ANALYSIS OF ENERGY EFFICIENCY DEVELOPMENT AT DIFFERENT AGGREGATION LEVELS IN THE MANUFACTURING INDUSTRIES EVIDENCE FROM GERMANY AND COLOMBIA

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- The 15th Annual International Sustainable Development Research Conference organised by the Copernicus Institute for Sustainable Development and Innovation, Utrecht University (Utrecht, Netherlands. 2009).
- The World Sustainable Energy Days 2010. Conference organised by O.Ö. Energiesparverband and European Comission (Wels, Austria. 2010).
- The A&WMA's Annual Conference & Exhibition technical program oragnised by Air & Waste Management Association (Calgary, Canada 2010).
- BIEE 8th Academic Conference Energy in a Low Carbon Economy: New roles for governments and markets organised by British Institute of Energy Economics (BIEE) and the United Kingdom Energy Research Centre (UKERC) (Oxford, England. 2010)

The research in this dissertation has been presented at the following events:

- The 6th PhD Student Workshop of the Gesellschaft für Energiewissenschaft und Energiepolitik e. V. (GEE) Student Chapter (Dresden, Germany. 2009).
- The 2nd Conference in Economics in memory of Vasillis Patsazis organised by the Department of Economics of University of Athens (Athens, Greece. 2009).
- Second International Conference on Energy and Sustainability organised by the University of New Mexico, USA and Wessex Institute of Technology, United Kingdom (Bologna, Italy. 2009).
- The Sparks poster session at the United Kingdom Energy Research Centre (UKERC) Annual Assembly and Summer School (Brighton, United Kingdom. 2009) UKERC Summer School Poster Session (Brighton, 2009).
- The 1st European PhD-students Day organised by the Vienna University of Technology, the Austrian Association for Energy Economics (AAEE) and Energy Economics Group (EEG) of Vienna (Vienna, Austria. 2009).
- The 10th IAEE European Conference organised by the International Association for Energy Economics (IAEE. Vienna, Austria. 2009).
- The International Energy Workshop (IEW) organised by Royal Institute of Technology (Stockolm, Swedish. 2010).

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Chapter 1.
Introduction

1.1 Energy and Environment

Energy use and supply are of fundamental importance to society, and it has been argued that energy is the key "to the advance of civilisation" and that the evolution of human societies is dependent on the conversion of energy for human use (Barbour et al., 1982). However, the concept that the standard of living and quality of civilisation are proportional to the quantity of energy a society uses[1] has been questioned, considering that nowadays a challenge of humanity is focused on finding alternatives to expand the quality and quantity of energy services while simultaneously addressing the environmental impacts associated with energy use.

After the industrial revolution and the exploration and development of fossil fuels, the use of energy has generated air and water pollution (e.g., emissions of sulphur, mono-nitrogen oxides, lead, particulate matter, and others); however, fossil fuel combustion plays an important role in the climate change that has observed in the last fifty years.

Moreover, fossil fuel combustion produces more carbon dioxide (CO_2) than any other human activity. This is the biggest source of the anthropogenic greenhouse gas emissions that are changing the composition of the atmosphere and could alter the global climate system, including the amount and pattern of rainfall (UNDP et al., 2004). Currently, total annual emissions of greenhouse gasses (GHGs) are rising. Over the last three decades, GHG emissions have increased by an average of 1.6% per year[2], with carbon dioxide (CO_2) emissions from the use of fossil fuels growing at a rate of 1.9% per year (IPPC, 2007), and these increases have been related to changes in snow cover, ice extent, sea level and precipitation. Furthermore, these changes have started to affect biological and physical systems and could generate negative impacts both on economic and social systems in the medium and long term. Hence, the challenge of society, according to the World Energy Assessment, is not a lack of resources but how to create a seamless transition to other resources than those currently used, especially from coal and oil, with the aim to stabilise atmospheric CO_2 concentration.

[1] This concept could be expressed as a formula: energy=progress=civilisation (Basalla, 1980).
[2] Total GHG (Kyoto gases) emissions in 2004 amounted to 49.0 $GtCO_2$-eq, which is up from 28.7 $GtCO_2$-eq in 1970 – a 70% increase between 1970 and 2004. In 1990, global GHG emissions were 39.4 $GtCO_2$-eq.

According to this aim, the main options for using energy in ways that support sustainable development with a consistent focus on social, economic, and environmental processes include (UNDP, 2004 and IPPC, 2007):

- More efficient generation, production and use of energy, especially at the point of end use in buildings, transportation, and production processes.
- Increased reliance on renewable energy sources.
- Accelerated development and deployment of new energy technologies – particularly next-generation fossil fuel technologies that produce near-zero harmful emissions.

Prior research shows that the main strategy to decrease greenhouse gas emissions in the next twenty years is based on energy efficiency improvements[3] (e.g., Vuurean et al., 2007, IPPC, 2007; Abulfotuh, 2007; Devezas et al., 2008; Kuuskraa et al., 2008;), and after 2030, other strategies will be key as fossil fuels are abandoned for renewable energy (solar, wind) and bio-fuels for power generation and the projects of carbon capture and storage are underway.

Furthermore, energy efficiency has become the first step to controlling and stabilising greenhouse gas concentrations at low levels because it is the most cost-effective and fastest option. Hence, it slightly improves the energy system by reducing losses and overload; it could reduce the investments in energy infrastructure; it will help mitigate energy price increases and volatility by easing short- and medium-term imbalances between demand and supply; and it will also help reduce CO_2 emissions and increase energy security. Additionally, energy efficiency offers non-energy benefits, such as reducing operating costs; growth in productivity; improvements in product quality, capacity utilisation, and worker safety; waste reduction and pollution prevention (Pye and Mckane, 2000; Boyd and Pan, 2000; UNF, 2007). Some worldwide declarations that have recognised the importance of promoting energy efficiency include: the 2005 Gleneagles Declaration, which expressed support for specific energy efficiency activities and policies; the 2006 St. Petersburg declaration, which reiterated support for existing proposals and extended discussions to improve efficiency to the energy supply

[3] The concept of energy from "efficiency" has the following perspectives, according to Wuppertal institute (2009): In *the macroeconomic aggregated perspective*, energy efficiency is either denoted as energy intensity (energy input is related to monetary output parameters) or reciprocally as energy productivity (the ratio of production is related to energy consumed); *the efficiency of energy conversion* (the ratio of generated end-use energy to primary energy or to secondary energy used); and *the energy end-use efficiency* (the proportion of amount of energy used for the satisfaction of personal needs and energy use for non-personal demands).

sector; and the Group of Eight (G8) countries' commitment to a collective goal of doubling the global historic annual rate of energy efficiency improvement to 2.5 percent per year from approximately 2012 through 2030 in their 2007 Summit in Germany (UNF, 2007).

This thesis is supported by the importance that is placed on improvements in energy use and the reduction of greenhouse emissions within an energy system and because energy efficiency has become a crucial strategy for sustainable economic development and climate stabilisation today and in the near future.

The measurement of energy efficiency (with different methodology approaches) plays an important role in the formulation, application and evaluation of energy policy due to the fact that its measurement allows energy use to be described, potentially saving energy, and can demonstrate the impact of various instruments by an increase or decrease of the energy consumed. In the next section, the different approaches to measuring energy efficiency will be elaborated upon in more detail.

1.2 The assessment of energy efficiency

Energy use plays an outstanding role in every country's sustainable development and environmental performance, so it is necessary to have data, indicators and energy modelling in order to identify and monitor policy decisions and to assess progress toward environmental and sustainable development goals. In general, energy measurement has focused on energy efficiency. Being efficient in the use of all resources makes an important contribution toward both environmental and economic sustainability (Unander, 2000).

The assessment of energy efficiency at the low aggregation level (e.g., equipment, machines, and service areas) can be easy and straightforward depending on the aim of the study and the methodology used. Nevertheless, in the design and planning of energy policy, it is crucial to measure and characterise energy efficiency at a higher aggregation level (e.g., policy instruments or policy mix of a country, region or industrial sector). In these cases, energy efficiency must be measured and analysed by means of models or indicators owing to the fact that it cannot be measured directly, and these analyses mainly lean on the type of evaluation method chosen, the availability of data, and the scope of the study.

The energy intensity indicators measure the quantity of energy required to perform a particular activity, such as the production of output (Martin et al., 1994), while energy productivity is the inverse of this ratio and refers to the output or activity delivered per unit of energy. The estimation of indicators[4], either in monetary or physical units, varies according to the nature of the analysis to be undertaken. In general, indicators calculated in monetary units are used in the analysis of energy efficiency at a macroeconomic level, while energy efficiency indicators estimated in physical units are better suited to sub-sectoral analysis.

The indicators of energy efficiency can be built from data ranging from aggregated international or national statistics to output data from individual operating units within a plant (see figure 1.1). At the highest level, there are only a few indicators of energy efficiency that can be built. Nevertheless, due to the large level of aggregation, these broad indicators often include many separate effects that can potentially bias the results[5]. Clearly, moving further down the pyramid increases the understanding of the multitude of factors that affect more aggregated measurements of energy efficiency and ultimately affect other variables, such as national energy consumption. However, as Figure 1.1 indicates, the quantity of data required (at the bottom of the pyramid) increases substantially, and the acquisition of data becomes increasingly laborious.

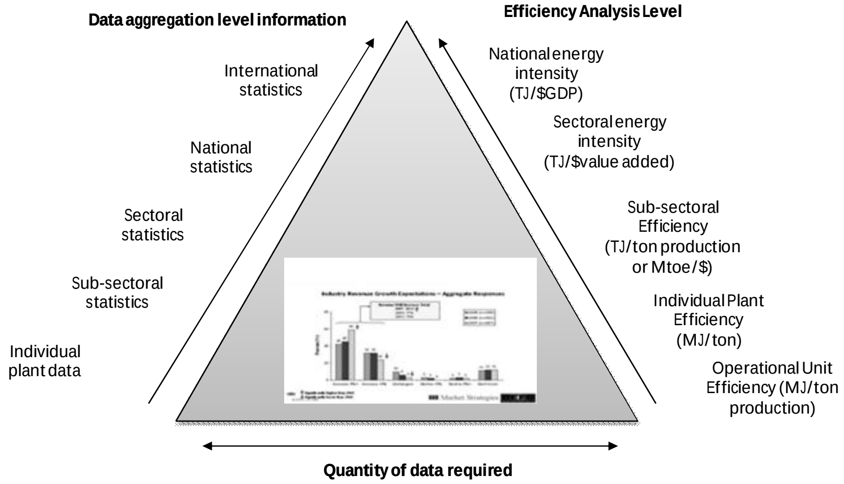
Moreover, improving energy efficiency is embodied in several multi-lateral agreements, such as the Kyoto Protocol, with the following goals: to enhance the efficient production, distribution and consumption of energy; to encourage energy research and development; and to promote cost-effective measures that improve the efficiency with which energy is used but reduce greenhouse gases. To study the effectiveness of energy efficiency, policy has developed several methodologies, such as bottom up methods (e.g., billing analysis, deemed estimates), top down methods (e.g., econometric modelling, monitoring specific indicators), ex-post evaluation, and the evolution of impacts from public support. The measurement of the impact of energy efficiency policy is important to reformulate and to design new policies and to determine the

[4] The fundamental requirements of energy efficiency indicators include: comprehensiveness with respect to scope of analysis, time span of data, and energy commodities; consistency, which ensures that energy efficiency indicators are comparable; and validation, which ensures the accuracy of the energy efficiency indicators and also serves as a useful error checking mechanism.

