randomly, there would be no reason for concern. However, it could be that companies base their disclosure decision on their actual level of emissions. For example, cleaner companies might be proud to disclose their emissions information, whereas dirtier companies might wish to keep this information private. If this is indeed the case, the sample of reported emissions is downward biased. There are also good reasons to believe that companies active in some specific sectors or incorporated in a given country are more prone to disclose their emissions. For instance, companies active in a sector that is subject to

[11] *reslosu=RES loans and subsidies, resfit=RES feed-in tariffs, chp=CHP loans and subsidies, eelosu=EE loans and subsidies, indaud=Energy audit.*

regulation requiring the reporting of emissions may be more likely to disclose their emissions in the survey because they have already compiled the figures. Thus, the outcome of the disclosure decision is likely to be related to other regressors and to the dependent variable, which means that ignoring the issue could create an omitted variable bias, as pointed out by Heckman (1979).

Therefore, to control for the selection problem, a two-step procedure is applied, which involves the estimation of the following equations:

$$disc_{it} = \alpha_h HR_{it} + \boldsymbol{\alpha_z} \mathbf{Z_{ict}} + \boldsymbol{\alpha_m} \mathbf{\bar{Z}_{ict}} + \upsilon_{it}^D \tag{2.3}$$

$$\Delta ln(E_{it}) = \boldsymbol{\beta_p} \mathbf{\Delta POL_{ct}} + \beta_r \Delta ln(R_{it}) + \beta_m \Delta ln(M_{it}) + \beta_t \Delta \xi_t + \beta_l \Delta \hat{\lambda}_{it} + \upsilon_{it}^E \tag{2.4}$$

In (2.3) $disc_{it}$ indicates whether emissions information has been disclosed for subsidiary i in year t, and $\mathbf{Z_{ict}}$ is a vector containing the explanatory variables in (2.1). We follow Semykina and Wooldridge (2010) in controlling for time invariant unobserved heterogeneity in the selection equation by including the time averages of the exogenous variables, $\bar{Z}_{it}$, and estimating (2.3) for each year t using probit regressions. $\hat{\lambda}_{it}$, the inverse Mills ratio, is obtained using the estimates from (2.3), and included in (2.4) as an additional regressor that allows controlling for self-selection in the equation of interest.

This procedure requires the inclusion of an instrument in the first step. One important condition is that the instrument must be related to disclosure but not to emissions, either directly or indirectly through unobservable variables contained in the error term υ_{it}^E. Our instrument is a measure of the company's engagement in monitoring human rights (HR). Since monitoring is a prerequisite to disclosure, HR provides us with valuable information on a company's overall commitment to monitor and report on aspects beyond the financial sphere. Therefore, it is a relevant variable for explaining a company's willingness to disclose GHG emissions. The validity of HR as an instrument is motivated by the fact that monitoring human rights has no relationship to GHG emissions, since it represents a social rather than an environmental concern. Nevertheless, it could be the case that companies that care about the environment also care about social aspects, and vice versa. Thus, companies that monitor the protection of human rights on their premises would also tend to have lower emissions levels. The main factor that gives us confidence about the validity of the instrument is that HR is measured at the corporate level while emissions are measured at the subsidiary level, generating some distance and therefore independence between human rights monitoring decisions and decisions concerning emissions behavior. Nonetheless, this does not affect the connection between HR and emissions disclosure since they are both measured at the corporate, that is, at the headquarters, level. There is no appropriate way of testing the exclusion restriction, but we can, and did, check whether there is a significant correlation between human rights monitoring and emissions. No significant correlation was found; thus, we can rule out an obvious violation of the restriction.

2.4 Data analysis

2.4.1 Estimation results

Table 2.4 sets out the estimation results. The results in columns (1) and (2) correspond to a model estimated on the subsample of emitting units for which emissions figures are available, ignoring the possibility of selection bias. The first column presents the result of an OLS estimation, without considering any of the endogeneity concerns raised in Section 2.3.1, while the second correspond to the estimation results for (2.2). Specification (3) presents the results of the second step of the selection correction procedure, estimated in first differences.

Comparing Specifications (2) and (3), we see that the significance and magnitude of the coefficients are maintained irrespective of the estimation method. An important observation from Specification (3) is that the coefficient of the parameter λ is statistically significant at the 10% level, giving some indication of the presence of self-selection.[12] The results for the disclosure equations are presented in Table A.2 in the Appendix. Each column presents the estimations result for each year of analysis. We see that human rights monitoring is in fact a relevant predictor of disclosure, as indicated by the highly significant coefficient estimates. Considering both coefficients on the human rights monitoring variables (the one on levels and the average over the sample period, introduced to account for the companies' heterogeneity) we see that, all else being equal, companies that monitor human rights on their premises are more likely to disclose their country-wide emissions. The results also indicate that for most

[12] We also perform the selection correction procedure using bootstrapping in order to take into account that λ is an estimated parameter and, therefore, its standard error needs to be adjusted. In that case, the standard error increases only by about 0.004 points, which does not have any implications for the statistical significance of λ.

years the probability of disclosure is higher for companies with higher market capitalization, which is in line with the findings by Prado-Lorenzo et al. (2009).

Since the results from Specifications (2) and (3) are very similar, the rest of the analysis deals with the results of the first-differences specification (column (2) of Table 2.4). Among the results for the policy measures of interest we find that financial incentives and legal requirements for energy auditing have a highly significant negative effect on emissions, so that an additional policy measure of this type reduces emissions by about 7%. One straightforward mechanism that could drive these results is that, after auditing their energy use, companies realize the cost savings potential of efficiency improvements, and thus implement new emission-reducing measures.

Moreover, the results indicate that the effect of feed-in tariffs aimed at increasing the use of renewable energy sources for electricity generation have a different effect on utilities' emissions than on other companies' emissions. If we perform the regression on the subpanel of utility companies, we find that, overall, this policy type increases utilities' emissions by 8.9% on average and that this effect is statistically significant. Although this finding might be surprising at first, a possible explanation involves considering the technology portfolio of utility companies and observations from the German electricity market, where CO_2 emissions per generated kilowatt hour increased between 2010 and 2012, according to the German Federal Environmental Office (Umweltbundesamt 2015). A possible mechanism driving this result can be explained in the following way. Since cleaner, more expensive fossil fuel power stations are placed at the bottom of the merit order, an increased generation from RES (which are financed by feed-in tariffs and either have preferential entry into the electricity network or are placed at the top of the merit order due to their low marginal costs) crowds out cleaner fossil fuel power stations from the wholesale market. As a result, generation by traditional utility companies is now dirtier on average. The use of the German example as an explanation might cause the reader to think that the results are specific to Germany, and yet running the regression without subsidiaries located in that country generates the same results. Thus, while the underlying mechanism might be different for other countries, we show that RES feed-in tariffs increasing utilities' emissions is not a phenomenon specific to Germany. This result shows that well-intentioned policies can lead to unintended outcomes, at least in the short run, by inducing behavioral changes in market actors. A theoretical motivation for this effect is provided by Böhringer and Rosendhal (2010).

Table 2.4 : Regression results OLS, FD and selection correction

	CO2e emissions		
	(1) OLS	(2) FD	(3) Selection cor. FD
RES loans and subsidies	-0.002	-0.007	-0.006
	(0.010)	(0.006)	(0.006)
UtilityxRES loans and subsidies	0.015	-0.004	-0.009
	(0.042)	(0.014)	(0.014)
RES feed-in tariffs	-0.048	-0.006	-0.002
	(0.050)	(0.012)	(0.013)
UtilityxRES feed-in tariffs	-0.091	0.057^{**}	0.057^{**}
	(0.137)	(0.028)	(0.028)
CHP	0.175^{***}	0.039^{**}	0.040^{**}
	(0.053)	(0.015)	(0.016)
UtilityxCHP	-0.136	-0.007	-0.019
	(0.276)	(0.032)	(0.037)
EE loans and subsidies	0.014	0.037^{**}	0.036^{*}
	(0.010)	(0.018)	(0.020)
Energy Audits	-0.115	-0.069^{***}	-0.064^{***}
	(0.116)	(0.022)	(0.023)
λ			0.095^{*}
			(0.053)
Year FE	No	Yes	Yes
Observations	6556	4349	4307
R^2	0.914	0.017	0.019

Notes: All regressions include revenue and market capitalization. Robust standard errors clustered by country. ***/**/* indicate significance at the 1%/5%/10% level.

Support schemes for CHP have a positive effect on the emissions of non-utility companies, while they do not seem to have a statistically different effect on the emissions of utility companies, as shown by the interacted coefficient.[13] The results can be seen as an indication that the introduction of CHP support schemes leads to an increase of about 4% in the emissions of companies in other sectors. A plausible mechanism causing this result is that the support scheme incentivizes companies in the manufacturing and mining and quarrying sectors to engage in power and heat generation as self-suppliers instead of purchasing it. While this

[13] An additional regression including only utility companies indicates no statistically significant effect of this type of policy on the emissions of utility companies.

"new product" increases companies' emissions, it is not sold and is therefore not reflected in their revenues. Even though this increases scope-1 emissions, on which the econometric analysis is based in the respective company, the global effect on emissions is ambiguous since indirect scope-2 emissions are reduced due to a decline in purchased electricity.

The coefficient estimates for energy efficiency improvement measures are positive, suggesting a rebound effect beyond 100%, and thus an increase of emissions. Saunders (2000) coined the term "backfire" for this special case of the rebound effect. This result is consistent with previous studies, e.g the empirical analysis of energy efficiency improvements of Brännlund et al. (2007) for Swedish households and Mizobuchi (2008) for Japanese households. Puzzling at first sight, Mizobuchi (2008) shed light on the mechanism behind this observation. The rebound effect can be decomposed in a direct and an indirect rebound effect. The former manifests itself as energy efficiency improvements for a specific energy service causing reductions in the effective price of that service and consequently leading to an increase in its consumption and therefore in emissions. That is, the initial negative effect on energy consumption and emissions would then be partially offset by the effect of the reduced effective price (Brännlund et al. 2007; Sorrell and Dimitropoulos 2008). The indirect rebound effect results from an income effect. The lower effective price for the energy service sets income free that is spent for the use of other inputs or in other production processes, and thus increase emissions. Brännlund et al.'s (2007) result showing a rebound effect of over 100% was contested by Mizobuchi (2008), who founds that the magnitude of the rebound effect is reduced from 115% to 27% when the capital costs for energy efficient appliances are considered in the estimation. More energy efficient appliances are generally more costly than the inefficient ones. Thus, the additional income resulting from savings on energy service expenditures due to the energy efficiency improvement is partially offset by the expenditures for the additional capital. This reduces the indirect rebound effect and consequently the total rebound effect. Since the policy measure analyzed in this paper typically aim at reducing or eliminating additional capital costs for energy efficiency improvements, it comes as no surprise that this distortion in the capital costs results in the undesired effect. By effectively generating additional income for the companies, the indirect rebound effect is strengthened and total emissions might increase. In a comparable analysis, Mizobuchi (2008) shows that reducing the additional capital cost to zero increases his estimated rebound effect to 117%.

While the empirical evidence is not conclusive of the magnitude of the rebound effect, most empirical studies find much lower estimates (Sorrell 2007; Blanco et al. 2014). The difference to our results can be, at least partly, explained by the the fact that, in most cases, empirical investigations estimate the direct rebound effect in households, while the estimates considering both direct and indirect effects are higher. Moreover, as pointed by Sorrel (2007) the rebound effect could be larger for EE improvements by producers.

Table 2.5 : Extended time pattern of policy effects

	CO2e emissions		
	(1) FD	(2) FD	(3) FD
RES loans and subsidies t-1	-0.007	-0.003	-0.009
RES loans and subsidies t-2		0.004	0.005
RES loans and subsidies t-3			-0.003
UtilityxRES loans and subsidies t-1	-0.004	0.001	0.003
UtilityxRES loans and subsidies t-2		-0.027	-0.023^{*}
UtilityxRES loans and subsidies t-3			0.018
RES feed-in tariffs t-1	-0.006	-0.006	-0.003
RES feed-in tariffs t-2		0.001	-0.001
RES feed-in tariffs t-3			0.013
UtilityxRES feed-in tariffs t-1	0.057^{**}	0.044^{*}	0.061^{**}
UtilityxRES feed-in tariffs t-2		0.047	0.081^{**}
UtilityxRES feed-in tariffs t-3			-0.117
CHP t-1	0.039^{**}	0.060^{***}	0.083^{***}
CHP t-2		-0.045^{*}	-0.084^{**}
CHP t-3			0.002
UtilityxCHP t-1	-0.007	-0.009	-0.034
UtilityxCHP t-2		0.027	0.020
UtilityxCHP t-3			-0.124^{*}
EE loans and subsidies t-1	0.037^{**}	0.039^{*}	0.031
EE loans and subsidies t-2		-0.007	-0.003
EE loans and subsidies t-3			-0.009
Energy audits t-1	-0.069^{***}	-0.067^{**}	-0.067^{**}
Energy audits t-2		-0.034	-0.040
Energy audits t-3			0.085^{*}
Year FE	Yes	Yes	Yes
Observations	4349	4349	4349
R^2	0.017	0.019	0.020

Notes: All regressions include revenue and market capitalization. Robust standard errors clustered by country. ***/**/* indicate significance at the 1%/5%/10% level.

No effect on emissions was detected with regard to the remaining policy measure, that is, loans and subsidies aimed at increasing the use of renewable energy sources for electricity generation. A potential source of statistical insignificance of the coefficient of some policies might be the time lag between the implementation of a policy and companies using the support schemes offered. Accordingly, we extend the analysis by also including policies implemented two and three years prior to the measurement of emissions as presented in columns (2) and (3) of Table 2.5. The first column contains the results presented in column (2) of Table 2.4 to facilitate comparison. For most of the policies for which we find significant effects in our baseline specification, we observe that the results for the policies implemented in $t-1$ remain stable as we include additional lags. This is reassuring because we can be confident that, by performing the analysis as in column (1), we do not capture the effects of policies implemented in the past. However, the opposite might hold for *EE loans and subsidies* since its statistical significance is increasingly affected as we include the second and third lag of the policy variable.

An interesting finding from the extension presented in column (2) of Table 2.5 is that, in the case of CHP, emissions decrease again after an initial increase following the implementation of this type of policy. A possible interpretation of this result is that the effect of companies engaging in self-supply dominates in the first two years immediately after the implementation of a CHP support scheme. In the third year, the impact of efficiency gains of CHP (compared to separate heat and power generation) is more prevalent.

2.4.2 Sensitivity analysis

By analyzing the sensitivity of the estimated coefficients to specification changes and to the exclusion of specific countries and other groups of observations, we rule out a wide set of possible sources of bias. The first set of results is summarized in Table 2.6, where column (1) is identical to column (2) in Table 2.4. Table 2.6 shows the results we obtain when each policy type is analyzed separately. Coefficient estimates and their statistical significance remain unchanged for *RES feed-in tariffs* and the interaction of *CHP* and *Utilities*, but not for *EE loans and subsidies* and *Energy audits*, where we see a considerable drop in the absolute magnitude of the coefficients.

A further test consist in including the annual average of the price for emissions allowances of the EU ETS, to verify that none of our policy measure is capturing its effect on emissions. Since future contracts represent over 80% of all EUA transactions (Kossoy and Guigon 2012), we rely on the price of this type of contract for the analysis. For subsidiaries that are not covered by the system, including those in non-EU ETS countries, the price for emissions permits is assumed to be zero. Moreover, New Zealand had to be excluded from the analysis because, although the country has an ETS in force, we do not have any data on emission permit prices.

This time too, as reported in columns (2) and (3) of Table 2.7 we determine no significant differences in the results.

Table 2.6 : Sensitivity analysis - single policies

	CO2e emissions					
	(1) FD	(2) FD	(3) FD	(4) FD	(5) FD	(6) FD
RES loans and subsidies	-0.007	0.003				
	(0.006)	(0.005)				
UtilityxRES loans and subsidies	-0.004	0.001				
	(0.014)	(0.015)				
RES feed-in tariffs	-0.006		-0.004			
	(0.012)		(0.012)			
UtilityxRES feed-in tariffs	0.057^{**}		0.056^{**}			
	(0.028)		(0.026)			
CHP	0.039^{**}			0.042^{**}		
	(0.015)			(0.020)		
UtilityxCHP	-0.007			-0.011		
	(0.032)			(0.034)		
EE loans and subsidies	0.037^{**}				0.025^{*}	
	(0.018)				(0.014)	
Energy audits	-0.069^{***}					-0.050^{**}
	(0.022)					(0.020)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4349	4349	4349	4349	4349	4349
R^2	0.017	0.015	0.016	0.016	0.016	0.016

Notes: All regressions include revenue and market capitalization. Robust standard errors clustered by country. ***/**/* indicate significance at the 1%/5%/10% level.

Table 2.7 also shows the results of including industrial electricity prices as an explanatory variable. The motivation behind this test is the concern that companies engage in CHP generation as a response to higher electricity prices rather than to the support schemes analyzed here. The number of observations is reduced by more than 25%, since we only have electricity prices for OECD countries, and even then, we are missing data for some countries and years. The results indicate that our *CHP* variable does not pick up the effect of electricity prices. However, the coefficients for *EE loans and subsidies* and *Energy Audits* decline in magnitude and lose their statistical significance. In a further analysis, we run our baseline regression for the set of countries for which we have data on electricity prices and determine the same changes for the *EE loans and subsidies* and *Energy Audits* variables: a drop in the coefficient and no statistical significance. We can therefore interpret these changes as the result of dramatic changes in the sample composition rather than the coefficients on *EE loans and subsidies* and *Energy Audits* capturing the effects of electricity price changes.

Table 2.7 : Sensitivity analysis - EUA and electricity prices

	CO2e emissions				
	(1) FD	(2) FD	(3) Selection cor. FD	(4) FD	(5) Selection cor. FD
RES loans and subsidies	-0.007	-0.008	-0.006	0.004	0.002
	(0.006)	(0.006)	(0.006)	(0.009)	(0.014)
UtilityxRES loans and subsidies	-0.004	-0.004	-0.007	0.014	-0.016
	(0.014)	(0.014)	(0.014)	(0.026)	(0.044)
RES feed-in tariffs	-0.006	-0.007	-0.003	-0.012	-0.014
	(0.012)	(0.012)	(0.013)	(0.015)	(0.012)
UtilityxRES feed-in tariffs	0.057^{**}	0.055^{*}	0.055^{*}	0.068^{**}	0.074^{**}
	(0.028)	(0.028)	(0.028)	(0.028)	(0.035)
CHP	0.039^{**}	0.038^{**}	0.039^{**}	0.116^{***}	0.115^{**}
	(0.015)	(0.015)	(0.015)	(0.023)	(0.046)
UtilityxCHP	-0.007	-0.007	-0.018	-0.017	0.018
	(0.032)	(0.032)	(0.036)	(0.110)	(0.173)
EE loans and subsidies	0.037^{**}	0.038^{**}	0.036^{*}	0.028	0.029
	(0.018)	(0.018)	(0.020)	(0.026)	(0.031)
Energy audits	-0.069^{***}	-0.069^{***}	-0.065^{***}	-0.037	-0.010
	(0.022)	(0.022)	(0.023)	(0.031)	(0.035)
EUA price		0.012	-0.004		
		(0.027)	(0.030)		
λ			0.087^{*}		0.149^{**}
			(0.049)		(0.068)
Ind. electricity price					0.267^{**}
					(0.126)
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	4349	4305	4263	3072	2850
R^2	0.017	0.018	0.019	0.020	0.022

Notes: All regressions include revenue and market capitalization. Robust standard errors clustered by country. ***/**/* indicate significance at the 1%/5%/10% level.

Additional robustness tests consist of excluding different groups of observations. For example, we run several regressions omitting one country at a time and find only minor changes in the significance levels and magnitudes of most of the coefficients; however, *EE loans and* *subsidies* is statistically insignificant in some cases. Alternatively, we trim the dataset based on different thresholds but, again, coefficient magnitudes and significance remain stable.[14] We also conduct the entire analysis, including all robustness tests, for the sub-group of OECD countries. We do not observe any significant differences in the magnitudes of coefficients or significance levels, except for the different trimming options for which the results are more stable for OECD countries than for the entire sample. Finally, the observation that data availability in some countries might be poor challenges the assumption that a policy measure was considered not to be in place in a country if none of the datasets consulted listed the measure for that country. We therefore exclude the five countries that presumably have the poorest data availability (Belgium, Brazil, Chile, Slovenia, and Iceland) to verify that they do not distort the results. The findings do not differ significantly from those in our baseline regression.

2.5 Conclusions

This paper studied the effect of climate policy on companies' GHG emissions using emissions data for the headquarters and subsidiaries of the world's largest companies. In our empirical analysis, we found that four out of the five policy types investigated have a significant influence on companies' GHG emissions: feed-in-tariffs aimed at increasing the use of RES for electricity generation, grants and subsidies for CHP, loans and subsidies aimed at increasing energy efficiency and financial incentives or legal requirements requiring the auditing of a company's energy use. The findings were not sensitive to several changes in the model specification, except for the effect of loans and subsidies aimed at increasing energy efficiency, whose magnitude and significance changed in some specifications.

With respect to the direction of the impact, our results suggest that financial incentives and legal requirements for auditing companies' energy use reduce their emissions. In the case of support schemes for CHP generation, the estimations point to an increase in emissions by companies in non-utility sectors, possibly because these companies now have an incentive to engage in the production of electricity and heat for their own use, increasing their emissions. This effect is reversed in the third year after implementation of the policies. Feed-in tariffs

[14] In the baseline, we trim the data at the 1.5 and 98.5-percentile of emissions changes. The cutoff levels were chosen to only eliminate obvious and implausible outliers

aiming at increasing the use of renewable energy sources for electricity generation also seem to increase utilities' emissions. We explain this effect as the consequence of renewable energy sources crowding out cleaner fossil fuel power stations from the wholesale electricity market, which results in traditional utility companies' generation now being dirtier on average. With regard to policies aimed at increasing energy efficiency, we found weak evidence that they increase emissions in companies, yet the effect vanished when we included more lags of the policy variable. This might be an indication of an initial rebound effect, something worth analyzing more closely.

There are numerous possibilities for extending this analysis, especially considering that, to the best of our knowledge, no other similar studies have been conducted. An invaluable project would involve overcoming data issues. Exerting effort towards collecting a more detailed compilation of climate policy measures implemented (e.g., listing the amount of funding dedicated to each measure) and towards obtaining figures indicating the share of the companies' production taking place in each country would make a more reliable analysis possible.

These data improvements would additionally permit the study of other interesting research questions, such as the assessment of carbon leakage occurring through the investment channel. This phenomenon occurs when climate policy provokes the relocation of production away from countries with a strict climate policy to countries where climate policy is laxer, undermining the effects of policy measures implemented in the former countries (Babiker 2005; Felder and Rutherford 1993; Reinaud 2008).

This study has shed some light on climate policy effects at the micro level. We hope that more research along these lines will be conducted, in addition to research that improves the availability and quality of data, providing a solid foundation for climate policy evaluation.

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3 Economic Effects of Regional Energy System Transformations: An Application to the Bavarian Oberland Region

3.1 Introduction

The lack of ambitious responses to climate change from the international community and from national governments motivates subnational entities to set their own goals and formulate their own plans towards the reductions of greenhouse gas emissions in their jurisdictions. From an economics perspective, national unilateral efforts (not to mention subnational unilateralism) are by no means the first best response to a global problem. Yet, it is laudable that civil society comes together and becomes active when they hold the view that they can do more. This is the case of three districts in the Bavarian Oberland Region, who set themselves the target to generate as much electricity and heat from renewable sources as they consume by the year 2035. Since 2014 a research consortium accompanies the region in identifying its potential for renewables generation, the degree of acceptability of the different technologies and, based on this, formulating possible scenarios for how the transformation path might look like from now until 2035, as well as quantifying the economic effects.

As it is often the case in the policy debate, there is a strong interest from local decision makers in the economic effects of the transition to an energy system based on renewable energies. Thus, the purpose of this study is to analyze the effects of the different energy transition paths on regional value added and on employment, divided in three qualification levels: low-skilled, medium-skilled, and high-skilled employment. This endeavor poses four main challenges, whose solutions constitute our contributions to the literature. Our first and most important contribution lies in taking into account the scarcity of factors of production and of financial resources needed to undertake the investments, giving rise to crowding out effects. Related to that, our second contribution involves an extension of Fisher and Marshall (2011), Benz et al. (2014), and von Schickfus and Zimmer (2018) aiming at satisfying the needs of a regional analysis. Third, we base the analysis on an input-output (IO) table where the energy sector is disaggregated to better account for the specificities of each generation technology and its interconnections with the rest of the economy. Our fourth contribution consists in taking into account the fact that the three districts are not economically isolated but interact with each other and with other regions.

We find that the three districts on the Oberland region benefit from investments towards the regional energy transition, both in terms of additional value added and employment. Yet, there are some differences in the extent to which the districts benefit and the positive development comes at the expenses of value added and employment in the rest of the country. Moreover, our analysis shows that medium-skilled employment increases most across all scenarios. In the light of the current shortage of medium-skilled labor in Germany (Stippler et al. 2019), this finding represents an alarm signal that calls for integrating labor market considerations into climate policy strategies.

Previous work on the economic impacts of (renewable) energy policy can be summarized in three main strands: input-output analysis; ex-post econometric studies, focusing on specific regions or policies; and more complex models or meta-studies. A number of often policy-commissioned reports use standard input-output analysis, evaluating the additional demand for products in other sectors due to the construction (and sometimes operation) of renewable energy facilities (Bickel et al. 2009; Böhmer et al. 2015; Breitschopf et al. 2015; Hirschl et al. 2015; Höher et al. 2015; Lehr et al. 2015; Lehr et al. 2011; Lutz et al. 2014; O'Sullivan et al. 2014; Ulrich and Lehr 2014). Their contribution lies in the construction of a demand vector specific to the installation (or operation) of different renewable energy technologies. These studies suffer from three limitations: first, they often focus on the construction of renewable energy plants, therefore concentrating on a one-off effect and neglecting the phase of operations, in particular their structural effect changing the interlinkages and production structure in the economy. Second, they disregard scarcity aspects: in these models, the demand created due to renewables expansion is always additional and does not come at the expense of other economic activities. Third, these studies do not take cross-country interlinkages into account, ignoring the dimension of internationally traded intermediate and final goods. The same is true for scholarly articles using an input-output approach, such as Allan et al. (2007) or Lehr et al. (2008). Heindl and Voigt (2012) represent an exception with respect to the consideration of crowding out effects, yet the interlinkages between countries and regions are not accounted for in this study.

The second strand of literature concerned with the economic effects of renewables expansion is econometric. For example, in an ex-post econometric exercise controlling for economic structure and other socio-economic variables, Brown et al. (2012) confirm the positive economic and employment effects of wind power expansions found in input-output studies. In a recent analysis, Buchheim et al. (2019) show that the employment effects depend on the tightness of the labor market, the effects being larger when unemployment is high. However, such econometric studies also mostly focus on one-off effects induced by policies (i.e., the effects of constructing or installing power equipment).

More complex models such as CGE, PANTA RHEI or E3ME can take “crowding-out” effects as well as international economic linkages into account (see, e.g., IRENA (2016b), the chapter on net effects in Lehr et al. (2011), or the special issue of the *Energy Journal* on “Hybrid Modeling of Energy-Environment Policies”). However, these models rely on a number of assumptions made “in the background” and are not replicable without access to the computational model. Meta-studies have combined results on job gains in renewable industries and job losses in conventional energy to estimate trade-offs (e.g., Meyer and Sommer 2014; Wei et al. 2010). The results of their spreadsheet models are useful, but not replicable as they rely on the availability of previous studies.

Our approach consists in an IO analysis which we extend in several dimensions. The advantage of IO analysis over other methods that are commonly used to estimate the economic effects of sectoral developments, like the analysis of value-added chains, lies in the ability to consider indirect besides direct effects on other sectors. That means that if a sector faces an increased demand for its goods, expanding production does not only increases demand for its direct inputs, but also for the intermediate inputs used to produce these inputs and so on. This can only be considered up to a limited extent in an analysis of the value-added chain, as done in (Hirschl et al. 2010; Hirschl et al. 2015). Thus, to be able to use this approach and based on the German IO table, we construct IO tables for the three districts in the Bavarian Oberland following the method proposed by Többen and Kronenberg (2015). It allows us to model trade between the districts as well as with the rest of the country and the rest of the world, which is important considering that the districts are open economies that interact with other regions. Thus, the additional demand generated by investments (in renewable energies) is not satisfied exclusively by the local economy but also by sectors outside of their borders. Ignoring this would lead to a overestimation of the economic effects derived from the investments.

One of the extensions of the traditional IO analysis, which also allows us to rule out further sources of overestimation of the economic effects, is considering scarcity of financial resources and production factors. We distinguish between investments by private households and investments by institutional investors. Moreover, for the latter, we further differentiate between the investment and the operation phase. In the case of private households, investments (in renewables, renovations and storage capacity) and the corresponding expenditures during the operation phase crowd out consumption in the same amount.[1] Similarly, investments by institutional investors crowd out alternative investments. This distinction allows us to take into consideration the different structure of these two final demand components (consumption by private households and investments by private organizations) and, thus, to explicitly consider the increasingly important role of private households as investors in the electricity and heating sectors.

For the operations phase, we take into account that the investments increase the capital stock of the concerned sectors. Assuming full employment of the factors of production and fixed factor input coefficients, the increased capital attracts labor from other sectors, reducing their production. For the analysis of the economic effects in the operations phase we further develop the approaches of Fisher and Marshall (2011), Benz et al. (2014), and von Schickfus and Zimmer (2018) to make them applicable in a context when small regions (which in our case are the three German districts) are embedded in a system with much larger regions such as the rest of the country and the rest of the world.

An important characteristic of our analysis is that it is made prior to the investments, allowing to take measures targeted at attenuating possible negative developments. For instance, the identification of sectors that might be negatively affected makes possible to support them in the appropriate manner before or during the transition. Moreover, identifying the sectors where labor requirements might increase most strongly allows a proactive approach to solve and prevent shortage problems.

The contributions of this paper do not only refer to the three districts in the Bavarian Oberland region. On the contrary, they can be applied to other regions, either at the same or other levels of regional sub-division, and also to other research and policy questions. Thus, the

[1] This can be seen as a simple representation of a policy instrument financed by a surcharge on the electricity price for all consumers, as in the German Renewable Energy Law (EEG)

methodology, which was further developed to satisfy the needs of a regional analysis is by no means exclusive to investments in the energy sector or to the Oberland region. Following the method described in Section 3.2.2 we can construct IO tables for other subnational regions. The method described in Section 3.2.3 can be applied to analyze the economic effects of all types of investments.