[5] For instance, although declines in measured national energy intensities for many economies suggest improvements in energy efficiency, other factors, such as the declining importance of energy-intensive sectors (structural change) and non-energy related efficiency improvements, also contribute to this result. When the level of aggregation decreases (moving down the pyramid in Figure 1), the influence of changing structural effects and other factors also declines (APERC, 2000).

improvement in energy efficiency and control of pollution in every country or specific industrial sector according to the measure carried out. This thesis focuses on "*top-down*" measurement of energy efficiency by indicators on different aggregated levels for "*bottom-up*" measurement of energy efficiency and end-use energy savings (Thomas, 2009).

Figure 1-1 Energy efficiency indicator pyramid



Source: Phylipsen et al., 1998

This thesis seeks to evaluate whether applying a set of analytical "top-down" methodologies (see figures 1.3 and 1.4) provides a feasible structure for analysing energy efficiency performance in the industrial manufacturing sector and to explain the factors that could influence energy efficiency performance.

1.3 Energy efficiency in the industrial manufacturing sector

The industrial sector accounts for about one–third of global energy demand and 36% of CO_2 emissions. This sector is very diverse and involves a wide range of activities, including the extraction of natural resources, conversion into raw materials and manufacture of finished products. The energy is used mainly to produce raw materials (e.g., chemicals, iron and steel, non-metallic minerals, pulp and paper and non-ferrous materials[6]). However, despite a history of growing energy efficiency in the industrial sector, total energy consumption by industry

[6] Moreover, these sectors are classed as the energy intensive sectors due to their higher contributions to total energy demand, accounting for approximately 45% of all industrial energy consumption. Further, their generation of CO_2 emissions, high homogeneity of products, process and technology and the ease of gathering reliable data have generated more interest in the research and analysis.

increased by 61% between 1971 and 2005. Much of this growth is seen in developing or transitioning countries (UNESCAP, 1999 and IEA, 2007).

During the last two decades, government policy-makers and industry leaders alike have come to recognise the important role energy efficiency plays in supporting economic growth, international competitiveness and environmental protection. Likewise, several studies have demonstrated that the industrial sector has major opportunities to increase energy efficiency and to reduce CO_2 emissions (e.g., IEA, 2007, Gielen and Taylor, 2007, IPPC, 2007) by implementation of new policies, incorporating technology, systematic improvements to motor systems, including adjustable speed drives; more steam systems, including combined heat and power (CHP); and by recycling materials. Hence, potential technical energy savings of 25 to 37 exajoules per year are available based on proven technologies and best practices. Moreover, improved energy efficiency contributes positively to energy security and environmental protection and helps to achieve more sustainable economic development. The industrial CO_2 emissions reduction potential amounts to 1.9 to 3.2 gigatons per year, about 7 to 12% of today's global CO_2 emissions (IEA, 2007).

However, these elements require energy information at a more detailed level than the broad, macroeconomic level to develop and implement effective strategies to enhance energy efficiency through understanding of key factors that might determine the improvement or worsening of energy efficiency[7] in the industrial sector, where in several sectors the studies have been limited. *Hence, this thesis seeks to analyse the development of energy efficiency between 1998 and 2005 in the manufcturing industrial sector with the aim to understand the key factors that might influence and drive the increase or the decrease of energy efficiency performance in this sector.*

[7] Some facts that might increase energy intensity are an adverse change in the fuel mix and an increase in the share of relatively more energy intensive industries (technical and economic factors). In contrast, the decrease of energy intensity might result from beneficial changes in the fuel mix, the increased share of relatively less energy intensive industries (technical and economic factors) and increases in energy efficiency, such as the introduction of new technologies, or more efficient utilisation of existing technologies (production technology factor).

1.4 German and Colombian industrial manufacturing sector[8]

The industrial sector in both Germany and Colombia is the motor of the social market economy, the driving force for more growth and employment, and in many branches it is the pioneer of technological and innovation development. The energy is used in the industry for generation (e.g., steam plant or power generation), conversion (e.g., process heating and cooling, electrochemical, machine drivers) and process energy use (e.g., separations, reactors, drying, and fabrication). Table 1.1 shows an overview of three indicators in Germany and Colombia: the share of industrial sector to GDP, total employment and total energy consumption. In 2005, the German industrial sector generated €407 billion of value added and employed 6 million persons (FMEL, 2005), whereas the Colombian industrial sector generated €16 billion of value added and employed 588 thousand persons (DANE, 2005).

Table 1-1 Overview of the importance of the German and Colombian industrial sectors in 2005

Country	Percentage of GDP	Percentage of employment	Percentage of total energy consumption
Germany	21	23	28.3
Colombia	15	14	27

Data sources: BMWI, DESTATIS and DANE

In energy terms in 2005, total final consumption in the German industrial sector was 83.53 Mtoe, primary energy supply (PES) had a relatively balanced mix of fuels, and oil makes up the largest share of PES at more than one-third, followed by coal (24%), natural gas (23%), nuclear (12%) and renewable (5%). In Colombia, total final consumption in the industry was 6.06 Mtoe, and the mix of fuels of PES included the greatest share of natural gas (31%), followed by coal (27%), oil (12%) and renewable (10%)[9]. Figure 1.2 plots the distribution of energy demand in the main industries in both countries. The largest energy consumers in Germany were the chemical industry and basic metal, whereas in Colombia, the glass industry, food industry and chemical industry were the greatest consumers.

In both countries, the fundaments of energy policy are energy security, economic efficiency and environmental sustainability (IEA, 2007 and UPME 2007). Table 2.2 shows the main policies,

[8] The German and Colombian industrial sectors were chosen as case studies at the macro level in order to show important features in energy use and energy efficiency development between countries with the different income (See numeral 1.6, Scope and outline).

[9] Renewable energy in Colombia includes mainly energy recovery and bio-mass.

objectives and instruments formulated to improve energy efficiency in the German and Colombian industrial sectors.

Figure 1-2 Distribution of energy demand in the German and Colombian industrial sectors, 2005

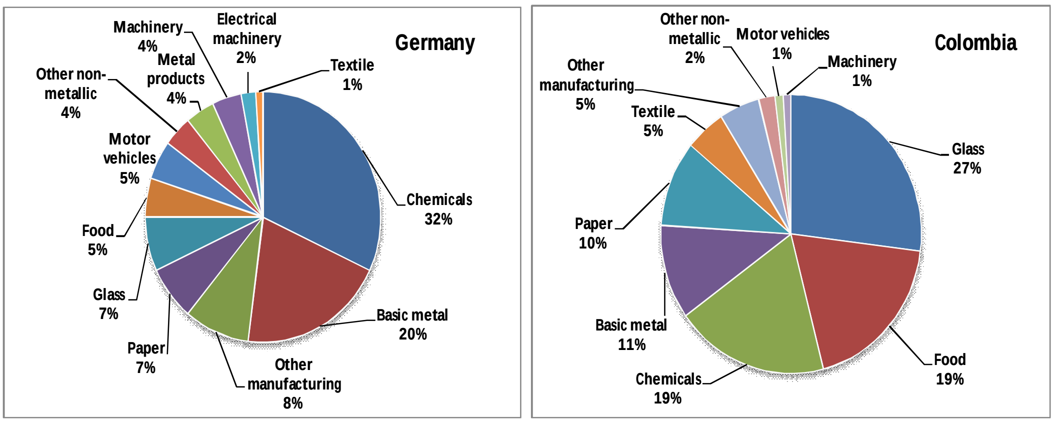


Table 1-2 The main policies, objectives and instruments developed to improve energy efficiency in the German and Colombian industrial sectors

	Germany	Colombia
Policies and objectives	• Increase the energy efficiency of the national economy with the objective of doubling energy productivity (a measure of GDP output per unit of energy use) by the year 2020 compared with 1990, requiring an annual increase of 3%. • Supporting European initiatives to improve energy efficiency. • Promoting the expansion of decentralised power plants and ultra-efficient CHP plants.	• Promoting of non-conventional sources (FNCE) and Rational Use of Energy (URE). • Strengthening the use of resources for specific investment in the URE. • Decreasing the relation between energy consumption and production. • Improving the quality of fuels used.
Instruments	Eco-tax and eco-tax exceptions, Emission Trading Scheme (ETS), voluntary agreements, public information and advice, few financial support schemes, CHP law.	URE programs, cogeneration program, Upgrading illumination Technology Program, optimisation of energy use in motors and combustion.

Hence, this thesis contains an analysis on how different factors have affected energy use at the macro-level in the German and Colombian manufacturing industries. This information is important if it can provide fundamental elements to formulate and to design effective policy and strategies to improve energy efficiency within sustainable development from the analysis of trends on energy consumption and energy efficiency in the industrial sector of a country.

1.5 Justification for the research and contributions

Generally, energy efficiency is measured through energy intensity indicators, which assess the quantity of energy required to perform an activity in monetary or physical units. Several alternative models for measuring changes in energy efficiency use these indicators, such as the following studies:

- Decomposition analysis[10] to determine the separate influences affecting energy consumption at different levels of aggregation (e.g., macroeconomic level or sub-sectoral analysis) is more frequently used at high levels of aggregation with monetary units (e.g., Unander (2000) examined manufacturing energy use in 10 IEA countries between 1973 and 1998; Alcantara and Duarte (2004) compared energy intensities in European Union countries; Cornillie and Frankhauser (2004) evaluated energy intensity of Central and Eastern Europe).
- Comparisons between specific energy-intensive sectors (e.g., Worell et al. (1997) compared energy intensity in the iron and steel industry with physical and economic indicators, and APERC (2000) examined iron and steel, cement, and paper in Russia and China).
- The methodology developed by Phylipsen et al.[11] (1998) to separate structural and efficiency effects in international comparisons.

However, different studies have recently used data envelope analysis (DEA) to evaluate the energy efficiency performances of various entities; this approach describes the energy consumption as an input within a production framework where both energy and non-energy inputs are used to produce good or desirable outputs[12].

[10]The index decomposition analysis decomposes the energy consumption or aggregate energy intensity into the change in intensities at the disaggregated sectoral level and the impact of changes in structural composition of the industrial sector (Ang and Zhang, 2000; APERC, 2000; Choi and Ang, 2003). Various decomposition methods (e.g., arithmetic mean Divisia index and log mean Divisia index (Ang and Liu, 2001; Hatzigeorgiou et al., 2008), Laspeyres type index (Eichhammer and Mannsbart, 1997), and mean-rate-of-change index (Lenzen, 2006)) have been used in energy-related environmental analysis.