In the following sections we first outline our approach to produce the multi-regional IO table, to disaggregate the energy sector, and to assess the effects of the energy transition. Section 3.3 describes the data sources and Section 3.4 presents the effects on value added and employment. Finally, Section 3.5 concludes.

3.2 Methodology

For the analysis of the effects of the energy transition we want to consider the impact on the whole regional economy, taking into account the direct and indirect effects, thus we rely on input-output analysis for the assessment. Therefore, we are confronted three methodological challenges. First, since subnational tables are not available in Germany, we are required to produce IO tables for each of the districts and link them to each other and to the tables for the other two regions. This requires estimating trade between the three districts of analysis but also of each of the districts with the other two regions. Second, the energy sector of the multi-regional IO table needs to be disaggregated in such a way that the different renewable energy technologies and conventional technologies are considered as individual sectors. This disaggregation is necessary to account for the different input structures and, therefore, for the specific interconnections of each technology with the rest of the economy. The third challenge is concerned with the calculation of the economic effects. In this respect, we extend the traditional IO analysis to consider scarcities of financial resources and production factors and, therefore, to account for the fact that investments in renewables energies crowd out other investments and production in other sectors. In the following we describe how we address each of these challenges.

3.2.1 Disaggregation of the energy sector

We start by disaggregating the energy sector in both source IO tables: the tables for Germany and the rest of the world from the World Input-Output Database (WIOD) (Timmer et al. 2015) and the German input-output table (GIOT) from the German statistical office. Thus, for instance, the sector "Electricity, steam and hot water, production and distribution services thereof" from the GIOT is disaggregated into nine subsectors.[2] These consists of different renewable and conventional technologies, transmission and distribution of electricity.[3] For disaggregation, we use the information contained in the IO table for Germany from EXIOBASE 2 (Wood et al. 2015), where the energy sector is disaggregated.[4]

Table 3.1 : Disaggregation of the intersectoral transactions of the energy sector

						Electricity				
					Coal	Solar	Distribution			
		Sector 1	…	Sector j	Sector h	…	Sector H	…	Sector J	**Total intermediate Use**
	Sector 1	z_{11}	…	z_{1j}	z_{1h}	…	z_{1H}	…	z_{1J}	$z_{1.}$
	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮	
	Sector i	z_{i1}	⋮	z_{ij}	z_{ih}		z_{iH}	⋮	⋮	
Coal	Sector e	z_{e1}	…	z_{ej}	z_{eh}	…	z_{eH}	…	z_{eJ}	$\mathbf{z_{e.}}$
Electricity Solar	⋮	⋮		⋱	⋮	⋱	⋮	⋱	⋮	⋮
Distribution	Sector E	z_{E1}	…	z_{Ej}	z_{Eh}	…	z_{EH}	…	z_{EJ}	$\mathbf{z_{E.}}$
	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮	
	Sector I	z_{I1}	…	…	z_{Ih}	…	z_{IH}	…	z_{IJ}	
Total inputs		$z_{.1}$			$\mathbf{z_{.h}}$	**…**	$\mathbf{z_{.H}}$			

To arrive at a matrix like in Table 3.1, we need to calculate the elements in the shaded areas, where z_{ih} represents the input from the non-electricity sector i required in the electricity subsector h, and z_{ej} represents the input from the electricity subsector e required in sector j.

2 For simplicity, in the following we will refer to the "Electricity, steam and hot water, production and distribution services thereof" sector as the electricity sector, although it also includes activities different to electricity generation.

3 For a complete description of the energy sectors see Table B.1 in Appendix B.1 (Sectors 10-18).

4 Note that we first need to aggregate the sectors in the EXIOBASE table and in the GIOT to be consistent with our final sector aggregation, described in Table B.1.

Thus, to calculate z_{ih} we scale the input from i required in the (only) electricity sector from the GIOT, z_{ih}^{GIOT}:

$$z_{ih} = z_{ih}^{GIOT} \frac{z_{ih}^{Exio}}{\sum_h z_{ih}^{Exio}} \qquad \forall \quad i \neq e, \tag{3.1}$$

where $\sum_h z_{ih}^{Exio}$ is the sum of interindustry sales of sector i to all electricity sectors. The superscripts $GIOT$ and $Exio$ indicate that the variables are obtained from the German IO table from the German statistical office and from the German EXIOBASE table, respectively. Accordingly, we calculate z_{ej} as

$$z_{ej} = z_{ej}^{GIOT} \frac{z_{ej}^{Exio}}{\sum_e z_{ej}^{Exio}} \qquad \forall \quad j \neq h. \tag{3.2}$$

To calculate the entries of the intersectoral transactions between the energy subsectors (i.e., in the darker area in Table 3.1) we need to proceed slightly differently:

$$z_{eh} = z_{eh}^{GIOT} \frac{z_{eh}^{Exio}}{\sum_e \sum_h z_{eh}^{Exio}}, \tag{3.3}$$

where z_{eh} is the input from the electricity subsector e required in the electricity subsector h.

The remaining components of the IO table for the electricity subsectors, that is, value added, output, imports of similar final goods, the different components of final demand (consumption of private households, consumption of private organizations, consumption of state organizations, investment and changes in stocks, exports), as well as total final demand are calculated in a similar manner. So, for instance, for value added, w_e, we scale w_h^{GIOT} by multiplying it with the share of w_h^{Exio} in total value added of all electricity subsectors, $\sum_h w_h^{Exio}$.

3.2.2 Construction of the multi-regional IO table

The goal of the process described in this section is creating a multi-regional IO table consisting of the IO tables of Miesbach (MB), Bad Tölz-Wolfratshausen (BW), Weilheim-Schongau (WS) (together, the Oberland region), the rest of Germany and the rest of the world. Their "internal" IO tables are on the main diagonal of the multi-regional matrix; the intermediates traded interregionally are in the off-diagonal parts. The construction of the multi-regional matrix follows four major steps. First, we construct regional IO tables by adjusting the German coefficients with regional output figures and scaling numbers for final goods use. In a second step we employ the modified “cross-hauling adjusted regionalization method” (CHARM) approach developed by Többen and Kronenberg (2015) to estimate each district’s sectoral trade flows with the rest of Germany and with the rest of the world. Applying a simple gravity approach in a third step, we model the multi-regional trade flows: sectoral trade flows between the districts and between each district and non-Oberland Germany. Finally, using the “proportionality assumption”, we create the multi-regional IO (MRIO) matrix by combining the data on sectoral trade flows and input coefficients.

So, the first and the last step are concerned with input-output tables. There we assume that the production technology in the districts is equal to Germany’s production technology. The inner two steps are about estimating inner-country trade flows.

Note that the regions we are interested in (the Oberland region) do *not* sum up to the national level. We index our districts by b, m, and w and denote the national totals by n. From the perspective of each district r, the rest of the country is denoted by q, such that, e.g., output is $x_{i,r} + x_{i,q} = x_{i,n}$. Similarly, if we look at all three districts together and the respective rest of the country, this is denoted by roc (the rest of the country, or “non-Oberland region”). The set G comprises these sub-regions and the rest: $g = b, m, w, roc$.

Construction of regional IO tables

Gross value added We start with regional data on gross value added, as this measure is the closest proxy to output that is available from administrative sources. Since regional value added data is only available at a highly aggregated sectoral level, we disaggregate the data using employment figures. [5] First, we compute preliminary disaggregated value added figures, $w^p_{i,r}$, by multiplying with the labor shares of the disaggregated sectors:

$$w^p_{i,r} = w_{a,r} \cdot \frac{L_{i,r}}{L_{a,r}} \cdot \frac{w_{i,n}/L_{i,n}}{w_{a,n}/L_{a,n}}, \tag{3.4}$$

where the subscript a stands for the aggregated sector containing sector i. The third term on the right hand side (RHS) captures the national productivity differences. It is used as a correction factor to account for potential differences in labor productivity across subsectors.

[5] Table B.2 provides an overview of the highly aggregated sector level and the comprised sectors.

In a second step, we scale the preliminary values so they match the totals of the aggregated sectors:

$$w_{i,r} = w^p_{i,r} \cdot \frac{w_{a,r}}{\sum_{i \in a} w^p_{i,r}}. \tag{3.5}$$

Regional output of non-energy sectors From the sectoral values on regional w, we compute output by scaling national sectoral output using regional to national w shares:

$$x_{i,r} = x_{i,n} \cdot \frac{w_{i,r}}{w_{i,n}}, \tag{3.6}$$

where x denotes output of intermediate and final goods.

The output values of the rest of the country can be calculated as a residual:

$$x^{roc}_i = x_{i,n} - \sum_r x_{i,r}. \tag{3.7}$$

Regional output of the energy sectors To take advantage of the fact that we have detailed information on the energy sectors in the region, we proceed differently when regionalizing these sectors. For each of the electricity and heat generation sectors we scale German output down to the district level by multiplying it with the ratio of generation (in GWh) in the district, $g_{i,r}$ to generation in Germany, $g_{i,n}$ per sector:

$$x_{i,r} = x_{i,n} \cdot \frac{g_{i,r}}{g_{i,n}}. \tag{3.8}$$

The scaling factor for regionalization of the "Transmission of electricity" and "Distribution and trade of electricity" sectors is based on the length of the transmission or the distribution network located in the region and in the whole of Germany.

Regional input-output matrix For the (technical) regional IO matrix capturing the use of intermediates, we multiply the input-output coefficients of the German IO table ($c_{ij,n}$) with the regional output values, assuming identical production technology at the national and regional level:

$$z_{ij,r} = x_{j,r} \cdot c_{ij,n}, \tag{3.9}$$

where $z_{ij,r}$ denotes the input from sector i required in region r's sector j.

Note that each of the regional matrices constructed in this way is "technical" in the sense that it doesn't distinguish between sources of intermediates. It simply states that in a region r and sector j, a certain amount of inputs from other sectors i is needed to produce this region's sectoral output. It does not make a statement on where these inputs come from. The technical regional input-output matrix derived here is used later on to construct the interregional and intraregional IO matrices.

Regional domestic final use Final goods use per sector and use item is only available at the national level.[6] We therefore need to scale it using Bavarian data on total final goods use, and regional data on disposable income in the case of household consumption.

For private household consumption, we start from the national sectoral value and scale it by Bavarian consumption shares, as well as regional disposable income in comparison to Bavaria:

$$d_{i,r}^{ph} = d_{i,n}^{ph} \cdot \frac{d_{by}^{p}}{d_{n}^{p}} \cdot \frac{di_r}{di_{by}}, \tag{3.10}$$

with d_{ph} denoting consumption (final demand) of private households, d_p denoting total private consumption, di denoting disposable income, and by denoting Bavaria.

For investment and consumption by private and state organizations, we again scale by Bavarian shares following Heindl and Voigt (2012) and then use regional GDP to scale to regional

[6] For simplicity we refer to the different final use items of the IO table as follows:
"Final consumption expenditure by households"= private household consumption;
"Final consumption expenditure by non-profit organizations serving households"= consumption of private organizations;
"Final consumption expenditure by government"= consumption of state organizations;
"Gross fixed capital formation"= investments;
"Changes in inventories and valuables"= changes in stocks.

level:

$$d^k_{i,r} = d^k_{i,n} \cdot \frac{d^k_{by}}{d^k_n} \cdot \frac{GDP_r}{GDP_{by}} \qquad \forall \qquad k \neq cs, \tag{3.11}$$

where GDP denotes gross domestic product. The index $k = cpo, cso, inv, cs$ denotes consumption of private organizations, consumption of state organizations, investments, and changes is stocks. We scale down changes in stocks, using the regional GDP share only.

Regional (domestic) total use By summing up intermediate use and domestic final use (by private households, denoted by ph, and organizations, denoted by k) we can derive total regional domestic use $d^t_{i,r}$:

$$d^t_{i,r} = z_{i\cdot,r} + d^{ph}_{i,r} + \sum_k d^k_{i,r} = z_{i\cdot,r} + d_{i,r}. \tag{3.12}$$

Rest of country The values for intermediate use, domestic final use, value added and output for the rest of the country are calculated as residuals, subtracting the values for the three districts from the national figures.

Estimation of interregional trade: application of modified CHARM

As noted by Kronenberg (2009), trade of regions with the rest of the country and the rest of the world is characterized by surplus imports and exports (trade balance) as well as substantial amounts of cross-hauling, which is the simultaneous imports and exports of goods or services of the same sector. The more heterogeneous the products within a sector are, the more cross-hauling takes place (Kronenberg 2009).

The adjusted CHARM as suggested by Többen and Kronenberg (2015) allows to estimate trade flows between each region and the rest of the country ("biregional trade"), as well as between each region and abroad, while taking into account cross hauling. An important assumption made in Kronenberg's CHARM and of the modified CHARM is that product heterogeneity in the region is the same as in the country, which is based on the argument that heterogeneity is a characteristic of the commodity and not of the geographical location (Kronenberg 2009). This assumption is criticized by Jackson (2014) who emphasizes that the product mix within an aggregate commodity might well be a function of the geographical location, since the region might not produce all commodity sub-types while the country does. According to the authors, the consequences of this assumption will depend on three aspects: First, the level of aggregation in the commodities classification; second, the unique character of different commodities; and third, the economic size of the subnational regions. Since our regions are rather small and we have a high level of aggregation, there are potentially consequences for regionalization in our framework. However, the lack of administrative data on trade between the districts and with the rest of the country and the world, makes it impossible to quantify the consequences. Thus, we have to keep in mind that the estimates for the interregional transactions might be inaccurate.

Estimating regional foreign trade As a first step, we estimate each region's foreign trade. The basic assumptions are that foreign imports are proportional to domestic demand, and foreign exports are proportional to domestic output. Then regional foreign exports (denoted by $e^f_{i,r}$) and imports (denoted by $m^f_{i,r}$) can be approximated as

$$m^f_{i,r} = m_{i,n} \frac{z_{i\cdot,r} + d_{i,r}}{z_{i\cdot,n} + d_{i,n}}, \tag{3.13}$$

$$e^f_{i,r} = e_{i,n} \frac{x_{i,r}}{x_{i,n}}. \tag{3.14}$$

We use foreign trade data from the German IO table and scale it with regional demand or supply figures, respectively. Foreign imports and exports for the rest of the country roc are calculated as a residual.

Estimating total interregional trade The second step is concerned with estimating trade within the country, between regions. The adjusted CHARM formula only works for a bi-regional setting. Therefore, we calculate cross-hauling between each of the districts and, from its perspective, the rest of the country, as suggested by Többen and Kronenberg (2015). These biregional values are what we refer to as "interregional".

The adjusted CHARM defines the cross-hauling potential as the minimum of output and domestic use. The intuition behind this is that the highest possible amount of cross-hauling occurs if the region with relatively small output figures exports all its output, and imports the same amount of goods. The (maximum) cross-hauling potential, q_i is then twice the amount of the region's output.