[11]This methodology compares actual energy efficiency levels (or rather, specific energy consumes (SECs) as energy intensity) with a reference energy efficiency level (reference SEC) at the given sector structure, and the difference between the actual and reference SEC is used as a measure of energy efficiency because it shows what is achievable in an analysis unit (Phylipsen, 1998). This methodology has been applied in several studies (e.g., energy saving potentials in the industrial sector in APEC economies (APERC, 2000), the quality of energy intensity indicators for international comparison in the iron and steel industry (Farla and Blok, 2001), benchmarking the energy efficiency of Dutch industry (Phylipsen et al., 2002)).

[12]DEA measures the energy efficiency within a production theory framework in which energy is one of the many inputs, recognising the role of input substitution in achieving energy efficiency (Mukherjee, 2008). This methodology has been used in several energy analyses (e.g., environmental performance measurement (Färe et al., 2001), an energy efficiency study (Hu and Kao, 2007), and a CO_2 and energy efficiency study (Oüde and Silva, 2003)).

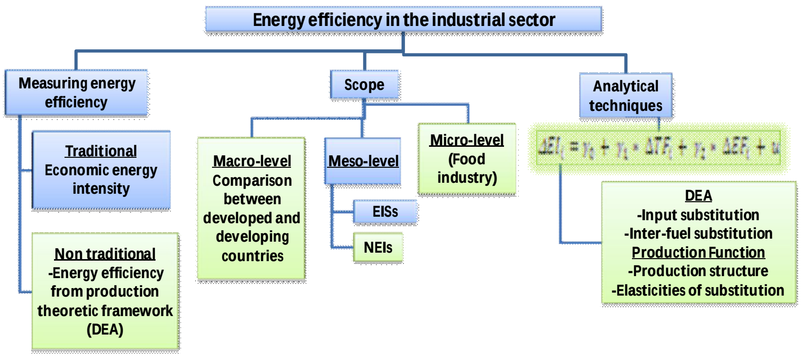
Studies have used macro-level approaches to study specific economies (e.g., Soytas and Sari, 2006) evaluated energy consumption and income in G7 countries; Araujo et al. (1995) analysed industrial energy efficiency in developing countries in terms of their present situation and scope for new initiatives; Castellanos and Luken (2008) compared energy use intensity in six country groups and estimated the potential for reducing energy use and CO_2) or to make comparisons between industrialised and developing countries (e.g., Soytas and Sari (2003) analysed the causality relationship between energy consumption and income between G-7 countries and emerging markets; Miketa (2001) studied the development of energy intensity over time and its relationship with sectoral economic development; Mielnik and Goldemberg (2000) evaluated the evolution of the energy intensity paths in developing and industrialised countries) or specific countries (e.g., Wing and Eckaus (2004) explained long-run changes in the energy intensity of the U.S. economy; Jollands and Aulkah analysed energy use patterns and energy efficiency trends; Phylipsen et al. (2002) elaborated on a benchmarking study of the energy efficiency of Dutch industry). Studies at the meso- and micro-levels have been focused especially on energy intensive sectors (e.g., Neelis et al. (2007) studied energy efficiency trends in the Dutch energy intensive sector; Barker et al. (2006) analysed the macroeconomic effects of efficiency policies for energy-intensive industries in the United Kingdom; Schwarz (2008) explained the driving forces and barriers to technology diffusion in the metal industries, with application to the German aluminium smelting industry; Schumacher and Sands (2007) explored methods for improving the realism of energy-intensive industries in top-down economic models). Moreover, these studies have analysed specific factors to explain energy efficiency performance as the impact of energy price, the application of energy policy, and the impact of technology, among others.

Other studies have worked with models of energy consumption and technical change using the concept of the "production function,"[13] where production structures and elasticities of substitution between energy and other inputs were analysed through dynamic models. These dynamic models have estimated production functions for climate policy models (Werf, 2008), energy consumption rebound and output/income effects (Saunders, 2008), energy production

[13] The production function relates the various input factors in production to the output from it. Within neoclassical production theory, the scope for substitution between two inputs (i,j), or two groups of inputs, is determined by the 'elasticity of substitution' (EoSij) between those inputs. High values of the elasticity of substitution between energy and other inputs mean that a particular sector or economy is more 'flexible' and may therefore adapt relatively easily to changes in energy prices. In contrast, low values of the elasticity of substitution between energy and other inputs suggest that a particular sector or economy is 'inflexible' and that increases in energy prices may have a disproportionate impact on productivity and growth (UKERC, 2007).

sector and energy use by households (Wei, 2006), description of production behaviour for the entire German industry (Kemfert, 1998), and other characteristics. These studies have concluded mainly that energy and capital can be described as substitutes or complements depending on assumptions and scope; the actual scope for substitution may be expected to vary widely between different sectors, different levels of aggregation, and different periods of time; energy consumption, economic output, and potentially high associated energy prices have a strong link to reducing energy consumption. This research contributes to the existing literature in the following manner (see figure 1.3):

Figure 1-3 Contributions of this research



First, this study investigated the different factors that could have determined changes in energy consumption and energy efficiency at 2- and 3- digit levels of aggregation in the manufacturing industries of a developed country (German case) and a developing country (Colombian case). Different factors were examined to determine their influence and significance level on energy efficiency performance in the manufacturing industries. To the author's knowledge, studies of factors influencing energy efficiency performance have only concentrated on one specific factor or variable (e.g., energy price, technological change or structural changes), and have not analysed other interrelationships. Moreover, they have not done cross-country comparisons between developed and developing countries in the industrial sector.

Second, energy efficiency was estimated through the use of traditional measures (energy intensity) and non-traditional measures using DEA from a production theoretic framework. Presently, studies on energy efficiency developments and their determinants are limited. These studies make use of traditional measures; DEA analysis has only been used in comparisons across countries, or across states or energy intensive sectors of a country. The application of these methodologies allows to analysis the rolle of input substitutions and inter-fuel substitutions in energy efficiency performance and to study sectors that have been neglected in energy analysis.

Third, the role of input substitutions and the relationship between energy efficiency and decreases in CO_2 emissions was investigated. To do so, energy efficiency was evaluated from a production theoretic framework where initially energy and other non-energy inputs (capital, materials, and labour) were used to produce good or desirable outputs. Energy efficiency was then evaluated within a production framework where energy input is divided according to fuel sources (e.g. electricity, natural gas, and other fuels) and the outputs as both desirable outputs (goods or money) and undesirable outputs (CO_2 emissions)[14]. Existing empirical studies analyse undesirable outputs with relationships to changes in technology or patterns of energy consumption, but do not examine the impact of other factors, nor the effects of energy efficiency on decreases of CO_2 emissions.

Fourth, this study estimated production functions for the Colombian manufacturing industry with the aim to determine the relationship between energy efficiency and investments using nesting structures for the constant elasticity of substitution (CES) production function through a factor demand model. The studies of energy efficiency that apply production functions are limited, and their analysis has focused mainly on analytical-descriptive studies or energy efficiency potentials. In contrast, this research aimed to empirically test several hypotheses derived from economic theory and analyse the role of investments on energy efficiency performance in the Colombian manufacturing industry. This is a singular feature of this research. This research tries to resolve these considerations by addressing several research questions and general and specific hypotheses that are discussed in more detail below.

1.6 Research questions and methodology

This thesis will present, apply and analyse a set of analytical tools to understand the development of energy efficiency in the manufacturing industry by analysing the factors that could affect the increase or decrease of energy efficiency during the period of 1998-2005. It also seeks to explain the observed variation in energy efficiency results across sectors in both countries. In this context, a general and specific hypothetical framework of factors influencing

[14] See e.g., Zhou et al., (2008) and Ramanathan (2006).

energy efficiency have been developed as shown in figure 1.3. This general framework will be applied on different levels of analysis throughout this research.

Factors are formulated from the literature as potentially important influences on energy efficiency in the industrial sector. These factors are: production technology Factors (TF)[15] and Economic Factors (EF)[16] and Political Factors (PF). It is hypothesised that energy efficiency development may be explained by a combination of these factors. Table 1.3 shows the factors and variables and their relationship with energy efficiency performance which is assessed with different techniques.

Table 1-3 Description of factors and variables and their relationship with energy efficiency performance

Factor	Relationship with energy efficiency	Variables
Political factor	Market forces and other factors determine energy efficiency in the manufacturing industry. However, these factors can be influenced by an effective energy policy that encourages cost effective energy efficiency through the application of different types of policy instruments that include information, regulation and economic instruments.	▪ Governmental initiatives (e.g., standards, grants and subsidies, fiscal /tariffs, eco-tax, soft loans for energy efficiency, renewable energy and CHP, emission trading and clean development mechanism, information). ▪ Voluntary initiatives (e.g., audits, energy management system, voluntary labelling).
Economic factor	Energy consumption in the manufacturing industry is influenced by the behaviour of several economic variables (e.g., high energy prices or constrained energy supply will motivate industrial facilities to try to secure the amount of energy required for operations at the lowest possible price (McKane et al., 2008); structural changes in the industrial sector cause shifts in final energy use and energy intensities;	▪ Energy prices (€/Kwh, €/t) ▪ Investments (the share of investments of gross production) ▪ Size of companies (Large enterprise, medium sized enterprise, small enterprise and micro enterprise) ▪ Concentration process (reduction in number of companies and the increase of large enterprise) ▪ Structural changes
Technology change	The need for improvement of energy efficiency is just one of the drivers for technology development in industry. Moreover, the potential technical energy savings are available based on proven technologies, best practices and use of new energy sources (IEA, 2007).	▪ Structure of energy source (electricity, gas, petroleum products, coal, and other; high efficiency fuels) ▪ Structure of production (process and operations, productivity)

[15] Technical progress generally leads to improved energy efficiency in manufacturing processes (IPCC, 2000), and energy efficiency is a parameter that depends on the state of technical factors such as technology and production methods (Vikström, 2008).

[16] Energy prices and taxes are among the most important determinants of energy consumption and efficiency and have been successfully used to promote energy savings in the last year in the industrial sector (Mure-Odyssee, 2006). More energy efficiency and savings in energy are key factors to improve productivity in the industrial sector, and more intelligent use of energy is an important economic factor (BMWI, 2006). High levels of energy efficiency are an essential part of a dynamic productive economy with a high 'quality of life'. Low economic productivity and energy inefficiency go hand-in-hand with a low 'quality of life'. Encouraging efficiency in all factors of production will result in a higher 'quality of life' and enable us to fund the transition to 'sustainable development' (Herring, 1998).

In the analysis of energy efficiency development in the manufacturing industry, panel data analysis[17] was applied to an eight-year cross-section of data from the manufacturing industry[18]. The purpose of this thesis is to describe the relationship between energy efficiency performance and different factors. The research questions that guide this thesis are the following:

- What are the differences in energy efficiency development at different aggregation levels and using different assessment approaches?
- What are the factors and variables that have played a significant role in energy efficiency improvement in the manufacturing industry?
- In the manufacturing industry, has the shift in the structure of energy sources from lower end use efficiency fuels (e.g., coal and petroleum products) to higher end use efficiency fuels (e.g., gas and electricity) improved energy efficiency as well as reduced green house gas emissions?

In order to answer these questions, a mix of methodologies is used. First, we review the literature on energy efficiency in the manufacturing industry with the aim of helping better assess the original contribution made by this research to the existing body of literature.

Second, we obtain estimates of energy efficiency for the German and Colombian industrial manufacturing sector from traditional indicators of energy efficiency (economic energy intensity at the macro-, meso and micro-levels) and a non-traditional measure from a production theoretic framework through the method of Data Envelopment Analysis (DEA). These indicators are selected in order to conduct an integral analysis of energy efficiency development in the industrial sector.

Third, econometric analysis is undertaken in two ways: First, the CES production function is applied to analysis the relationship between investments and energy efficiency performance in Colombian manufacturing industry. Second, to explain the observed variation in energy efficiency across sectors are used different econometric techniques. To this end, it takes the

[17] Panel data combines cross-sectional and time series data, and panel analysis allows the study of the dynamics of change with short time series. The combination of time series with cross-sections can enhance the quality and quantity of data in ways that would be impossible using only one of these two dimensions (Gujarati, 2003).
[18] The sample period was selected due to the availability of data (reliable and detailed) to build a balanced panel that consists of repeated observations on a set of measures for a sample where there are no missing values and taking into account the convention of panel data analysis, where the number of cross-sectional observations N dominates the number of time series observations T, N >T (Walker, 2007). On average, 90 and 40 industrial sectors are covered at the 3- and 2-digit level of statistical aggregation, respectively.

current state of the art in structural econometric research on energy efficiency and energy use in the manufacturing industry as a starting point. A set of theory-guided hypotheses regarding the different factors that impact energy efficiency performance are formulated and econometrically tested. After the stage of model estimation is completed, model specification tests will be performed in order to check the models' accuracy and performance (e.g., in terms of possible misspecification and the robustness of the results). If the diagnostics are satisfactory, hypothesis testing and the assessment of validity for the theoretical predictions can follow. Finally, the outcomes of the empirical analyses are compared with the insights from the literature. Finally, the analyses corroborates (or invalidates) the hypotheses.

Fourth, a mail survey of the main industrial associations and representative firms in Germany and Colombia is conducted. The survey is designed to identify factors and variables that determine energy efficiency in the industrial sector.

1.7 Hypothesis of this research

In this context, the general hypothesis is that energy efficiency performance in the manufacturing industry depends on change and development of different factors and variables that are related to high or low energy consumption. The specified hypotheses were formulated taking into account the literature shown previously, the expected results and a preliminary analysis. It formulates the following research hypothesis:

- The economic and production technology factors significantly influence energy efficiency performance in the manufacturing industry, and this influence could be more or less according to the level of aggregation studied.
- The economic factor influences energy efficiency performance in the manufacturing industry. Therefore, energy efficiency improves with an increase in the investments and the energy prices.
- The production technology factor exerts a greater influence on energy efficiency in the manufacturing industry. Therefore, energy efficiency performance could depend of the changes in the production methods and technological progress.

The hypotheses are analysed and evaluated in this thesis. The first part assesses different factors at the macro and meso levels; the second part evaluates the same factors with their variables at the micro level (food industry), and the third part summarises the results at different aggregate levels in the industrial sector. To test the postulated hypotheses it employs different econometric techniques.

1.8 Scope and outline of this thesis

The overall aim of this thesis is to analyse the energy efficiency developments and to determine the influence of different factors in their performance at different levels of aggregation in the manufacturing industry. The general criterion to choose the case studies was the availability of data to obtain reliable time series with a sufficient level of detail to allow the factors behind energy efficiency changes to be analysed. The following case studies were selected in every level:

At the macro level, this thesis seeks to study the differences between developed and developing countries, and the German and Colombian manufacturing industrial sectors were selected as case studies. Germany was chosen because it is a world leader in energy efficiency, showing important developments in energy efficient-technology and achieving significant improvement in energy efficiency performance in the manufacturing industry[19], making it possible to evaluate different factors of energy efficiency in relation to best practices in developed countries. This can then be analysed with the aim to develop plans on how to make improvements or adopt best practices in developing countries. The Colombian case was chosen because within the Latin American context, and especially during the period being studied, this country showed strong and steady GDP growth, the industrial sector has achieved decreased energy intensity, mainly in the production of food, textiles, chemicals, parts and accessories for motor vehicles, iron and steel, and it is an environmental leader among countries with comparable incomes[20].

[19] According to the Federal Ministry of economics and technology, in recent years Germany has achieved a decrease in its energy consumption even though the gross domestic product has more than doubled, and, German researchers and companies have submitted many global patent applications in the development of energy efficient industrial cross application technologies.

[20] According to Proexport (2008) and the World Bank (2007), Colombia's economic growth since 2001 has outpaced that of the Latin American region (two full points faster than the Latin American average), the industrial sector has generated a sustained, solid and dynamic growth of approximately 2% per year (e.g., automotive sector 20%, chemical sector and iron and steel 3% average per year), energy intensity has decreased in the last 15 years 20% whereas countries such as Argentina and Brazil have increased this indicator (GTZ, 2003 and WEC, 2004), and Yale and Columbia's Environmental Performance Index ranks Colombia ninth overall, with exceptional grades in

Therefore, the manufacturing industr of this country has typical features of a developing country, making it possible to define and compare key factors of energy performance and to define strategies to improve energy efficiency at this level.

At the meso level, the manufacturing industry was divided into energy intensive sectors (EISs) and non-energy intensive sectors (NEISs) according to the criteria of German energy tax law. The analysis at this level makes it possible to analyse the determinant factors in energy efficiency performance in two manufacturing industrial groups, taking into account the effective use of energy in the process, energy intensity, position in the value chain and output levels where these features are key to the design and application of effective energy policy instruments and the adoption of best practices that guarantee improvements in energy efficiency at this aggregation level.

At the micro level, food industry[21] was selected to be a sector with a high level of aggregation, high energy consumption and low energy intensity. This analysis allows to determine key factors in energy efficiency development at a micro level with the aim to determine what are effective strategies and procedures to improve energy efficiency in this sector. This may lead to the possibility to transfer these results to other industrial sectors.

According to the hypothesis proposed, overall aim and scope, the specific goals of this thesis are the following:

1. To study the developments in energy use and energy intensity at the macro and meso levels and to determine the different factors that have influenced energy efficiency performance in the industrial sector at these two levels.
2. To apply several methodological approaches for measuring changes in energy efficiency and to analyse the different factors that have affected energy efficiency performance in the manufacturing industry.

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biodiversity and habitat—a 75, compared with an average of 43 for the region and 54 for its income group (Ambrus, 2008).

[21] The food industry includes 10 sub-sectors at the 3-digit level of aggregation ISIC (International Standard Industrial Classification). In Germany and Colombia, this sector holds fourth and first place in energy consumption, respectively, and in terms of costs, energy only amounts to 2% of the total production costs.

3. To compare the relationship between energy efficiency performance and different factors to suggest recommendations for the overall energy policy mix especially for the Colombian manufacturing industry.

This thesis is composed of three parts, one for each of the specific goals mentioned above and level of aggregattion (see figure 1.5). The first part (Chapter 2) takes a broad view. It analyses the energy efficiency development in the manufacturing industrial sector and it describes the energy demand and economic energy intensity in the period of 1998-2005 for this sector in Germany and Colombia. Chapter 3 applies the Data Envelope Analysis (DEA) and regression analysis[25] to describe the main factors and variables that could affect energy efficiency performance in EISs and NEISs in both countries. Chapter 4 applies a simple factor demand model to determine the relationship between investments and energy efficiency.

The second part (Chapters 5) focuses on a specific industrial sector (food indusry), describing and analysing the development of energy use and energy efficiency performance.

In part three (Chapter 6), the relationship between political, economic and production technology factors and energy efficiency performance is compared at different levels of aggregation in the manufacturing industry.

The contents of the various chapters, methodologies used and contributions are discussed in more detail below.

In chapter 2, energy efficiency performance in the German and Colombian manufacturing industrial sectors will be analysed. First, the development of the German and Colombian industrial sectors at the 2- and 3-digital levels of statistical aggregation is described with respect to their energy consumption, energy intensity, value added, production value, energy prices and fuel sources. Finally, a decomposition methodology is applied to separate the influences of structural, production and intensity effects. The contribution of this chapter is the analysis of the energy efficiency of manufacturing industries at the macro (German and Colombian case) and the meso (EISs and NEISs) levels and to define the factors that might determine energy efficiency performance at different aggregation levels.

Chapter 3 examines the concept of energy efficiency using the Data Envelope Analysis. First, the criteria to classify the industrial sectors into energy intensive sectors and non-energy intensive sectors through cluster analysis and the concept of Germany's Ecological Tax Reform are examined. Then, Data Envelope Analysis is applied to EISs and NEISs. Finally, regression analysis is used to define the relationships between the different factors that could have influenced the differences in energy efficiency performance between EISs and NEISs, with data at the 2- and 3-digit levels of statistical aggregation respectively during the period of study in both countries. This chapter contributes to the existing literature through the application DEA to study energy efficiency performance in the manufacturing industry at the meso level (EISs and NEISs) and determine the differences in the energy efficiency performance at different levels of aggregation and the role that has played the non energy inputs and inter-fuel substitutions.