Correspondingly, the method defines the cross-hauling potential at national level to be constrained as $\max q_{i,n} = 2\min(x_i; z_{i\cdot} + d_i)$.[7] Then the national product heterogeneity measure is calculated as

$$h_{i,n} = \frac{q_{i,n}}{2\min(x_{i,n}; z_{i\cdot,n} + d_{i,n})}. \tag{3.15}$$

Following the above reasoning and in order to ensure accounting balances between the two regions, the adjusted CHARM sets upper limits for the cross-hauling potential. Denoting the cross-hauling in interregional trade between regions r and q by q_i, their maximum CH potential can be written as

$$\max(\frac{q_i}{2}) = \min(x_{i,r} - e^f_{i,r}; z_{i\cdot,r} + d_{i,r} - m^f_{i,r}; x_{i,q} - e^f_{i,q}; z_{i\cdot,q} + d_{i,q} - m^f_{i,q}). \tag{3.16}$$

Assuming that $h_{i,n} = h_{i,r}$, biregional cross-hauling can be estimated as the national heterogeneity parameter (which is the share of national cross-hauling in national cross-hauling potential) times the regional cross-hauling potential:

$$q_i = 2h_{i,r}\min(x_{i,r} - e^f_{i,r}; z_{i\cdot,r} + d_{i,r} - m^f_{i,r}; x_{i,q} - e^f_{i,q}). \tag{3.17}$$

In a further step we calculate interregional gross trade flows, which are interregional gross exports and imports and are defined bilaterally: t_{rq} is the trade flow from region r to region q. To calculate them, we need to combine our estimate of cross-hauling with the commodity balance. The commodity balance, b, is usually defined as the difference between regional supply and demand (resulting in a value for net regional imports or exports), and in the subnational case it needs to be corrected for foreign imports and exports:

$$b_{i,r} = -b_{i,q} = (x_{i,r} - e^f_{i,r}) - (z_{i\cdot,r} + d_{i,r} - m^f_{i,r}). \tag{3.18}$$

[7] Note that, since there is a large quyntity of variables and parameters to be estimated in the regionalization of the IO table and calculation of the economic effects, some letters are used twice: once to denote a variable and once to denote an index. While this is not optimal, please note that there is no implicit relation between the index and the variable, although the are denoted by the same letter.

Then, the gross trade flows between the two sub-regions are given by[8]

$$t_{i,rq} = \frac{q_i + |b_{i,r}| + b_{i,r}}{2}, \tag{3.19}$$

$$t_{i,qr} = \frac{q_i + |b_{i,q}| + b_{i,q}}{2}. \tag{3.20}$$

Estimation of multi-regional trade: gravity

As we have more than two regions in our setting, we need to distribute the interregional (or biregional) trade flows calculated above among the several regions. We apply a simple gravity framework for this: we assume that trade between sub-regions is proportional to their economic size and their distance from each other. Moreover, we estimate the trade share ts of one region with another as the quotient of estimated trade flows between regions r and s and the estimated trade flows of region r with all other regions:

$$ts^1_{rs} = \frac{\ln(GDP_r GDP_s) - \ln(dist_{rs})}{\sum_{u \neq r}(\ln(GDP_r GDP_u) - \ln(dist_{ru}))}. \tag{3.21}$$

The denominator is similar to the "multilateral resistance" term in gravity trade models.[9] Here, u is an index over all districts other than r - so it refers to the rest of the country from r's perspective. It is similar to the index q as in the notation for the modified CHARM formula further above, but in the trade share calculations we actually use data on each of the 380 other German districts individually. Therefore, we use another index here to avoid confusion.

Note that we could also have a denominator based on region s's multilateral trade. Essentially, we can follow two approaches, which result in different trade shares. The first is to use r's trade share for estimating all of r's exports, which means that each region s's imports from r are scaled by r's multilateral resistance. The second approach is to use s's trade share for estimating all of s's imports, which means that r's exports to s are scaled by s's multilateral resistance.

[8] Note that we need to divide cross hauling by 2 because we are interested in one-directional flows from r to q, whereas cross-hauling gives the sum of simultaneous imports and exports.

[9] The specification in (3.21) implies trade elasticities of one with respect to GDP and distance.

Approach 2 reads:

$$ts^2_{rs} = \frac{\ln(GDP_r GDP_s) - \ln(dist_{rs})}{\sum_{u \neq s}(\ln(GDP_s GDP_u) - \ln(dist_{su}))}. \tag{3.22}$$

Combining the multi-regional trade share with interregional trade flows gives the multi-regional trade flows (shown here according to approach 1):

$$t^1_{i,rs} = t_{i,rq} \cdot ts^1_{rs}. \tag{3.23}$$

Trade between each district and the non-INOLA region is calculated as a residual. So, for instance for district b

$$t_{b,roc} = t_{bq} - t_{bm} - t_{bw}, \tag{3.24}$$

where q denotes the rest of the country from the perspective of the exporting district, and m and w denote the other two Oberland districts.

Since both approaches for the calculation of the districts' trade flows lead to different estimates, we chose to combine the two approaches. To guarantee that the calculation for the rest of the country in (3.24) does not deliver negative values, we always use the smaller of the two:

$$t_{i,rs} = \min(t^1_{i,rs}; t^2_{i,rs}). \tag{3.25}$$

Construction of the multi-regional IO matrix

Imported intermediates - proportionality assumption To construct the MRIO matrix from the technical IO matrix and the multi-regional trade flows, we use the proportionality assumption also used by Benz et al. (2014) among others. According to this assumptions "an industry uses an import of a particular product in proportion to its total use of that product" (OECD 2002, p. 12). For example, if the motor vehicles industry in region A uses steel in production and 10% of all steel is imported from a particular region B, then 10% of the steel used by the motor vehicles industry in region A is imported from region B.

So the intermediate inputs used by region r's sector i from region s's sector j read as

$$z_{ij,sr} = z_{ij,r} \frac{t_{j,sr}}{d^t_{j,r}}, \tag{3.26}$$

where $d^t_{j,r}$ denotes total use of product j in region r. In a similar manner, we calculate the intermediate inputs used by region r's sector i from sector j of the rest of the world (ROW), using the foreign imports $m^f_{i,r}$ calculated above and the proportionality assumption, and denote them $z^{row}_{ij,r}$.

Intersectoral transactions within each district We then calculate the within-district IO matrix as the residual of the "technical" matrix calculated above, and all imported intermediates from the other districts, the rest of the country and the rest of the world

$$z_{ij,rr} = z_{ij,r} - \sum_{s \neq r} z_{ij,s} - z_{ij,rowr}. \tag{3.27}$$

Linking the regional and German tables to the rest of the world Having the MRIO table for the districts and the rest of the country, we proceed to link it to the rest of the world. We aggregate the individual countries of the WIOD table (except Germany) to form the ROW region and the sectors to match the sectors of the IO tables for the districts. Aggregated WIOD tables are taken as the base table. We then disaggregate the intersectoral transaction within Germany from the WIOD table, $z^{WIOD}_{ij,n}$ using origin-destination shares that can be calculated from the MRIO table generated using the methodology described above:

$$z_{ij,rs} = z^{WIOD}_{ij,n} \frac{z^{GIOT}_{ij,rs}}{\sum_r \sum_s z^{GIOT}_{ij}}, \tag{3.28}$$

where the superscript $GIOT$ denotes the variables that were calculated above using the German IO table from the German statistical office. The intersectoral transactions between German sectors and ROW's sectors are regionalized in proportion to output, that is: $z_{ij,rrow} = z^{WIOD}_{ij,nrow} \frac{x^{GIOT}_{i,r}}{x^{GIOT}_{i,n}}$.

Factors of production

Starting from the production factor figures for Germany, we scale down the respective factor to the district level using the sectoral factor coefficients for Germany and sectoral output for the districts. For instance, we compute K_{ir}, the capital stock in region r's sector i, as

$$K_{ir} = K_{in}\frac{x_{i,r}}{x_{i,n}}, \tag{3.29}$$

where K_{in} denote the sectoral capital stock for the whole of Germany. The factors of production for the rest of the world are calculated in a similar way.

3.2.3 Economic effects: extended IO analysis

Being placed in an IO framework, we implicitly assume a Leontief production function with fixed input coefficients and constant returns to scale. Furthermore, although the period of analysis is relatively long (from 2015 to 2035), we also need to make the assumption that the input coefficients and factors coefficients will stay the same throughout the period of analysis, that is, the production technology of the economy will remain unchanged. This assumption becomes more realistic for other possible applications with shorter periods of analysis.

For the assessment, we consider both the one-off effects of the investment (or construction) phase as well as the effects of the operations phase. Importantly, we take into account scarcity of financial resources and of the factors of production, thus in the investment and in the operation phase crowding out of other activities occurs. Specifically, investments in the energy transition crowd out other investments by companies or consumption by private households. Here we assume that financial resources do not only come from the region where investments take place but also from other regions. The rationale behind this assumption is that investments in the energy transition are typically financed by national climate policy instruments that redistribute funds from the whole of the country to the actual investment location.[10] Similarly, in the operations phase factors of production that could be employed otherwise, are used in the operation and maintenance of renewables, reducing their activity (and therefore output) in other sectors.

[10] An example for such a redistribution mechanism is the German EEG which finances the investments via a surcharge on the electricity price paid by all consumers (with some exceptions). In the case where policies are financed by the national public budget, redistribution occurs through the tax system.

The next subsections describe our methodology. First, we introduce the general method to compute the amount of output necessary to meet the additional investment demand generated by the energy transition. We then present the method to consider scarcities in the investment phase and the operation phase. Finally, we show how we calculate the effects on value added and employment, starting from the additional output figures.

Additional output

The starting point of our analysis are the future investments in renewable energies for electricity and heat generation, energy efficiency measures and electricity storage appliances.[11] We denote these by $\mathbf{f}$, which is a $N \times 1$ column vector, where N is the total number of sectors per region. The vector $\mathbf{f}$ describes how total demand for investment goods is composed of investment goods from other specific sectors, thus it breaks down the overall investment in region r into the components needed from each sector i. Note that this vector does not provide information on the geographical origin of the components yet, thus we use the intra-sectoral transactions in intermediates from the MRIO table as a proxy to distribute the sectoral investment demand among the regions and obtain the additional investment demand:

$$\Delta \mathbf{d}^{\mathbf{inv}} = \mathbf{U}\mathbf{f}. \tag{3.30}$$

where d^{inv} is a $IR \times 1$ column vector, and R is the total number of regions. $\mathbf{U}$ is a $IR \times IR$ matrix whose elements, $u_{ij,rs}$, describe the share of $z_{ij,rs}$ (i.e., of inputs from region r's sector i used in regions s's sector j), in the intrasectoral transactions:

$$u_{ij,rs} = \frac{z_{ij,rs}}{\sum_{r=1}^{R}\sum_{s=1}^{R} z_{ij,rs}} \qquad \forall \quad i = 1, \ldots, N \quad \text{and} \quad j = i. \tag{3.31}$$

Following classical IO analysis, the amount of output of final goods and intermediates, $\boldsymbol{\Delta}\mathbf{x}$, that its necessary to satisfy the additional investment demand can be computed as follows:

$$\boldsymbol{\Delta}\mathbf{x} = (\mathbf{I} - \mathbf{L})^{-1}\boldsymbol{\Delta}\mathbf{d}^{\mathbf{inv}}, \tag{3.32}$$

where $\mathbf{I}$ is the unity matrix and $\mathbf{L}$ is the matrix of fixed input coefficients, which shows the direct use of intermediates per unit of output. Leontief's inverse, $(\mathbf{I} - \mathbf{L})^{-\mathbf{1}}$, is the matrix to

[11] For simplicity, in the following the expression *investment in renewables* will also mean energy efficiency measures and the deployment of storage capacity.

which the infinite sum of $\mathbf{L}$ converges. Accordingly, it accounts for the fact that, besides the directly used intermediates, output production also uses indirectly the intermediates used for production of the direct intermediates and so on. Thus, Leontief's inverse indicates the level of output needed to satisfy a unit vector of final demand after infinite rounds of this process.

To this point we have not considered any scarcity effects and have assumed that additional resources and factors of production are readily available and enter the system in an unlimited manner. However, it is more reasonable to assume that investments in renewables crowd out other types of demand, e.g., alternative investment or consumption by private households. Moreover, factors of production are not unlimited in stock and waiting to be employed. To consider scarcity effects we follow two different approaches depending on the actors undertaking the investment: private households or institutional investors. Moreover, we distinguish between the investment phase and the operation phase.

Considering scarcity in the investment phase Crowding out in the investment phase for both types of investors follows a similar principle: investments in renewables crowds out an alternative average investment (alternative average consumption) in the same amount as the total investment in renewables. Thus, the calculation of additional output, net of crowding out reads:

$$\mathbf{\Delta x^{inv,net}} = (\mathbf{I} - \mathbf{L})^{-1}(\mathbf{\Delta d^{inv,ii}} + \mathbf{\Delta d^{inv,ph}} - \mathbf{\Delta d^{invco}} - \mathbf{\Delta d^{phco}}), \tag{3.33}$$

where $\mathbf{\Delta d^{inv,ii}}$ and $\mathbf{\Delta d^{inv,ph}}$ denote the additional investment demand generated by institutional investors and by private households, respectively. $\mathbf{\Delta d^{invco}}$ is a vector of crowded out investment demand and $\mathbf{\Delta d^{phco}}$ is a vector of crowd out consumption by private households. The elements of $\mathbf{\Delta d^{invco}}$ are defined as

$$\Delta d_{i,r}^{invco} = \frac{d_{i,r}^{inv}}{\sum_{i,r} d_{i,r}^{inv}} \sum_{i,r} \Delta d_{i,r}^{inv,ii}. \tag{3.34}$$

The fraction on the right hand side of (3.34) describes the proportional distribution of an average investment among sectors and regions.[12] In other words, it describes how many cents out of each Euro invested in any of the regions appear as investment demand in a specific

[12] Recall that $d_{i,r}^{inv}$ is investment demand and is readily available for the IO tables.

regional sector. The last term on the right hand side is the sum of the investments. $\mathbf{\Delta d^{phco}}$ is similarly defined, yet in this case an average consumption vector is multiplied with the additional investment demand generated by private households.

Considering scarcity in the operation phase To consider crowding out in the operations phase we extend the approach introduced by Fisher and Marshall (2011) and further developed by von Schickfus and Zimmer (2018) to suit the requirements of an analysis of small regions embedded in an international IO table.

Before turning to the formal representation, consider first the intuition behind our approach. By investing in renewables the capital stock of each renewables sector increases by the amount of the respective investment. Assuming that there are no changes in technology, the capital stock increase attracts into the renewables sectors the amount of labor that is necessary to use the new capital stock in the production process. Assuming scarcity in the factors of production, which is a sensible assumption considering the current situation on the German labor market, labor is necessarily attracted from other sectors of the same or of other regions. Thus, output in these sectors decreases. This is, of course, a simplified representation of the whole process, since actually the adjustment consists of infinite rounds.

Formally, we assume the Leontief production function to be transregional as in Benz et al. (2014). That means that production of final goods in one region potentially uses factor inputs from all other regions by using intermediates from the other regions. The production function is then given by

$$y_{ir} = min\left\{\frac{v_{ir11}}{a_{ir11}}, \ldots, \frac{v_{irfs}}{a_{irfs}}, \ldots, \frac{v_{irFS}}{a_{irFS}}\right\} \quad \forall \quad i = 1, \ldots, N \quad \text{and} \quad r = 1, \ldots, R, \tag{3.35}$$

where y_{ir} is final goods output in sector i of region r. v_{irfs} is the amount of region s's factor f used in region r's sector i, and a_{irfs} the input coefficient that determines the amount of factor input f from region s which is required to produce one unit of output in sector i of region r. The number of factors is denoted by F.

Assuming full employment, scarcity and a positive remuneration of all production factors, implies that the employment of region r's factor f in all regions in all sectors equals the endowment of region r with factor f

$$v_{rf} = \sum_{s=1}^{S} \sum_{i=1}^{I} a_{irfs} y_{ir} \quad \forall \quad f = 1, \ldots, F \quad \text{and} \quad r = 1, \ldots, R. \tag{3.36}$$

Writing (3.36) in matrix notation leads to

$$\mathbf{v} = \mathbf{A}'\mathbf{y}, \tag{3.37}$$

where information on each region's factor endowment is contained in $\mathbf{v}$, which is a column vector of length FR. Furthermore, the column vector $\mathbf{y}$ of length IR contains each region's final goods output in each sector. $\mathbf{A}$ is a matrix of dimension $IR \times FR$ containing the *direct* and *indirect* factor requirements expressed as factor input coefficients.

$\mathbf{A}$ is not readily available from the data, however, Fisher and Marshall (2011) show that it can be obtained by multiplying the matrix of direct factor inputs, $\mathbf{B}$, with the Leontief inverse:

$$\mathbf{A}' = \mathbf{B}'(\mathbf{I} - \mathbf{Z})^{-1}, \tag{3.38}$$

where $\mathbf{B}$ is the matrix of *direct* factor inputs. It contains information on the factors of production directly employed to produce one unit of domestic total (intermediate and final goods) output, $\mathbf{x}$. Denoting low, medium and high-skilled labor as L, M and H, respectively, and capital as K, and assuming mobile factors of production, that is, that factors of production of each region and each sector can be directly employed across sectors and regions, $\mathbf{B}_m$ reads

$$\mathbf{B}_m = \begin{bmatrix} L_{11} & M_{11} & H_{11} & K_{11} \\ \vdots & \vdots & \vdots & \vdots \\ L_{ir} & M_{ir} & H_{ir} & K_{ir} \\ \vdots & \vdots & \vdots & \vdots \\ L_{NR} & M_{NR} & H_{NR} & K_{NR} \end{bmatrix}, \tag{3.39}$$

and its dimensions are $IR \times F$. However, we assume the factors of production to be partly mobile, that is, mobile within Germany and between sectors in Germany but not to be directly employed in the rest of the world.[13] Thus, there are two types of each factor, one for Germany and one for ROW, which means that $\mathbf{B}_{pm}$ is of dimensions $IR \times G$, where $G = 2F$ and the subscript pm stands for partly mobile. Assuming the rest of the world is the last region in the multi-regional matrix and letting $(R-1)$ denote the penultimate region, $\mathbf{B}_{pm}$ reads

$$\mathbf{B}_{pm} = \begin{bmatrix} L_{11} & 0 & M_{11} & 0 & H_{11} & 0 & K_{11} & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ L_{I(R-1)} & 0 & M_{I(R-1)} & 0 & H_{I(R-1)} & 0 & K_{I(R-1)} & 0 \\ 0 & L_{1R} & 0 & M_{1R} & 0 & H_{1R} & 0 & K_{1R} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & L_{IR} & 0 & M_{IR} & 0 & H_{IR} & 0 & K_{IR} \end{bmatrix}. \tag{3.40}$$

Fisher and Marshall (2011) further show that, although $\mathbf{A}$ is not invertible because the number of factors F and the number of sector-region combinations IR are not equal, the full employment condition in (3.37) can be solved for $\mathbf{y}$ with the Moore-Penrose Pseudo inverse of $\mathbf{A}$ denoted by $\mathbf{A}^{+}$. Thus, it follows

$$\mathbf{y} = \mathbf{A}'^{+}\mathbf{v} + (\mathbf{I} - \mathbf{A}'^{+}\mathbf{A}')\mathbf{z}, \tag{3.41}$$

where $\mathbf{z}$ is an arbitrary vector.

Taking the derivative with respect to factor endowment leads to the result that $\mathbf{A}'^{+}$ indicates the output response in each region in each sector to a unit increase in each production factor. However, the approach of taking the derivative with respect to factor endowment at this stage is not appropriate in a context where the regions are so different in their size and the sectors in the different regions are assumed to have the same technology.[14] The reason is that in the process of reallocating factors so as to maximize output, there is no further information available than the production technology. Since we assume the production technology to be the same in the rest of Germany and the three districts, the same absolute amount of factors is assigned to a specific sector in all regions, leading to very implausible values for

[13] This is a strict assumption, yet, in general, any mobility assumption would be possible. While we considered several different specifications, which serve as robustness checks, this specific assumption is the simplest setting that allows to cover our policy questions.

[14] As outlined in Section 3.2.2, lacking detailed administrative data at the regional level we need to make the "same technology assumption" to be able to produce IO tables and estimates of the production for the districts.

the regionalized sectors.[15] In this context, $\mathbf{z}$ becomes relevant and although it is not further specified in Fisher and Marshall (2011), and we cannot solve for it analytically, we develop an algorithm to approximate its elements.

The routine starts by assigning an initial value to each element of $\mathbf{z}$ and calculate the predicted $\hat{\mathbf{y}}$ using (3.41). Since we know the actual $\mathbf{y}$ we calculate $\hat{y}_{ir}$'s relative deviation from y_{ir}. The algorithm's goal is to find a vector $\hat{\mathbf{z}}$ that minimizes the maximum relative deviations. Note that minimizing the absolute deviations as in a least squares estimation technique would give more importance, or even only consider, the deviations in the ROW region since the deviation in the three districts are technically insignificant in absolute terms in comparison to the ROW. However, we are particularly interested in the districts, so we minimize the relative deviations.

Specifically, after assigning an starting value of one to each element of $\mathbf{z}$, and initially defining a prediction, $\hat{y}_{ir}$, to be an outlier if it is 4 times larger (or $1/4$ times smaller) than the actual y_{ir},[16] we proceed as follows:

1. Calculate $\hat{\mathbf{y}}$ using (3.41) and inserting the current values for $\hat{\mathbf{z}}$
2. Identify outlier sectors
3. Adjust the values of the $\hat{\mathbf{z}}$ vector for the outlier sectors according to $\Delta\hat{z}_{ir} = f(\hat{y}_{ir} - y_{ir})$[17]
4. Adjust the threshold for the definition of outliers by 1%
5. Repeat steps 1 to 4 until there are no more improvements in the relative deviations within a chosen limit of iterations (1 million in our case)

We can then insert the estimated $\hat{\mathbf{z}}$ in (3.41). We extend the right term of the right hand side by $\mathbf{v}^{+}\mathbf{v} = 1$ to obtain

$$\mathbf{y} = (\mathbf{A}'^{+} + (\mathbf{I} - \mathbf{A}'^{+}\mathbf{A}')\hat{\mathbf{z}}\mathbf{v}^{+})\mathbf{v}. \tag{3.42}$$

[15] Indeed, even if the production technology of sector i differs for the regions, the differences would not be substantial. Since $\mathbf{A}'^{+}$ does not contain information on the size of the sector, very similar amounts of factors of production would be assigned to sector i in all regions.

[16] The initial definition of an outlier sector can be chosen arbitrarily, but it should be in a range that only few outlier sectors exist.

[17] To ensure convergence it proved preferable to use only one percent of the total difference for the adjustment, thus: $f(\hat{y_{ir}} - y_{ir}) = 0.01 \cdot (\hat{y_{ir}} - y_{ir})$

This last transformation allows us to determine how sectoral final goods output, $\mathbf{y}$, reacts to changes in the factors of production. Thus, rearranging (3.42) it follows :

$$\mathbf{\Lambda} = \mathbf{A}'^{+} + (\mathbf{I} - \mathbf{A}'^{+}\mathbf{A}')\hat{\mathbf{z}}\mathbf{v}^{+}, \tag{3.43}$$

where $\mathbf{\Lambda}$ is a matrix whose columns indicate the response in final goods output in each sector in each region to a unit increase in each factor of production. We extract the columns of $\mathbf{\Lambda}$ to have eight single column vectors, one for each factor of production. So, for instance, the vector containing the effect of a unit increase in the capital stock in Germany on output is denoted as $\lambda^{\mathbf{KG}}$.

Having all the elements to compute the change in output of intermediate and final goods, we can now outline the procedure. First, we calculate the initial change in output without considering scarcities as follows:

$$\mathbf{\Delta x^{op,p}} = (\mathbf{I} - \mathbf{L})^{-1}\mathbf{\Delta d^{K}}, \tag{3.44}$$

where $\mathbf{\Delta d^{K}}$ is a vector of the changes in final demand, whose elements are calculated by multiplying ΔK_{ir} and the fraction of final demand per capital stock, $\frac{d_{ir}}{K_{ir}}$. Furthermore, we assume that ΔK_{ir} is equal to the investment in each type of renewables.

The preliminary changes in $\mathbf{x}$ require changes in the employment of production factors. We denote these preliminary changes $\Delta K_{ir}^{op,p}$, $\Delta L_{ir}^{op,p}$, $\Delta M_{ir}^{op,p}$, $\Delta H_{ir}^{op,p}$ and compute them as follows

$$\Delta H_{ir}^{op,p} = \Delta x_{ir}^{op,p}\frac{H_{ir}}{x_{ir}}, \tag{3.45}$$

where $\frac{H_{ir}}{x_{ir}}$ is the factor coefficient, defined as the ratio of high-skilled labor per unit of output. Accordingly, we can calculate the changes in value added, as well as low and medium-skilled labor by inserting the appropriate factor coefficient. Aggregating the effects across sectors at the level of the regions where production factors are mobile, that is, within Germany and within ROW, we get for the preliminary changes in high-skilled labor $H^{G,op,p}$.

To compute the net effects on $\mathbf{x}$ we subtract the effects generated by the scarcity of factors of production. However, we first need to translate the scarcity effects to express them in terms of intermediates and final goods output, $\mathbf{x}$, since they were computed in terms of final goods output, $\mathbf{y}$. Sticking to the example for high-skilled labor in Germany, we compute:

$$g_{ir}^{HG} = \lambda_{ir}^{HG} \frac{x_{ir}}{y_{ir}}. \tag{3.46}$$

Now, we can proceed as follows to calculate the net effect on $\mathbf{x}$ in the operations phase:

$$\Delta x_{ir}^{op,net} = \Delta x_{ir}^{op,p} - g_{ir}^{LG} L^{G,op,p} - g_{ir}^{MG} M^{G,op,p} - g_{ir}^{HG} H^{G,op,p} - g_{ir}^{KG} K^{G,op,p}. \tag{3.47}$$

The total effect on output from the investment and the operations phase is then:

$$\Delta x_{ir}^{net} = \Delta x_{ir}^{inv,net} + \Delta x_{ir}^{op,net}. \tag{3.48}$$

Value added and employment effects

To evaluate the effects of investments in renewables on regional value added, low, medium and high-skilled employment we can now use the total changes in output from (3.48) and the factor coefficients as in the following example for high-skilled employment:

$$\Delta H_{ir} = \Delta x_{ir}^{net} \frac{H_{ir}}{x_{ir}}, \tag{3.49}$$

We can derive aggregate effects for the regions, by summing across the sectors in each region:

$$\Delta H_r = \sum_{i=1}^{N} \Delta H_{ir}. \tag{3.50}$$

Similarly, we can aggregate the effects to present results for the single sectors, across regions:

$$\Delta H_i = \sum_{r=1}^{R} \Delta H_{ir}, \tag{3.51}$$

or aggregate to consider only the three districts.

3.3 Data

3.3.1 Input-output table

The IO tables on which the analysis is based are the German IO table of inland production and imports for the year 2014 and the 2014 World IO Table from WIOD (Timmer et al. 2015). For disaggregation of the energy sector we use Exiobase 2 (Wood et al. 2015), which is, to our knowledge, the only table where the energy sector is disaggregated into several electricity production technologies, electricity transmission, electricity distribution, heat production, and gas distribution.

3.3.2 Regional data

From the Regional Accounts database of the federal and regional statistical offices we obtain data for the districts' GDP, aggregated gross value added data and disposable income of private households for the districts. GDP, government consumption, gross investments in equipment and buildings and private consumption for Germany and Bavaria are also obtained from this database. Employment statistics by sector both for Germany and the districts come from the federal employment statistics office.

Electricity and heat consumption, as well as data on electricity generation in the three districts was obtained from Reinhardt et al. (2017). Updated information was generously provided by the authors. Data on the length of electricity transmission lines in the districts were obtained from the Bavarian State Ministry of Economics and Energy (StMWi 2018). Data on electricity and heat generation by energy source in Germany comes from IEA (2017).

3.3.3 Factors of production

The three categories of labor input (low-, medium-and high-skilled) for Germany and the ROW are also from Exiobase 2 (Wood et al. 2015). Data for capital stocks for Germany was obtained from von Schickfus and Zimmer (2018), who in turn derive the data from various sources including Eurostat (2016), ENTSO-E (2017), IRENA (2016a), and Deutsche Energieagentur (2012).

3.3.4 Future renewables deployment and investments

Future deployment of renewables for electricity and heat generation, energy efficiency measures and electricity storage in each of the three districts were obtained from the simulations done in the framework of the project by two Geography Departments of the LMU Munich. Thus, the deployment figures constitute an exogenous input in the present study. The simulations are based on the natural potential for renewable energy generation in the region, the available land use restrictions (e.g., due to conservation areas), the preferences of the population regarding technology types and installations' size, and the profitability of the measures, besides the usually considered factors like interest rates and energy prices. The scenarios are constructed along two dimensions: one describing the overall economic and social setting, and another outlining possible deployment paths. The first dimension considers, on the one hand, a business-as-usual (BAU) scenario and, on the other hand, a scenario with a trend towards a more sustainable economy and society (GREEN). The deployment paths differentiate between focusing primarily on small scale installations or on large scale installations of renewable energies. Combining both dimensions leads to 4 scenarios: BAU SMALL, BAU LARGE, GREEN SMALL, and GREEN LARGE.[18] From the simulations we obtain the annual average sum of renovation expenditures per district and information on the capacity (in kWp) installed per technology type and year from 2015 to 2035. In our analysis, we consider the average installed capacity per year.

Table 3.2 depicts the comprehensive set of technologies and measures we consider in the analysis. It also shows that companies and other institutional investors invest in almost all type of technologies and measures except in heat pumps. Investments by private households take place in rooftop solar PV, solar thermal installations and heat pumps, on the generation side, and in district heating networks, renovations and batteries, on the energy infrastructure side.