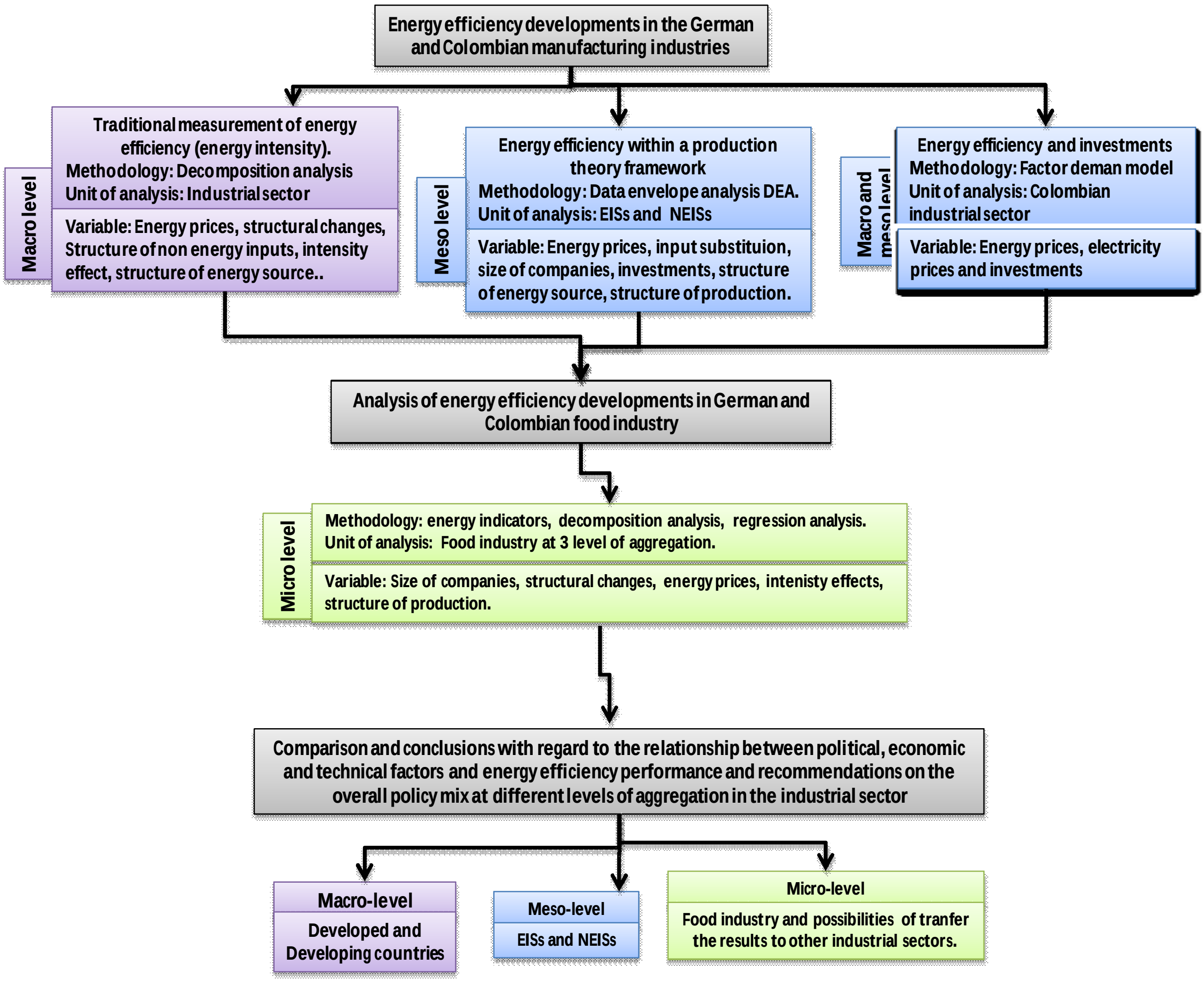
Chapter 4 investigates the effects of investments on energy efficiency performance using data from Colombian manufacturing industries through a factor demand model. The main contribution of this chapter is the analysis of the role of investments and energy prices on energy efficiency in Colombian manufacturing industries at different levels of aggregation between 1998 and 2005 where the studies are limited.

Chapters 5 provide analyses of energy use and energy efficiency performance for the food industry. The chapter begins with an analysis of production and energy consumption in both countries. Then, it evaluates the changes in energy efficiency by applying several methodologies. Finally, it analyses the possible factors and variables that have defined the results in the food industry. The main contribution of this chapter is the analysis of energy efficiency in a sector with high energy consumption and low energy intensity and defines the effects of different variables in the results of energy efficiency where the researches are limited.

Chapter 6 describes the relationship between political, economic and production technology factors and energy efficiency performance at different levels of aggregation in the industrial sector and shows the results of analysis of several case studies through application of surveys in determined industries or industrial associations and it gives recommendations for the overall policy mix especially for Colombian manufacturing industry.

This thesis concludes with chapter 7, where the results are summarised and main conclusions are drawn.

Figure 1-4 Methodologies used in the development of this thesis



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PART I.

ENERGY EFFICIENCY IN THE MANUFACTURING INDUSTRIES

The challenge for governments is to adopt policies that address
the increasing energy demand but within the long-term context of climate change.
Many elements can be considered: ways of making coal cleaner;
rapidly developing and supporting a suite of renewable energy technologies
with an emphasis on increased energy efficiency;
carbon caps and trading; and, of course, looking hard at ways
of reducing and localising energy demand.
Peter Garrett

Chapter 2.

Energy efficiency developments in the manufacturing industries of Germany and Colombia, 1998-2005*

Abstract

This chapter describes the energy efficiency development in the German and Colombian industrial sectors between 1998 and 2005. Using data at the two- and three-digit levels for the German and Colombian manufacturing industry, the performance of the industrial sector is analysed in terms of energy intensity, value of production, value added, fuel sources and energy costs. It is found that energy consumption in the industrial sector has increased by 2.3% in Germany and 5.5% in Colombia, whereas the energy intensity decreased 12% and 6% respectively during the sample period. A decomposition analysis was performed in order to separate structural, production and intensity effects. It found that in both countries, the aggregate energy intensity in the industrial sector was highly dependent on the changes in the energy intensive sectors (EISs). The trend is to produce more while consuming less energy. In Germany, structural and intensity effects contributed to energy efficiency improvement, whereas in Colombia, intensity effects dominated over structural effects. Moreover, in both countries the capital intensity and energy prices influenced the changes in the aggregate energy intensity, whereas the changes in labour intensity did not show a clear relationship with the energy intensity results. These results showed the importance of the formulation and adoption of energy policies to the industrial sector, taking into account that several differences in energy efficiency performance exist at the different levels of aggregation and that energy policy instruments ought to encourage cost-effective energy efficiency.

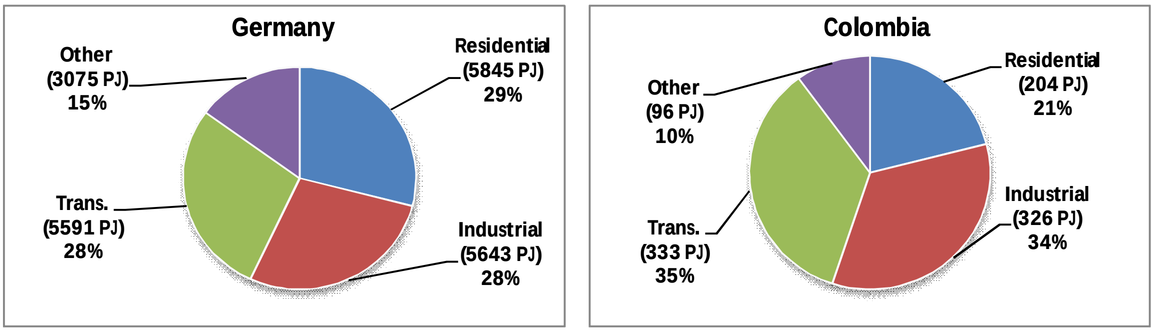
* Published Article in Energy for Sustainable Development 13 (2009) 189-2001.

2.1 Introduction

Energy efficiency plays an important role in reducing fossil energy consumption, thus reducing air pollution and slowing down anthropogenic climate change. Accordingly, several countries have formulated political, economical and technical strategies across all sectors of the economy with an aim toward reducing energy demand.

Energy demand comes from four major sectors: residential, industry, transportation and a group formed by commercial and government buildings, street lighting, etc. Moreover, the key factors that determine energy demand in the industrial sector are the growth in economic activity, the population and the composition of the industry. In 2005 the German industrial sector consumed 28% of the total supply of energy; in Colombia it consumed 34% (Figure 2.1). This means that in Germany the industrial sector has implemented different measures to improve the efficient use of energy, which is shown by the fact that between 1990 and 2005 the consumption decreased by 3.5%, particularly in the most intensive segment of consumption, whereas Colombia in the same period increased its consumption by 1% (BMWI, 2007 and UPME, 2007).

Figure 2-1 Energy consumption by economic sector in Germany and Colombia, 2005



Sources: BMWI, 2007 and UPME, 2007

Furthermore, according to the International Energy Agency, in 2005 the industrial sector alone, in terms of total energy consumption, accounted for about 12% of coal consumption in Germany and 23% of coal consumption in Colombia, and 33% of gas consumption in Germany and 22% of gas consumption in Colombia (IEA, 2005). This substantial share explains the attention paid to this sector by energy and climatic policies. Different studies have provided general analyses of the industrial sector and energy, e.g., *Energie in Deutschland*[22] identifies the use of energy in

[22] Statistisches Bundesamt, 2006.

the whole German industrial sector, Blesl et al., 2006 discussed the role of energy efficiency standards in reducing CO_2 emissions, and the Report of the Intergovernmental Panel on Climate Change (IPCC), in *Special Report on Emissions Scenarios,* describes the general impact of emissions in the industrial sector. Other research has reviewed specific sector industries, e.g., paper, glass[23] and chemicals. However, these studies neither analysed the industrial sector at high aggregation levels nor defined the factors that might determine energy efficiency performance at different aggregation levels. With this in mind, the aim of this chapter is to study the development of German and Colombian industrial energy consumption and to review political, economic and technical factors that have affected the changes in energy intensity in the manufacturing industries at the macro and meso levels.

This chapter is organised as follows: Section 2.2 contains data and methodology; section 2.3 shows the trends and development of energy use in the industrial sector of both countries, including aspects such as energy consumption, fuel sources, activity indicators, energy intensity, and decomposition analysis (the influence of activity, structure, intensity and production effects)[24]. The discussion of results is shown in section 2.4, and the conclusion is presented in the last section.

2.2 Data and methodology

2.2.1 Data

This chapter, which studies the German and Colombian manufacturing sectors,[25] has used data published by the Statisches Bundesamt Deutschland (German Bureau of Statistics) and the Departamento Nacional de Estadística (Colombian Department of Statistics, DANE). Data on energy consumption in Germany are published in *Use of the Environment and the Economy* (*Destatis*, reporting period 1991-2005-a). Data on the producer price index, labour cost, value added and gross production are published in *Produzierendes Gewerbe* (*Destatis*, annual publication-b), and energy cost is published by the Bundesministerium für Wirtschaft und Technologie. Colombian data are published in the *Annual Manufacturing Survey* and in reports of UPME. They base their analysis on 2- and 3-digit levels of disaggregation of the German and

[23] Idem.

[24] The total energy consumption is analysed with three variables: Activity or production effect, which measures sectoral activity either in economic or physical units and consists of sub-sectoral output; energy intensity effect of sub-sectors, defined as a sub-sectoral energy consumption per unit of activity; and structure effect, defining the share of the sub-sector in the total sectoral output.

[25] Germany has taken the initiative in efficient energy consumption through research and technical advice to industries; in Colombia, UPME has developed preliminary studies to determine the energy efficiency of the paper and glass industries.

Colombian International Standard Economic Classification (ISEC[26]). The advantage of using this highly disaggregated data is that it is closer to the industrial process itself.