The investment and operating costs for most power and heat generating technologies, as well as their distribution among sectors was obtained from Hirschl et al. (2010). The information for deep geothermal is from Hirschl et al. (2015). The renovations costs as well as their distribution among sectors is obtained from Hinz (2015), Loga et al. (2015) and IWU (2018). For

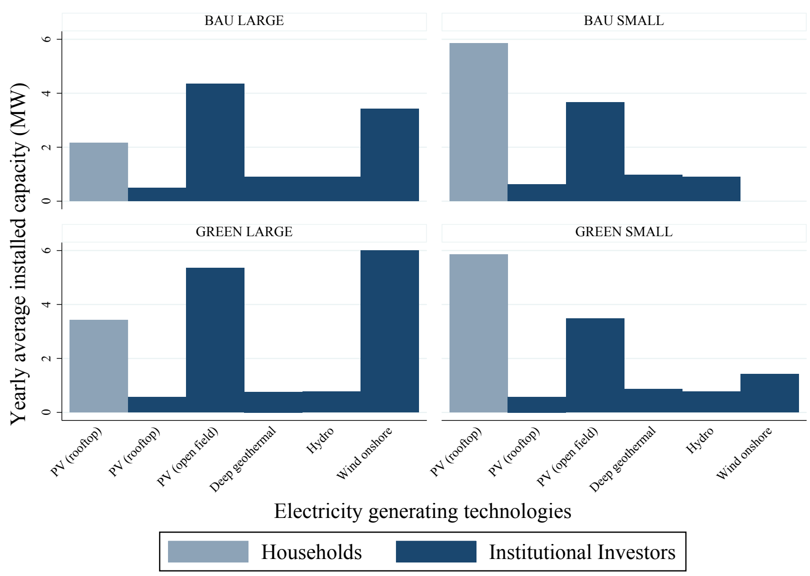
[18] For more information on the simulations see Danner et al. (2019). Table B.3 in Appendix B.2 provides an overview of the scenarios. For a more detailed information of the scenario construction process see Musch and Streit (2017).

each scenario we combine this information with the installed capacity by year, technology, investor type and district, which results in several cost vectors. We subsequently sum up over technologies to arrive at a vector by investor type, district and scenario. These vectors are the basis of the methodology outlined in Section 3.2.3.

Table 3.2 : Technologies, measures and type of investor

Technology	Companies	Private households
PV (rooftop)	x	x
PV (open field)	x	
Solar thermal	x	x
Biomass	x	
Wind onshore	x	
Hydro	x	
Deep geothermal	x	
Geothermal heat pumps		x
District heating network	x	x
Renovations	x	x
Batteries	x	x
Power-to-Gas	x	
Gravity storage	x	

Figure 3.1 : Installed capacity by scenario, yearly average



In the following, we describe the deployment figures obtained from Danner et al. (2019) (forthcoming). Figure 3.1 shows the average installed capacity for electricity generating technologies, classified by technology, type of investor and scenario. From the figure becomes clear that the largest differences in the yearly installed capacity arise from concentrating the efforts on small scale installations (scenarios BAU SMALL and GREEN SMALL) or focusing on large scale installations (scenarios BAU LARGE and GREEN LARGE). So, for instance, in the GREEN SMALL scenario the average installed capacity of rooftop solar by households is, with 6 MW, twice as large than in the GREEN LARGE scenario. The contrary and with even more pronounced differences, occurs for wind installations, where the average installed capacity in the GREEN LARGE is 6 MW versus 1.2 under the GREEN SMALL scenario. Figure B.1 in the Appendix shows a similar pattern for heat generating technologies.

Expressing these figures in relation to the number of inhabitants, allows a comparison to current deployment in the whole of Bavaria. We see that for the GREEN LARGE scenario, the yearly PV and wind installations are equivalent to 25.7 kW per 1,000 inhabitants and 18.5 kW per 1,000 inhabitants, respectively. The newly installed capacity in kW per 1,000 inhabitants in Bavaria for the year 2017 (2018) was 50.9 (31.3) for PV and 24.2 (17) for wind (Agentur für Erneuerbare Energien 2019). Thus, putting the regional deployment figures into context shows that, although the regional energy transition in the Bavarian Oberland requires an important deployment of renewable technologies, it does not require an unrealistic development. Yet, it is important to mention that these deployment scenarios would not achieve a complete coverage of the energy demand by renewables by 2035, but would bring the coverage rate in electricity from 38% in 2015 to 51-62% in 2035. For heating the coverage rate would improve from 26% in 2015 to 62-66% in 2035. Although the natural and technical potential would allow the region to meet its target by 2035, in the deployment simulations an annual technology specific “administrative installation cap” was set. The main rationale behind this cap was to account for the observed limited capacity of the public administration when it comes to granting the necessary licenses for the installation of renewable energies.

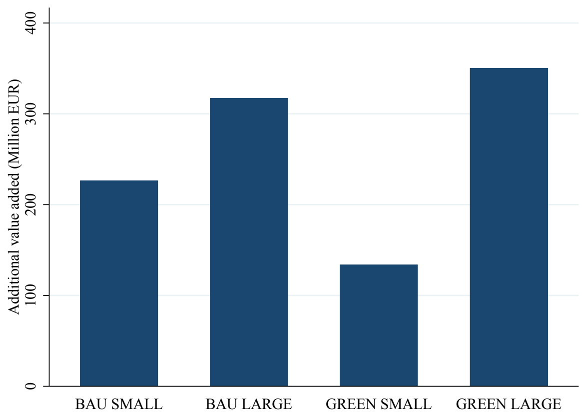
3.4 Results

In this section we present the results obtained by applying the methodology outlined in Section 3.2 to investigate the economic effects of a future energy transition in the Bavarian Oberland region. We start by presenting aggregated effects for the whole region and then dig deeper and show value added and employment effects for the individual districts and for individual sectors.

3.4.1 Effects on value added

Investments in renewables generate an aggregated regional value added ranging from 133 to 350 Million EUR, depending on the scenario, as shown in Figure 3.2. Considering that the value added in 2014 amounted to 9.5 Billion EUR, the presented figures translate to an increase in value added of between 1.4% and 3.6%. The result that the GREEN SMALL scenario leads to the lowest value added effects can be explained by this scenario having the highest energy savings and, therefore, requiring lower deployment rates. In Figure 3.3 we see that although all three districts benefit from RES investments, in two out of the four scenarios (the ones relying more heavily on large appliances), the district of Miesbach, which is the smallest district in economic terms, benefits the most. The district of Weilheim-Schongau benefits most in the other two scenarios, but the differences to Miesbach are almost negligible. The overall effects for the whole of Germany (that is, including the Oberland region) are also positive, yet the rest of the country suffers from the crowding out of alternative investments and consumption, and from the Oberland region attracting factors of production which are then missing for production in the rest of Germany. The reason for the overall effects for Germany to be positive is that we allow for financial resources to be attracted from the rest of the world when considering crowding out effects in the investment phase. This approach leads to a lower investment crowding out in Germany than if we had restricted financial resources in the investment phase to come only from Germany.

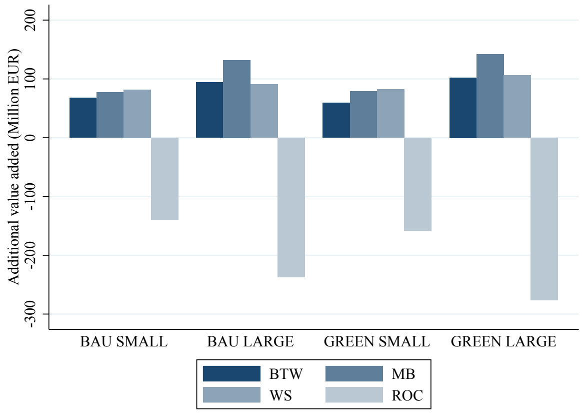
Figure 3.2 : Aggregated effects on value added, by scenario



Notes: The bars show the aggregate value added figure for the three districts in the Oberland region.

Looking at the sectoral effects in Figure 3.4, which shows exemplarily the results for the GREEN LARGE scenario, it is not surprising that the winners from the energy transition in the

Figure 3.3 : Effects on value added, by scenario and region

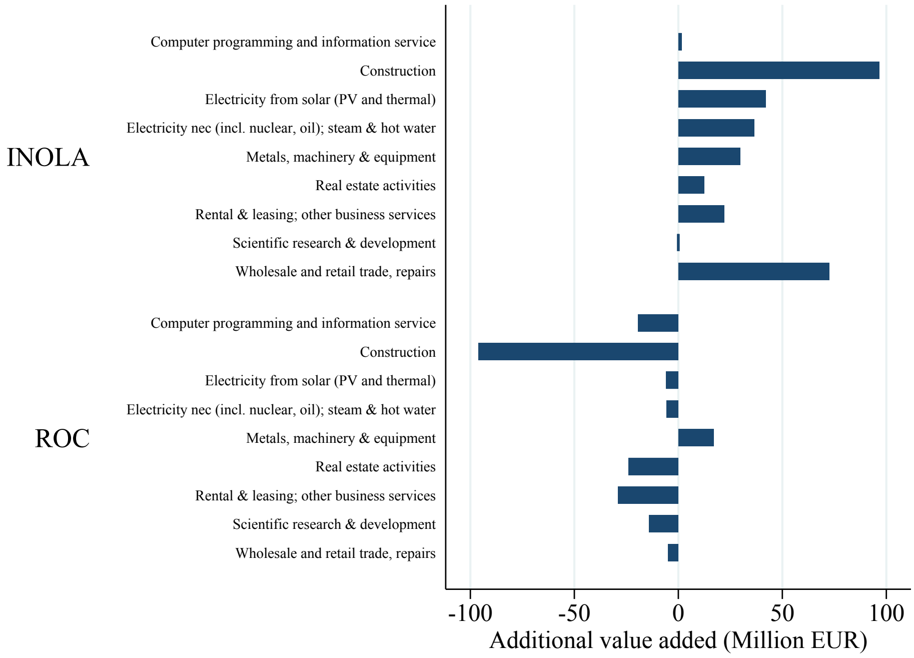


Oberland region are the sectors that are more closely related to the installation and operation of renewables as well as to renovations to increase the energy efficiency of buildings. Capturing about 30% of the additional value added, the *Construction* sector benefits the most across all scenarios, as can also be seen for the remaining scenarios depicted in Figures B.5 to B.7 in the Appendix. *Wholesale and repairs*, *Electricity from solar* and *Electricity nec; steam and hot water* are also among the sectors that benefit most across all scenarios.[19] Although we cannot verify the subsectors's share in the increase or decrease in a sector's value added, it can be argued that *steam and hot water* are the subsectors contributing most to the increase in value added in the *Electricity nec; steam and hot water* sector. Within the Oberland region there are no proper losers from the energy transition. The sector with the most negative change in value added is *Human health and social work activities* with a decrease of 0.5 Million EUR. To a certain extent, this can be explained by our assumption that factors of production are fully mobile within Germany, granting the Oberland region access to a large pool of factors. The consequence of the assumption is that sectors in the Oberland region increase their production at the expenses of sectors in the rest of the country and not at the expenses of other sectors within the region.

The careful reader might be missing conventional electricity sectors among the losers of the energy transition. In fact, in the rest of the country value added in the sectors *Electricity from coal* and *Electricity from gas* decreases, yet, only by about 5 Million Euro, corresponding to a decrease of approximately 0.02% of these sectors' value added in 2014. The almost

[19] nec: not elsewhere classified.

Figure 3.4 : Effects on value added for selected sectors, GREEN LARGE scenario



Notes: For a better visualization some sector descriptions have been shortened. See Appendix B.1 for the full sector descriptions.

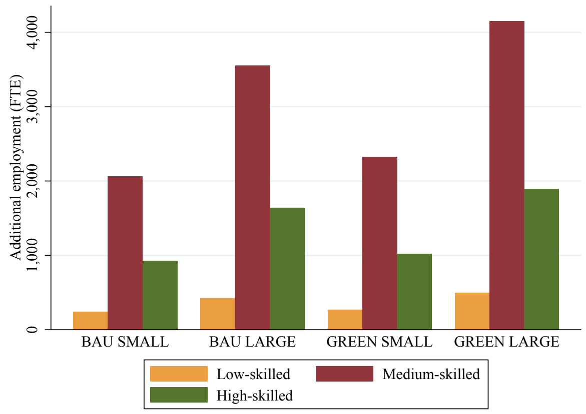
insignificant loss for these two sectors is more reassuring than worrying, given the small size of the Oberland region compared to the rest of Germany. Since there are no coal power plants in the Oberland region, there is no *Electricity from coal* sector in any of the districts and, therefore, no value added losses.

3.4.2 Effects on employment

The employment effects of the energy transition in the Oberland region are shown in Figure 3.5. Most of the increase occurs in medium-skilled employment, making up about 63% of the additional full time equivalent (FTE) jobs.[20] Under the GREEN LARGE scenario, for instance, the considered investments in renewables create 4,150 medium-skilled jobs in the region, while

[20] Considering that in 2014 medium-skilled labor accounted for 52% of employment across all categories, this result implies that the increase in medium-skilled labor is more than proportional to the pre-energy transition shares.

Figure 3.5 : Aggregated effects on categories of employment in the Oberland region, by scenario



the increase in high-skilled and low-skilled jobs is close to 1,900 and 500, respectively.[21] In relative terms the increase in medium-skilled employments lies between 2.5% and 5.1% with respect to the year 2014. For low-skilled and high-skilled employment the percentage increase is 1.8-3.6% vs. 1.5-3.2%, respectively. This implies that, in contrast to the absolute changes, the relative increase in low-skilled employment is larger than in high-skilled employment.

Looking at the regional distribution of the employment effects we see that it follows a similar pattern as the effects on value added (see Figure 3.6). Miesbach benefits the most in terms of employment for all three categories and across all scenarios, while Weilheim-Schongau is second when the focus lies on small scale installations (see Figure 3.6 and Figures B.2 to B.4 in Appendix B.3). In the scenarios when efforts are concentrated towards deploying large scale installations, the employment effects in Bad Tölz-Wolfratshausen and Weilheim-Schongau are approximately the same. The negative effects for the rest of the country in all three categories show that most of the employment effects occurring in the Oberland region are job reallocations from the rest of the country and, therefore, cannot be referred to as job creation.

Breaking down the employment effects in the GREEN LARGE scenario by sector delivers the results in Figure 3.7.[22] Considering the results presented so far, it is not surprising that for medium-skilled labor the *Construction* sector exhibits the largest positive effects for the

[21] Note that, technically, we should rather refer to a reallocation of jobs instead of job creation, since we assume labor to be scarce. However, interpreting the results as job creation in the region is not wrong per se, but we need to keep in mind that this requires that jobs are “destroyed” somewhere else.

[22] A sector breakdown for the other scenarios can be found in Figures B.8-B.10.