In this study, unless otherwise specified, energy refers whole energy consumption for each industrial sector only. The energy costs, which were taken from the German and Colombian Bureau of Statistics, were used as an index price by year and percentage of gross production.

In addition, when referring to relative changes, this study will use log percentage change ($L\%$) instead of ordinary percentage because the latter has asymmetric and non-additive properties (Tornqvist and Vartia, 1985). The relative change of numbers X_1 and X_2 is expressed as

$$L\% = \ln(X_2/X_1) \times 100 = [(X_2 - X_1) / L(X_2, X_1)] \times 100 \qquad (1)$$

indicating that the log difference is literally a relative difference with respect to the logarithmic meaning. $L\%$ is symmetric (independently of which point is taken as point of comparison), additive (successively relative changes can be added) and normal, all of which are desirable properties for measuring relative changes (see Tornqvist and Vartia, 1985, for more information).

2.2.2 Energy intensity

Energy intensity indicators measure the quantity of energy required to perform an activity. The measurement of indicators, either in physical or monetary units, and the type of indicator to use vary according to the nature of the analysis to be undertaken[27]. In this study, the energy intensity (EI) is defined as the energy used per unit of economic production. Literature indicates that production value (PV) should be used instead of value added (VA) since the latter tends to exaggerate annual changes in efficiency (Freeman et al., 1997). Nevertheless, this study considers it worthwhile to compare the results obtained using both measures of output.

To make international energy intensity comparisons, PV and VA can be measured using two methods: a. Exchange rates, where results are subject to a great deal of volatility due to economic fluctuations, and b. Purchasing Power Parities (PPP) that reflect differences in price

[26] Some activities within the manufacturing sector are excluded: coke, refined oil products and nuclear energy (23), office equipment and computers (30), mining, agriculture, construction and recycling (37).
[27] Generally, indicators measured in monetary units are applied to the analysis of energy efficiency at a macro-economic level, while physical units are applied to sub-sectoral level indicators (APERC, 2000).

levels among countries, increasing the economic values in regions with a low cost of living, and thereby decreasing their energy intensities. However, the main problem of this method is that PPP is based on an American basket of goods, which is inappropriate for many nations, and it could generate inappropriate valuations (WEC, 2008 and Nanduri, 1998). With these concepts in mind, this analysis considers it important to use both measures to compare the results and determine the differences between the two methods[28].

2.2.3 Decomposition analysis

An index decomposition methodology is applied to analyse the change effect of a sector's structure on energy intensity and energy consumption. There are several decomposition methods; Ang and Zhang (2000) give a survey of different methodologies. This study chooses to use a Multiplicative Log-Mean Divisia Method, which has shown to be "perfect in decomposition but also consistent in aggregation" (Ang and Zhang, 2000)[29].

Two approaches have been applied: one based on energy intensity and another one based on energy consumption. In the energy intensity approach, the total change in aggregate energy intensity (EI_{agg}) is decomposed into a structural effect (F_{str}) associated with the industrial composition of the sector, and an intensity effect (F_{int}) associated with changes in sector energy intensity. The energy consumption approach includes a third component, a production effect (F_{pdn}) associated with changes in the output levels in the whole industrial sector. This last approach is added in order to explain the change in energy use in absolute terms[30]. The equations used are shown below (Ang and Zhang, 2000):

- Decomposition method:

$$E_t = \sum_i E_{it} \qquad (2)$$

E_t = $\text{The manufacturing sector's energy consumption in the year } t$

E_{it} = $\text{Subsector's energy consumption in the year } t$

i = $\text{The index of sub} - \text{sector}$

---

[28] PV and VA are converted to purchasing power parities at 1998 prices and parities, and they are also measured at constant prices and exchange rates provided by World Bank, German Federal Bank and Central Bank of Colombia.

[29] Some studies have used this methodology because it allows the impact of a structural shift in industrial production on total industrial energy consumption to be quantified in order to gain a better understanding of the mechanisms of change in energy use in industry. For instance, Boyd et al. (1988) studied US industrial energy consumption, and Ang and Zhang (1999) used the methodology for international comparisons in energy-related CO_2 emissions.

[30] These two approaches are used because the first allows measurement of efficiency, separating out the influences of structure and energy intensity, and the second analyses the effects of production level on the whole industrial sector. Moreover, the changes in energy intensity and energy consumption can be interpreted as "indicators" of change in energy efficiency.

$$Y_t = \sum_i Y_{it} \quad (3)$$

$Y_t = Level\ of\ output\ or\ total\ industrial\ production\ in\ year\ t$

$Y_{it} = Unit\ of\ activity\ or\ subsector's\ production\ in\ year\ t$

$$EI_{it} = E_{it}/Y_{it} \quad (4)$$

$EI_{it} = Energy\ intensity\ of\ subsectors$

$$S_{it} = Y_{it}/Y_t \quad (5)$$

$S_{it} = Structural\ parameter$

- Energy intensity approach:

$$EI_{agg} = \sum_i S_{it} * EI_{it} \quad (6)$$

$EI_{agg} = Aggregate\ energy\ intensity$

$S_{i,t} = Production\ share\ of\ sector\ i\ in\ year\ t\ (= Y_{i,t}\ /\ Y_t)$

$EI_{i,t} = Energy\ intensity\ of\ sector\ i\ in\ year\ t\ (= EI_{i,t}\ /\ Y_{i,t})$

$$F_{tot} = EI_{aggt}\ /\ EI_{agg0} = F_{str} * F_{int} \quad (7)$$

$F_{tot} = Total\ change\ in\ aggregate\ energy\ intensity$

$F_{str} = Structural\ effects$

$F_{int} = Intensity\ effects$

$$F_{str} = exp\left\{\sum_i \frac{L\ (\omega_{i,t}\ \omega_{i,0})}{\sum_i L\ (\omega_{i,t}\omega_{i,0})} \ln(\frac{S_{i,t}}{S_{i,0}})\right\} \quad (8)$$

$$F_{int} = exp\left\{\sum_i \frac{L\ (\omega_{i,t}\ \omega_{i,0})}{\sum_i L\ (\omega_{i,t}\omega_{i,0})} \ln(\frac{EI_{i,t}}{EI_{i,0}})\right\} \quad (9)$$

$\omega_x = Energy\ share\ of\ sector\ i\ in\ year\ t\ (= E_{i,t}\ /E_t)$

Where

$L(x, y) = (y - x)/\ ln\ (y/x)$

- Energy consumption approach:

$$E_t = \sum_i Y * S_i * EI_i \quad (10)$$

$$F_{tot} = E_t\ /\ E_0 = F_{pdn} * F_{str} * F_{int} \quad (11)$$

$$F_{pdn} = exp\left\{\sum_i \frac{L\ (\omega_{i,t}\ \omega_{i,0})}{\sum_i L\ (\omega_{i,t}\omega_{i,0})} \ln(\frac{Y_t}{Y_0})\right\} \quad (12)$$

$F_{pdn} = Production\ effects$

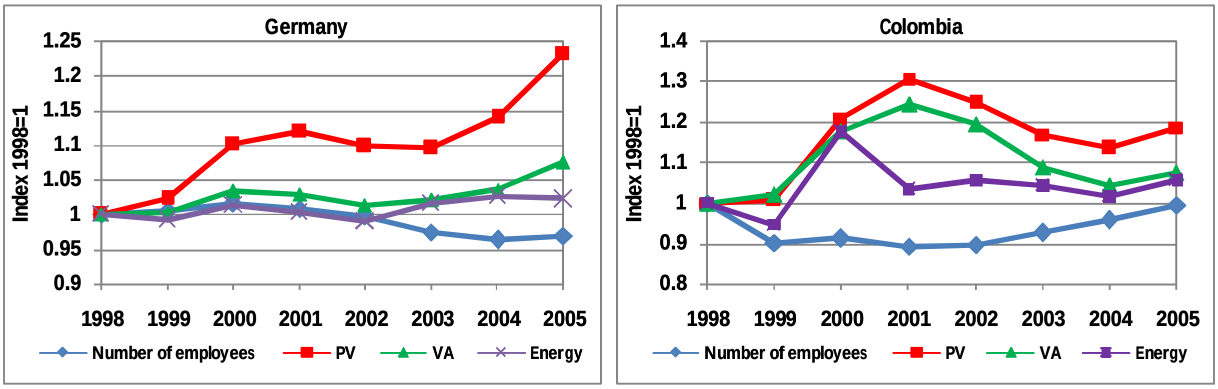
2.3 The industrial sector; trends and development in Germany and Colombia

The industrial sectors in both countries are the most important branch of economic activity and possess a high share of total economic production. German industry is very diversified, and in many sectors it is a global leader, as in the automobile industry, machine and plant construction and, the chemical industry, among others. Colombian industry is in a growth and development process where the agro-industrial sector and the manufacturing of chemical products and substances are most important sectors of the manufacturing industry. Table 2.1 shows the main economic variables of the industrial sectors in Germany and Colombia, and figure 2.2 shows the development of energy, production, value added and employment in the manufacturing industries of both countries between 1998 and 2005.

Table 2-1 The main economic variables in the German and Colombian manufacturing industries, 2005

Country	No. of companies	Thousands of employees	Gross production (Billion Euro)	Value added (Billion Euro)	Energy Consumption (PJ)
Germany	36675	6110.5	1473.9	403.2	5643
Colombia	7524	587.6	33.3	13.8	326

Figure 2-2 Activity indicators for the German and Colombian industrial sectors, 1998-2005

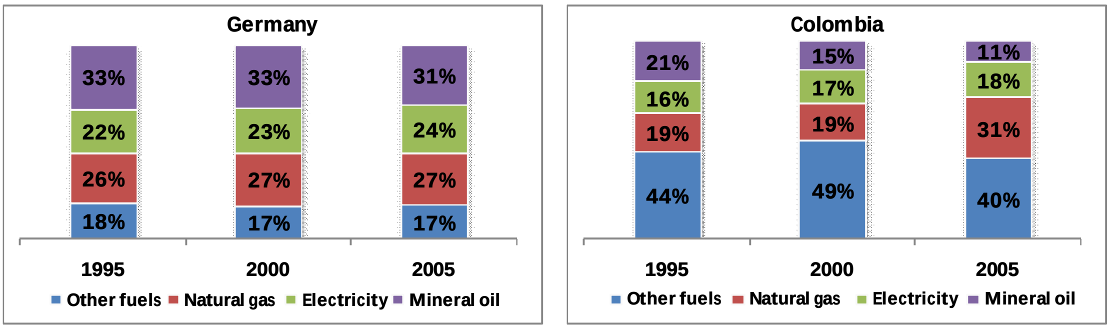


Energy consumption in the industrial sector increased by 2.3% in Germany and 5.5% in Colombia in this period, while production value and value added increased by 20% and 4.4% respectively in Germany and in Colombia 18% and 5% respectively. On the other hand, employment decreased by 3% in Germany and 1% in Colombia. However, in Colombia the trends of these indicators have been unstable in comparison with Germany, mainly due to the fluctuation of the exchange rate between the local currency and the Euro and the economic crisis at the end of the 1990s.

The industrial sectors with the largest increases in energy consumption in this period were paper (26%) and tobacco (28%) in Germany and the automotive industry (42%) and cement industry (26%) in Colombia, whereas the largest decrease in Germany was by the cement industry (30%) and in Colombia the machinery industry (40%). In both countries these results coincide with trends of production value, initially indicating a direct relation between production levels and the energy consumed. Decomposition analysis is used to understand this relation, as will be shown in the next section.

Figure 2.3 shows the average fuel shares in the German and Colombian manufacturing industries. In Germany, the main fuel sources were mineral oil, electricity and gas; these last two have increased their shares between 1995 and 2005. In Colombia, the main fuel sources were electricity and natural gas, which also increased their shares in the sample period.

Figure 2-3 Energy consumption by type of fuel sources in the German and Colombian manufacturing industries

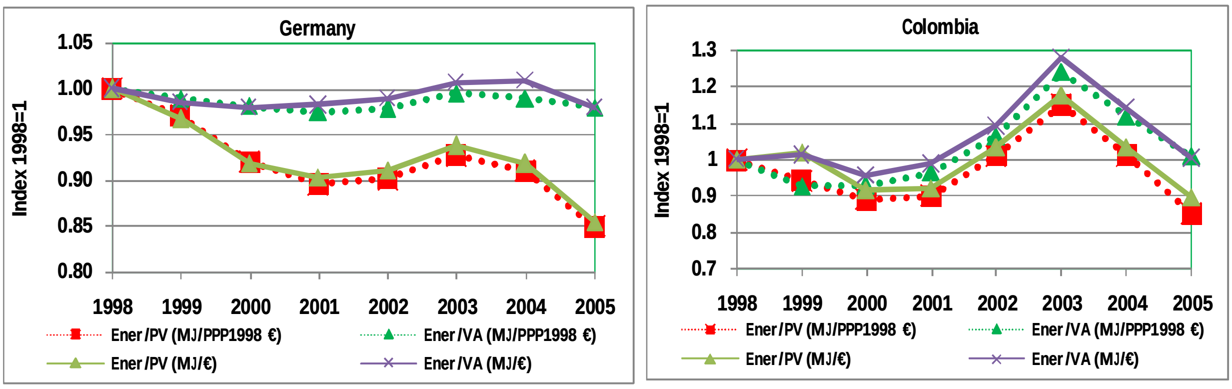


Finally, Appendix 1 plots the distributions of fuel sources for the German and Colombian manufacturing sectors. As stated above, in Germany and Colombia, electricity and gas dominate among fuel sources in all branches of industry. In Germany, clothing and leather manufacturers have the highest percentage of electricity consumption (70%) while tobacco manufacturing has the highest rate of gas consumption (54%). In Colombia, wood and chemical products have the highest percentages of gas consumption - 56% and 49% respectively - while textile and leather manufacturing have the highest shares of electricity consumption (37%). These percentages are related to specific requirements of the productivity process or machinery used, as is the case for the boilers used in the chemical industry or the electrical machinery used in the textile industry.

2.3.1 Energy intensity

Figure 2.4 shows developments in average energy intensity for the industrial manufacturing sectors in Germany and Colombia between 1998 and 2005. In Germany, these indicators decreased 15% as production value and 2% as value added and in the Colombian case decreased 10% as production value and energy intensity as value added increased 0.4%. In both countries, several energy intensive sectors have driven the decreases in these indicators for the whole manufacturing sector (in the case of Germany, the chemical industry and basic metal, and in Colombia, basic metal and some sectors of the glass industry). Moreover, in the Colombian case, it is clear that the use of purchasing power parities changes the magnitude of the indicators but does not affect the trends[31].

Figure 2-4 Energy intensity developments for the German and Colombian industries (energy per value added and per production value), 1998-2005



2.3.2 Decomposition analysis

In order to analyse other effects that may have determined energy intensity performance in the industrial sector, the Multiplicative Log-Mean Divisia Method I was used, which was described in the methodology section. The analysis was carried out for every industrial sector (3-digit level of disaggregation) in both countries between 1998 and 2005. The changes observed in energy consumption and aggregated energy intensity and the relative contributions of the structure, intensity and production effects are shown in tables 2.2 and 2.3[32]. In this analysis, a value of one meant that the variables (such as structure, intensity or production) had no impact on aggregate intensity and energy consumption. Values over one indicated a contribution to higher aggregate intensity and energy consumption while values below one indicated a decline. A decrease in aggregate energy intensity meant an increase in energy efficiency during the sample period.

[31] Similar results found by WEC, 2008 and Kaupp, 2007.
[32] The results using purchasing power parities are given in Appendix 2.

- **Energy intensity approach**

Results for decomposition of aggregate energy intensity, electricity intensity and fuel intensity using value added and value of production as the economic measures of output in the German and Colombian industrial sectors are plotted in table 2.2. In both countries, an outstanding increase in the values of the aggregate energy intensity occurs between 2002 and 2003, especially when value added is used as the measure of economic output (e.g., Germany: 3% measured as exchange rates and PPP and Colombia 30% and 10%, respectively), indicating a decrease in the energy efficiency in these years in the industrial sector. A possible explanation for this change may be that in these years the world economy was characterised mainly by sluggish growth of output, euro revaluation and inflation edging upwards, indicating the direct relationship between improvement of energy efficiency and economic stability. Moreover, the increases had a higher impact in Colombia, suggesting that the energy efficiency performance in the industrial sector is dependent on economic factors and that energy intensity performance is more sensitive to economic changes in developing countries than developed countries due to the fact that industrial output is so closely linked to economic growth and prosperity[33], as can be observed in the results for both countries.

The decomposition analysis shows that:

- In Germany, structural and intensity effects had similar results (values between 0.98 and 1.02), which indicate that both effects caused the decrease and the almost constant value of the aggregate energy intensity, measured as production value and value added respectively. Hence, the results for aggregate energy intensity were caused by intensity and structural changes in the industrial sector. In the first case, the contribution could be due to improvements in technology or production standards, and the second case was due to the decrease of production in energy intensive sectors (e.g., the textile and glass industries, with an average of 8% and 5%, respectively).
- In Colombia, intensity effects (values between 0.94 and 1.03) dominated over structural effects, meaning that the results for aggregate energy intensity were primarily caused by changes in the intensity. This might be attributed to fact that during the sample period, a concentration process generated improvement in production standards and process optimisation (mainly in the chemical, food, basic metal, and glass industries). The role of the structural effects is very small because the majority of the sectors maintained their

[33]The energy use, the level of economic activity and the structural change in the economy are strongly linked, and they contribute to energy intensity performance in the industrial sector of a country (Stern, 2003 and Cotte, 2007).

production at almost constant levels. However, the structural effects contributed to increases in the aggregate energy intensity of electricity and fuel between 2002 and 2003 (with increases between 7-8%), probably indicating changes in the energy sources during these years in the Colombian industrial sector.

- In both countries, the results showed that the aggregate energy intensity in the industrial sector was highly dependent on the productive changes in the energy intensive sectors (EISs), and the use of value added as an economic measure of output tended to amplify its result, whereas the use of PPP tended to decrease its result, especially in the Colombian case.

- **Energy consumption approach.**

The analysis of the aggregate energy intensity and production effects for energy, electricity and fuel consumption are shown in table 2.3 (exchange rates) and Appendix 2 (PPP). In Germany, the growth in production and energy consumption did not determine increases in the aggregate energy intensity measured as production value because this aggregate decreased 12% in the sample period. This could mean that the German industrial sector has improved its production standards through new technologies or a structure of production that sought optimisation of the energy use per unit of output. In Colombia, the results showed increases in the energy consumption in some years, although the production levels decreased, meaning a higher value of aggregate energy intensity (especially between the years 2002 and 2003, with increases of 200%). However, during the sample period the aggregate energy intensity measured as production value decreased 6%. These facts might prove that economic and technical factors have played an important role in the energy efficiency performance because increases in economic growth and technology improvements increase the industrial sector's ability to improve energy efficiency, as is observed in the German and Colombian cases.

Moreover, in both countries the trend is to produce more with less energy consumption[34]. In the German case, a higher increase in energy efficiency is clearly present in the industrial sector than can be seen in Colombia, where energy efficiency has decreased in several industrial sectors (e.g., wood and glass industries).

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[34] In recent years, the changing structure of world industry has shown the ability to produce more with less, as well as the increasing integration of industry and services (WCED, 1987).

2.4 Discussion of results

So far, the analysis shows that in both countries the industrial sector has increased its energy consumption, by 2.3% in Germany and 5.5% in Colombia, in an 8-year period (1998-2005). In both countries, intensity and structural effects have induced in higher or lower proportion the changes in the aggregate energy intensity, and energy intensive sectors have played an important role in the energy intensity changes. During the sample period, several companies have begun to produce more using less energy. With these results in mind, this section will discuss the veracity of the results and differences between the two countries. In order to do so, several economic and technical factors and their relationship with the results and political guidelines will be analysed.

a. The differences between energy intensive sectors and non-energy intensive sectors in energy efficiency performance. Decomposition analysis showed that in both countries, structural effects contributed to decreases in the aggregate energy intensity[35]. To confirm this fact, energy efficiency performance was analysed by dividing the industrial sectors between energy intensive sectors (EISs) and non energy intensive sectors (NEISs). The criterion used to determine the limit between EIS and NEIS was the share of energy costs, where EISs have a share below 3% (see figure 2.5)[36].

In Germany, EISs and NEISs have maintained similar behaviour during the sample period. However, the decomposition analysis results showed that the improvement in energy efficiency has been driven by EISs, where structural effects dominated over intensity effects (values between 0.94 and 1), and the majority of sectors decreased their energy intensity (between 1-2%) and energy consumption (e.g., the glass industry decreased its energy consumption by about 15%). However, NEISs maintained or increased these variables, and structural and intensity effects determined the improvement in energy efficiency. Moreover, the aggregate energy intensity measured as gross production decreased 12% in EISs and 6% in NEISs. In the Colombian case, the situation was similar, and the highest decrease of energy intensity was found for EISs (e.g., the basic metal industry decreased its energy intensity by about 15% and

[35] Structural changes in industrial sectors that have different energy intensity levels may have a substantial effect on energy use. Therefore, if the EISs' share increases their production, overall industrial sector energy intensity should increase, indicating a positive relationship (Bernstein et al., 2003).