Figure 3.6 : Effects on employment by category and region, GREEN LARGE scenario

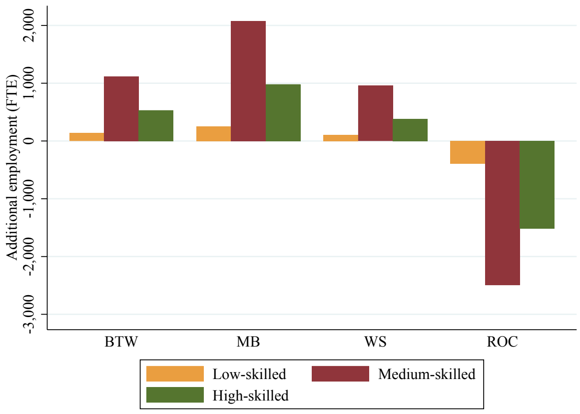
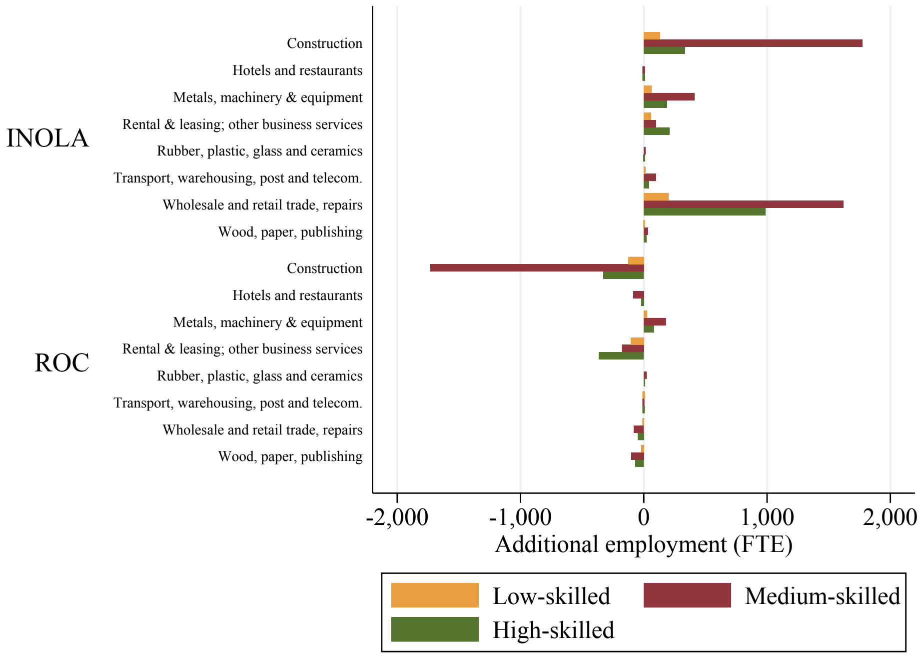


Figure 3.7 : Aggregated effects on employment by category, selected sectors and aggregated region, GREEN LARGE scenario



Notes: For a better visualization some sector descriptions have been shortened. See Appendix B.1 for the full sector descriptions.

Oberland region and the largest negative effects for the rest of the country. *Electricity from solar* and *Electricity nec; steam and hot water* are among the sectors that benefit most in terms of value added, yet, due to their low labor intensity, the employment effects in these sectors are rather low.

3.5 Conclusions

In this investigation of the economic effects of an intended energy transition in the Bavarian Oberland region we contribute to the literature in several ways. First, we disaggregate the energy sector in the IO table to be able to consider the specificities of each technology's interlinkages with the rest of the economy. Second, we contribute to the literature on the economic effects of regional investments, in a broader sense, and more specifically, on the effects of regional investments towards a transformation of the energy system. The key contribution to this literature is the consideration of scarcities, which generate crowding out effects both in the investment and in the operation phase. A third contribution consists in expanding the approach developed by Fisher and Marshall (2011), Benz et al. (2014), and von Schickfus and Zimmer (2018) to improve its performance in a subnational context.

We show that following investments in a sector embedded in a framework where full employment and scarcity of financial resources is realistically assumed, value added and employment in this and other sectors increase, but this comes at the expenses of other sectors and other regions. We further show that assuming full mobility of factors of production within Germany, gives the sectors in the Oberland region access to a very large pool of workers and capital, that is, that of the rest of the country. Thus, the negative effects on other sectors are almost fully "exported" to the region(s) where the investments do not take place. In our case the decline in value added and employment occurs almost exclusively in sectors of the rest of the country and not in our region of study. Moreover, we find that although employment in the Oberland region increases in all three categories (low, medium and high-skilled), the increase in medium-skilled employment is stronger than for the other two categories.

Thus, from the analysis of the employment effects of the intended energy transition in the Bavarian Oberland region we can also draw conclusions for the whole of Germany and for other countries with similar conditions. Irrespective of whether the energy transition occurs at the regional or the national level, our results show that fundamentally restructuring the energy system, as it is necessary to reduce greenhouse gas emissions in a serious manner, requires an intensified employment of medium-skilled labor. Thus, considering that already today Germany suffers from medium-skilled shortages, this can turn into a bottleneck for the transformation of the energy system. We could expect market forces to fix the shortages by increasing incentives (i.e., wages) in the demanded professions. Yet, the working of market forces could take time, which is not available when talking about mitigating climate change.

The other, better option is to act proactively and increase the awareness for the importance of these professions and their attractiveness as part of climate and energy policy interventions.

It is important to take into account that our analysis of the economic effects of a regional energy transition is placed in a context where investments in renewable energies remain constant outside of the Oberland region. If, on the contrary, other regions pursue a similar goal or the energy transition at the national level is intensified, scarcities in the factors of production would inhibit the achievement of the goals and therefore limit the positive effects on the regional economy. Hence, further questions that arise in this context concern the consequences of a far-reaching regionalization of the energy transition goal, that is, when many regions intend to totally cover energy consumption by renewable energy generation. In particular, an interesting question would be whether this regionalization could give rise to a systems competition between the regions, seeking to attract capital (and labor) for the respective energy transitions.

Possible extensions of the methodology could consider alternatives to our assumption of full mobility of factors of production within Germany. On the one hand, the full mobility assumption is a plausible assumption, specially for the production factor capital. On the other hand, although in theory it is possible that workers move freely, there might also be frictions binding workers to a specific region. A further development of our methodology could deal with restricting mobility partially, so that it is possible to attract workers form other regions, but to a limited extent. One possibility in this respect is to include neighboring districts in the analysis to allow mobility within that larger region, but not with the rest of Germany.

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A Appendix to Chapter 2

Table A.1 : Sensitivity Analysis - sample composition

	CO2e emissions	
	(1) FD	(2) FD
RES loans and subsidies t-1	-0.007	-0.001
	(0.006)	(0.006)
UtilityxRES loans and subsidies t-1	-0.004	-0.000
	(0.014)	(0.014)
RES feed-in tariffs t-1	-0.006	0.008
	(0.012)	(0.012)
UtilityxRES feed-in tariffs t-1	0.057^{**}	0.053^{*}
	(0.028)	(0.028)
CHP t-1	0.039^{**}	0.031^{*}
	(0.015)	(0.018)
UtilityxCHP t-1	-0.007	-0.005
	(0.032)	(0.066)
EE loans and subsidies t-1	0.037^{**}	0.010
	(0.018)	(0.018)
Energy audits t-1	-0.069^{***}	-0.056^{**}
	(0.022)	(0.024)
Year FE	Yes	Yes
Observations	4349	3335
R^2	0.017	0.023

Notes: All regressions include revenue and market capitalization. Robust standard errors clustered by country. ***/**/* indicate significance at the 1%/5%/10% level.

Table A.2 : First stage selection correction

	Disclosing emissions					
	(1) 2007	(2) 2008	(3) 2009	(4) 2010	(5) 2011	(6) 2012
Human Rights Monitoring	-0.428^{***} (0.105)	-0.104 (0.084)	-0.786^{***} (0.091)	-0.253^{***} (0.087)	0.168^{**} (0.069)	0.504^{***} (0.055)
Avrg. HR Monitoring	0.778^{***} (0.092)	0.676^{***} (0.104)	1.572^{***} (0.123)	0.721^{***} (0.124)	0.517^{***} (0.102)	-0.073 (0.081)
Revenue	-0.306^{**} (0.133)	0.108 (0.143)	-0.335^{**} (0.131)	0.112 (0.147)	0.543^{***} (0.139)	0.563^{***} (0.104)
Avrg. Revenue	0.504^{***} (0.137)	0.048 (0.146)	0.542^{***} (0.131)	0.069 (0.148)	-0.404^{***} (0.139)	-0.408^{***} (0.103)
Marketcap	-0.162^{***} (0.053)	-0.191^{***} (0.048)	-0.123^{**} (0.057)	0.017 (0.057)	0.162^{***} (0.046)	0.143^{***} (0.042)
Avrg. Marketcap	0.111^{*} (0.064)	0.147^{**} (0.058)	0.040 (0.055)	-0.012 (0.061)	-0.184^{***} (0.047)	-0.176^{***} (0.042)
Observations	5987	5978	5979	5965	5953	5951

Notes: All regressions include policy variables and their mean according to (2.3). Robust standard errors clustered by country. ***/**/* indicate significance at the 1%/5%/10% level.

Table A.3 : Number of surveyed companies per country and selection rule

	Region/sector	Based on	Index used
800 of the largest	Global	market cap.	FTSE All-World Developed—Large Cap
800 of the largest and mid-sized	Emerging markets	market cap.	S&P/IFCI Large/Mid Emerging Market Index
725 of the largest	UK	market cap.	FTSE All-Share and FTSE Fledgling Index
500 of the largest	Global	market cap.	Global 500
500 of the largest	Japan	market cap.	
500 of the largest	USA	market cap.	S&P 500
300 of the largest	Europe	market cap.	FTSEurofirst 300 Eurozone
260 of the largest	Nordic	market cap.	
250 of the largest	France	market cap.	SBF 250
250 of the largest	Germany, Austria	market cap.	
250 of the largest	Korea	market cap.	
250 of the largest	Electric utilities globally	market cap.	
200 of the largest	Australia	market cap.	ASX 200
50 of the largest	New Zealand	market cap.	NZX 50
200 of the largest	Canada	market cap.	
200 of the largest	India	market cap.	BSE 200
180 of the largest	Issuing bonds	market cap.	S&P CDS U.S. Investment Grade Index and Markit iBoxx USD Liquid Investment Grade Index
170 of the largest	Asia exc. Japan, India, China, Korea	market cap.	Asia ex-JICK
150 of the largest	Netherlands, Belgium, Luxemburg	market cap.	
125 of the largest	Spain and Portugal	market cap.	
100 of the largest	Brazil	market cap.	BM&FBOVESPA IBrX100
100 of the largest	Central & Eastern Europe	market cap.	
100 of the largest	China	market cap.	
100 of the largest	Italy	market cap.	
80 of the largest	Latin America	market cap.	
100 of the largest	South Africa	market cap.	FTSE/JSE 100
100 of the largest	Switzerland	market cap.	SPI Large & MidCap SOCI
100 of the largest	Transport sector globally	market cap.	
100 of the largest	Turkey	market cap.	ISE 100
50 of the largest	Russia	market cap.	RTS Index
30 of the largest	Ireland	market cap.	

Source: CDP (2013)

B Appendix to Chapter 3

B.1 Sectors

Table B.1 : Sector description and numbers

Sector number	Sector description
1	Agriculture, forestry and fishing
2	Mining and quarrying
3	Food, beverages, textiles, leather
4	Wood, paper, publishing, broadcasting, arts, entertainment, recreation
5	Coke and refined petroleum products
6	Chemicals and pharmaceuticals
7	Rubber, plastic and glass products and ceramics
8	Metals & metal products, machinery & equipment, and other products
9	Water supply, sewerage, waste management and remediation
10	Electricity from coal
11	Electricity from gas
12	Electricity from hydro
13	Electricity from wind
14	Electricity from biomass and waste
15	Electricity from solar (PV and thermal)
16	Electricity nec (incl. nuclear, oil); steam & hot water
17	Transmission of electricity
18	Distribution and trade of electricity
19	Manufacture of gas; distribution of gaseous fuels through mains
20	Construction
21	Wholesale and retail trade, repairs, including motor vehicles
22	Hotels and restaurants
23	Transport, warehousing, post and telecommunications
24	Financial and insurance services
25	Real estate activities
26	Rental & leasing; other business services
27	Computer programming and information service
28	Scientific research & development
29	Public administration & defense, social security
30	Education
31	Human health and social work activities
32	Activities of membership organizations and other personal service activities

Table B.2 : Available regional gross value added values

Aggregated sector	Corresponding CPA classifications	Sector description
A	1-3	Agriculture, forestry and fishing
B-E	5-39	Industry excluding construction
C	10-33	Manufacturing
B, D, E*	5-9, 35-39	Industry excluding construction and manufacturing. B: Mining and quarrying; D: Electricity, gas, steam and air conditioning supply; E: Water supply; sewerage, waste management and remediation activities
F	41-43	Construction
G-J	45-63	G: Trade, repair of motor vehicles; H: Transportation and storage; I: accommodation and food services; J: Information and communication
K-N	64-82	K: Financial and insurance activities; L: real estate activities; M: Professional, scientific and technical activities; N: Administrative and support service activities
O-T	84-98	O: Public administration and defense, social security; P: Education; Q: Health and social work; R: Arts, entertainment and recreation; S: Other service activities; T: Activities of households as employers

B.2 Scenarios

Table B.3 : Scenario description

Green scenario	Business as usual scenario
Low price path for fossil energy sources on the global market	High price path for fossil energy sources on the global market
Return to the historical interest rate level in Germany	Moderate recovery of interest rates in Germany
Strong increase of the Gross Domestic Product in Germany	Moderate increase of the Gross Domestic Product in Germany
Increasing globalisation, increasing trade relations with a global paradigm shift on sustainability	Increasing globalisation, increasing trade relations without common environmental and energy targets
Higher population (weak decrease), higher migration balance	Higher population (weak decrease), higher migration balance
Societal value orientation: trend towards a sustainable materialism	Societal value orientation: trend towards differentiation
Trend towards a decentralised energy production and storage	Trend towards a mixed structure in energy production and storage
Preference for technology-specific economic instruments for the energy sector (e.g., EEG)	Preference for technology-specific economic instruments for the energy sector (e.g., EEG)
Higher policy stability for the energy sector	Constant level of policy stability for the energy sector
Redistribution of the EU Common Agricultural Policy funds: More funding for environmental protection in agriculture	Continuation of the EU Common Agricultural Policy
Intensified environmental and resource protection in Germany	Constant level of activity in environmental policy in Germany
Comparatively low global greenhouse gas concentration (temperature increase 2046-2065 probably between $0.4°$C and $1.6°$C)	Medium level of global greenhouse gas concentration (temperature increase 2046-2065 probably between $0.9°$C and $2°$C)

Source: Musch and Streit (2017)

B.3 Additional figures

Figure B.1 : Installed capacity for heat generation by scenario, yearly average

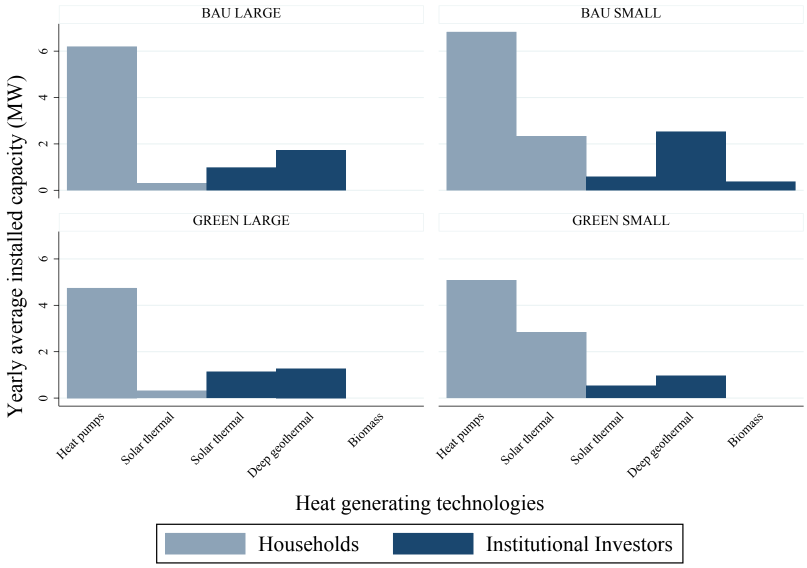


Figure B.2 : Effects on employment by category and region, BAU SMALL scenario

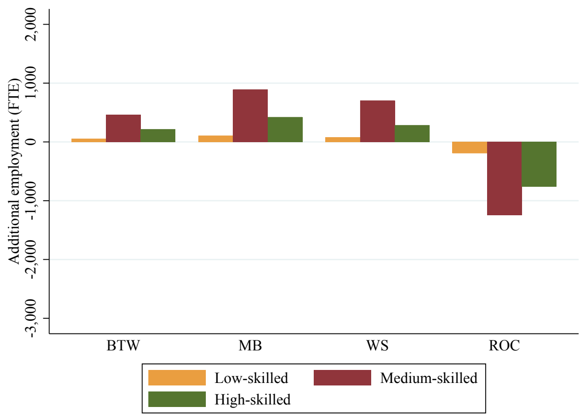


Figure B.3 : Effects on employment by category and region, BAU LARGE scenario

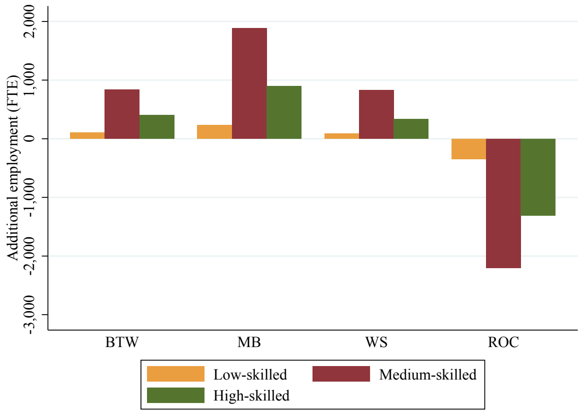


Figure B.4 : Effects on employment by category and region, GREEN SMALL scenario

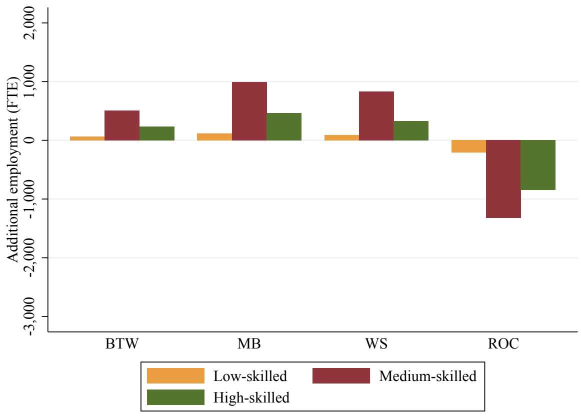
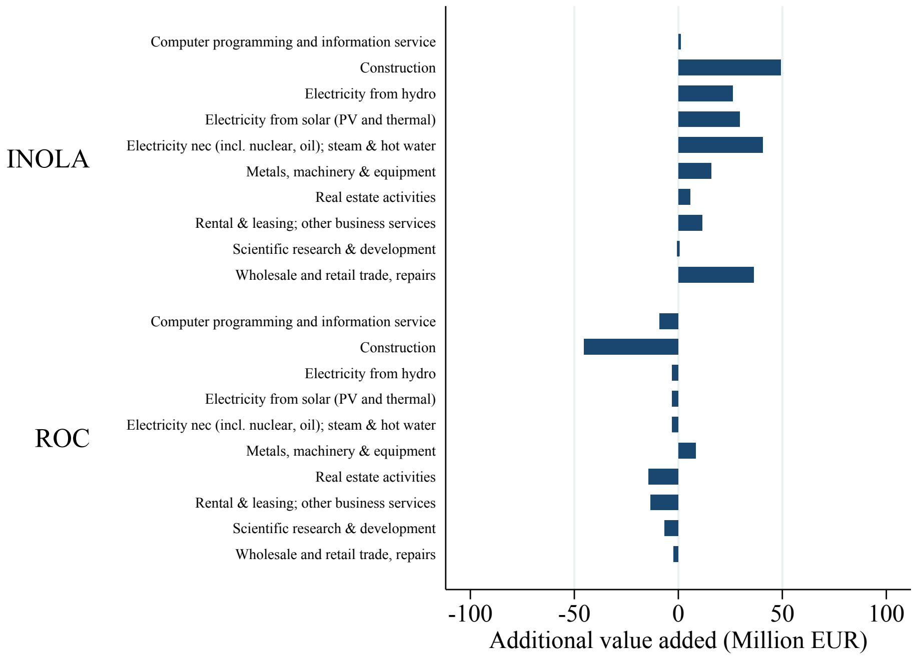
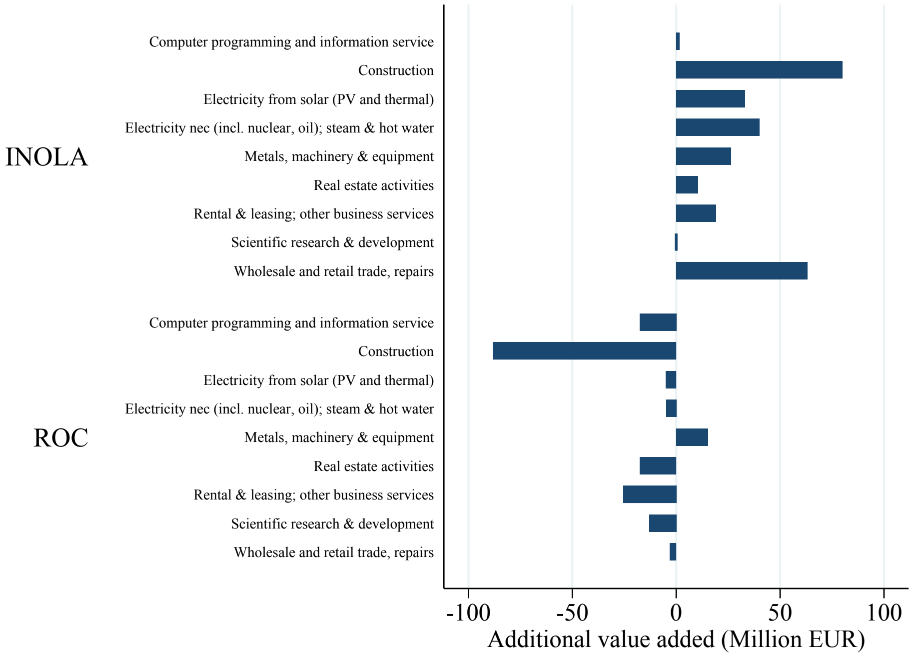


Figure B.5 : Effects on value added for selected sectors, BAU SMALL scenario



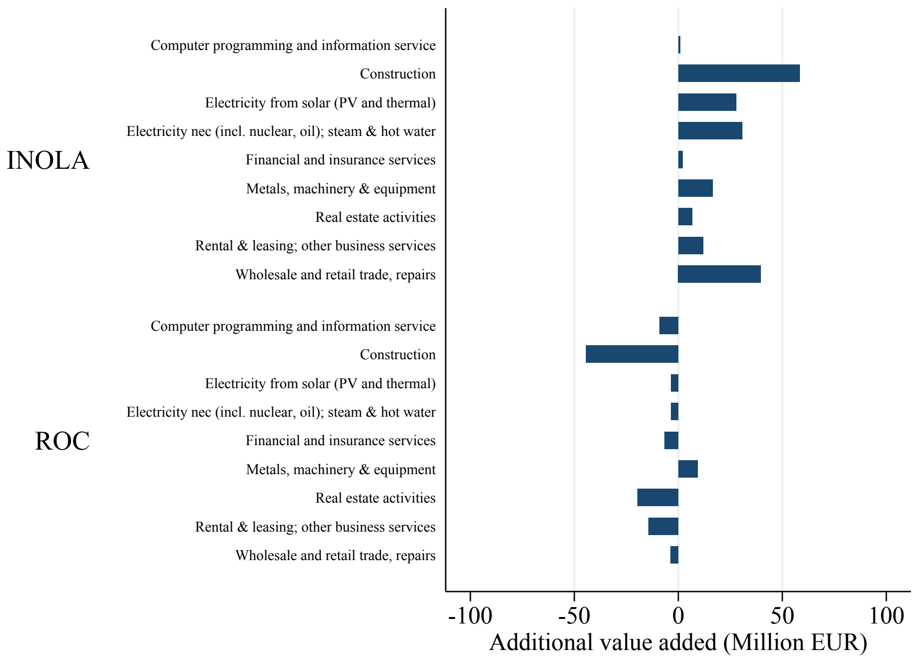
Notes: For a better visualization some sector descriptions have been shortened. See Appendix B.1 for the full sector descriptions.

Figure B.6 : Effects on value added for selected sectors, BAU LARGE scenario



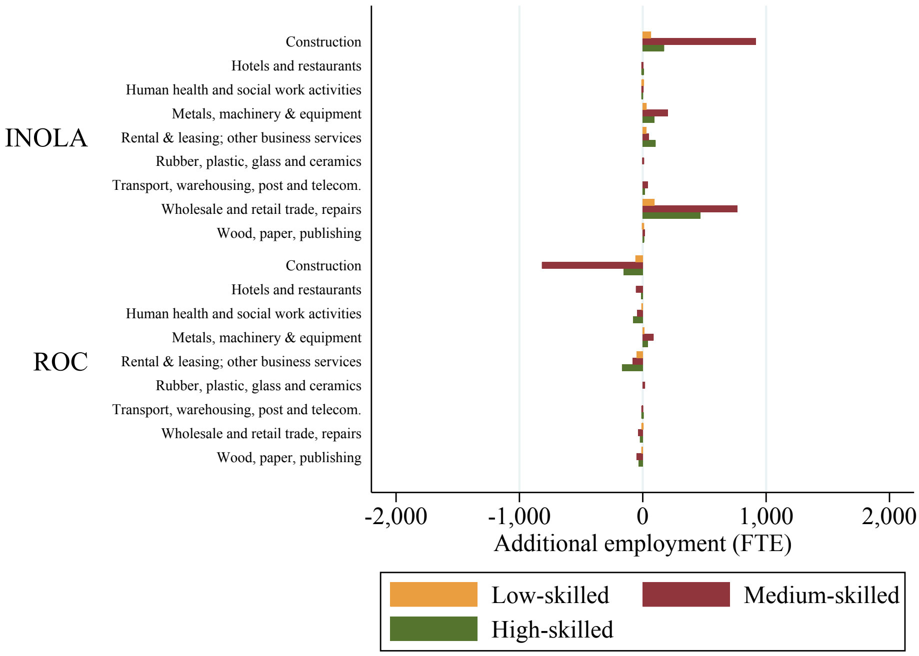
Notes: For a better visualization some sector descriptions have been shortened. See Appendix B.1 for the full sector descriptions.

Figure B.7 : Effects on value added for selected sectors, GREEN SMALL scenario



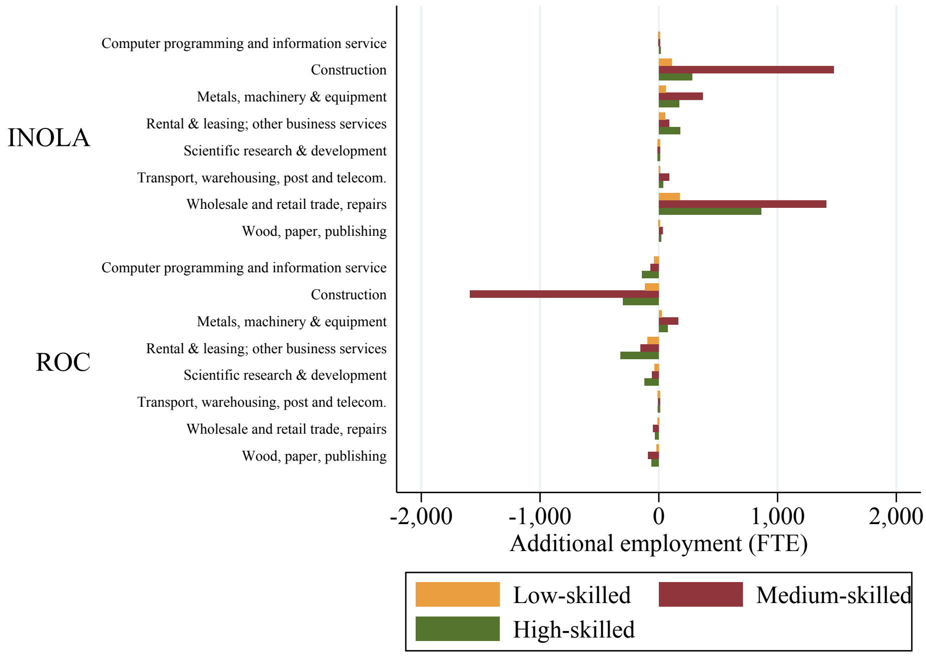
Notes: For a better visualization some sector descriptions have been shortened. See Appendix B.1 for the full sector descriptions.

Figure B.8 : Aggregated effects on employment by category, selected sectors and aggregated region, BAU SMALL scenario



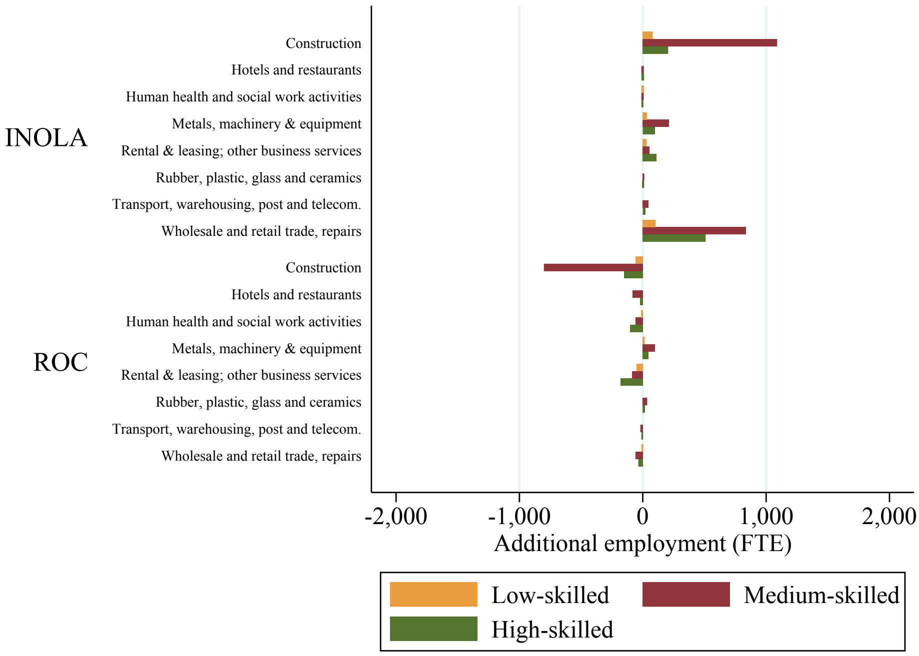
Notes: For a better visualization some sector descriptions have been shortened. See Appendix B.1 for the full sector descriptions.

Figure B.9 : Aggregated effects on employment by category, selected sectors and aggregated region, BAU LARGE scenario



Notes: For a better visualization some sector descriptions have been shortened. See Appendix B.1 for the full sector descriptions.

Figure B.10 : Aggregated effects on employment by category, selected sectors and aggregated region, GREEN SMALL scenario



Notes: For a better visualization some sector descriptions have been shortened. See Appendix B.1 for the full sector descriptions.

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