[36] German energy tax law defines the EISs as the sectors where the cost of energy is above 3% of total costs. Moreover, to confirm this criterion, applied cluster analysis was performed, using as criteria the energy intensity, the share of energy cost and energy consumed by every industrial sector at the 2-digit level of aggregation.

energy consume by about 3%), whereas NEISs maintained or increased these variables (e.g., machinery and metal products). In both sectors, intensity effects dominated over structural effects. These results, both in Germany and Colombia, might demonstrate that the energy efficiency developments of the industrial sector of a country are driven by the energy performance of EISs[37]. However, NEISs have an important role in improving the energy efficiency measured as an aggregate of energy intensity in the industrial sector due to their production levels, economic contribution and relatively high growth rate, as shown in the results of both countries[38]. Energy policy ought to establish different strategies and instruments, taking into account the key elements that encourage and the barriers that inhibit improving energy efficiency in EISs and NEISs.

[37] According to OECD/IEA (2007) the energy efficiency has improved substantially in all energy-intensive manufacturing industries over the last twenty-five years. This fact reflects the adoption of cutting-edge technology in enterprises where energy is a major cost component, and Hudson and Jorgenson (1998) showed that sectoral changes are closely related to the energy intensity of production. The largest reductions in output occur in energy intensive sectors, and the smallest reductions occur in non-energy intensive sectors or services that use relatively little energy per unit of output.

[38] The projections of the non-energy intensive manufacturing show that in the coming years, the average annual increase in energy demand will be between 0.5% and 30% per year, especially in the computer and electronics industry and machinery and equipment (EIA, 2007).

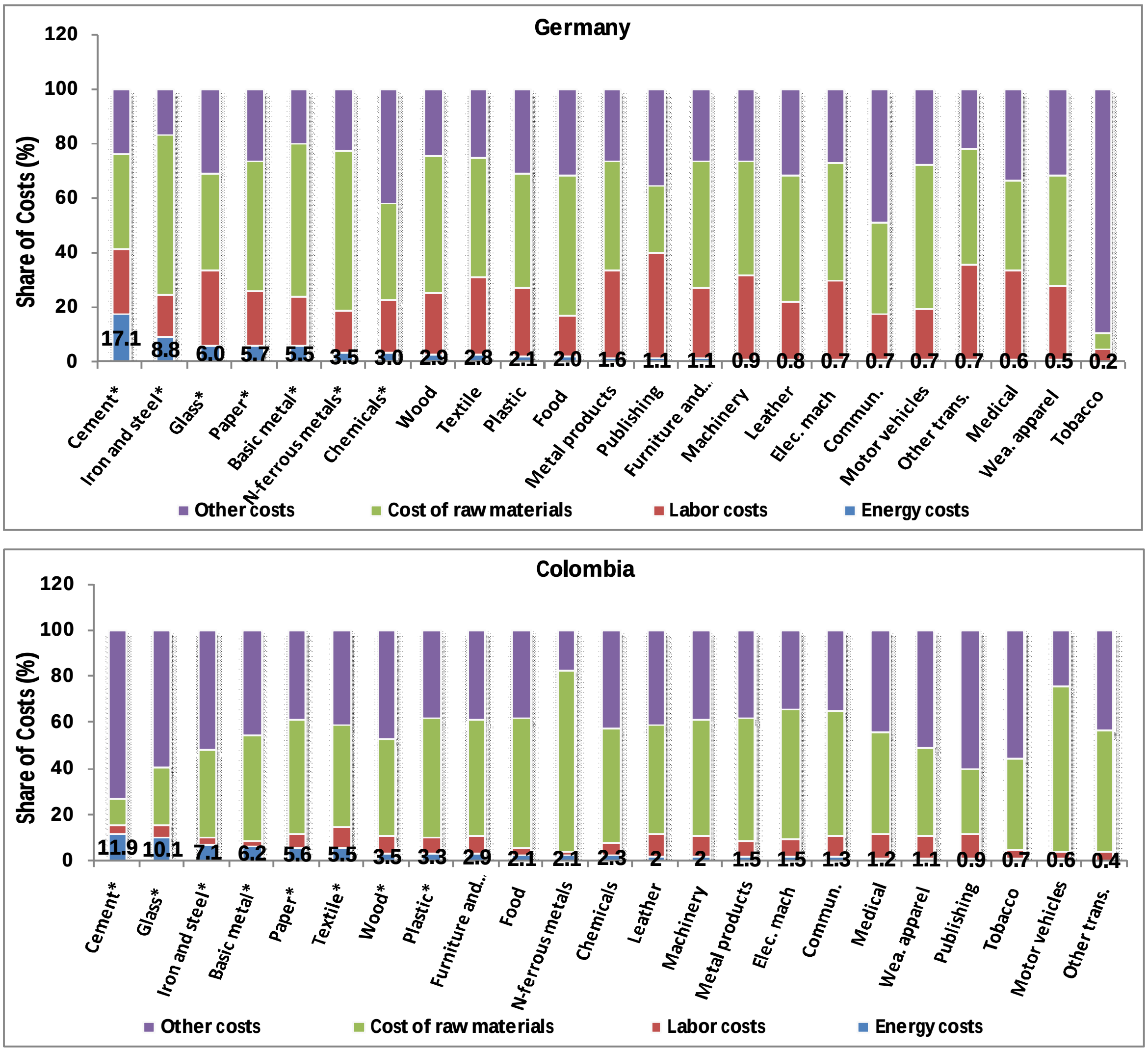
Table 2-2 Decomposition of aggregate energy intensity, electricity intensity and fuel intensity for the German and Colombian industrial sectors into structural (Fstr) and intensity (Fint) effects using production value (PV) and value added (VA) as measures of economic output at exchange rates

German industrial sector. Energy																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.997	1.001	0.995	0.999	0.995	0.999	0.993	0.998	0.993	0.998	0.988	0.992	0.988	0.992
F_{int}	1	1	0.999	0.999	0.991	0.996	0.991	0.996	0.997	1.004	0.997	1.004	0.998	1.006	0.994	1.010
EI_{agg}	1	1	0.927	1.010	0.911	0.970	0.927	1.010	0.945	1.030	0.960	1.030	0.908	0.990	0.882	1.001
Colombian industrial sector. Energy																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.998	0.997	0.998	0.997	1.001	1.002	1.002	1.003	1.006	1.005	1.014	1.011	1.020	1.011
F_{int}	1	1	0.996	0.995	0.980	0.986	0.977	0.984	0.993	0.999	1.016	1.038	0.996	1.012	0.971	0.989
EI_{agg}	1	1	0.901	0.949	0.869	0.894	0.901	0.949	1.013	1.059	1.218	1.307	1.116	1.215	0.946	1.045
German industrial sector. Electricity																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.997	0.999	0.998	1	0.995	0.995	1.013	1.012	1.007	1.003	0.991	0.992	0.985	0.993
F_{int}	1	1	0.999	1	0.993	1	0.996	1.007	0.997	1.008	1.004	1.020	1	1.012	1.002	1.011
EI_{agg}	1	1	0.936	1.018	0.936	0.997	0.936	1.018	1.065	1.141	1.073	1.124	0.939	1.031	0.901	1.024
Colombian industrial sector. Electricity																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	1	0.997	1.006	1.005	1.006	1.007	1.084	1.072	1.083	1.069	1.018	1.015	1.015	1.014
F_{int}	1	1	1.004	1.006	0.986	0.993	0.990	0.998	1	1.018	1	1.049	1.015	1.036	0.998	1.015
EI_{agg}	1	1	0.973	1.043	0.945	0.986	0.973	1.043	1.787	1.775	2.070	2.121	1.307	1.443	1.104	1.235
German industrial sector. Fuel																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.997	0.999	0.997	1	0.994	0.995	1.013	1.012	1.007	1.003	0.991	0.992	0.986	0.992
F_{int}	1	1	0.998	0.999	0.988	0.994	0.992	1.004	0.989	1	0.997	1.008	0.993	1.006	0.997	1.008
EI_{agg}	1	1	0.910	0.990	0.900	0.959	0.910	0.990	1.013	1.085	1.030	1.079	0.901	0.990	0.886	1.007
Colombian industrial sector. Fuel																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	1	0.996	1.006	1.004	1.005	1.006	1.083	1.071	1.083	1.070	1.017	1.015	1.015	1.014
F_{int}	1	1	0.987	0.990	0.958	0.966	0.955	0.963	0.974	0.983	0.992	1.008	0.967	0.983	0.944	0.960
EI_{agg}	1	1	0.765	0.820	0.782	0.816	0.765	0.820	1.467	1.457	1.640	1.681	0.916	1.012	0.753	0.843

Table 2-3 Decomposition of energy consumption, electricity consumption and fuel consumption for the German and Colombian industrial sectors into production (*Fpdn*) and intensity (*Fint*) effects using production value (PV) and value added (VA) as measures of economic output at exchanges rates

German industrial sector. Energy ($E_{Cons.}$: Energy consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	1.014	1.001	1,015	1.005	1.016	1.003	1.012	1	1.011	1.001	1.016	1.003	1.019	1.001
$E_{Cons.}$	1		1.006		1.004		1.029		1.025		1.038		1.015		1.011	
EI_{agg}	1	1	0.927	1.010	0.911	0.970	0.927	1.010	0.945	1.030	0.960	1.030	0.908	0.990	0.882	1.001
Colombian industrial sector. Energy ($E_{Cons.}$: Energy consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	1.001	0.988	1.005	0.997	1.003	0.996	1	0.985	1.001	0.961	1.003	0.972	1.001	0.997
$E_{Cons.}$	1		0.877		0.876		0.923		0.951		0.988		1.002		1.021	
EI_{agg}	1	1	0.901	0.949	0.869	0.894	0.901	0.949	1.013	1.059	1.218	1.307	1.116	1.215	0.946	1.045
German industrial sector. Electricity ($El_{Con.}$: Electricity consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	1.004	1.001	1.014	1.005	1.015	1.003	0.992	0.982	0.996	0.989	1.016	1.002	1.019	1.001
$El_{Con.}$	1		1		1.031		1.039		1.012		1.043		1.050		1.034	
EI_{agg}	1	1	0.936	1.018	0.936	0.997	0.936	1.018	1.065	1.141	1.073	1.124	0.939	1.031	0.901	1.024
Colombian industrial sector. Electricity ($El_{Con.}$: Electricity consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	0.990	0.990	1.014	1.008	1.016	1.006	0.934	0.935	0.92	0.916	0.997	0.984	1.023	1.007
$El_{Con.}$	1		0.954		1.346		1.090		1.144		1.196		1.283		1.298	
EI_{agg}	1	1	0.973	1.043	0.945	0.986	0.973	1.043	1.787	1.775	2.070	2.121	1.307	1.443	1.104	1.235
German industrial sector. Fuel ($F_{Cons.}$: Fuel consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	1.004	1.001	1.014	1.005	1.015	1.003	0.993	0.983	0.996	0.989	1.016	1.002	1.020	1.001
$F_{Cons.}$	1		0.990		0.992		1.010		0.963		1.001		1.007		1.017	
EI_{agg}	1	1	0.910	0,990	0.900	0.959	0.910	0.990	1.013	1.085	1.030	1.079	0.901	0.990	0.886	1.007
Colombian industrial sector. Fuel ($F_{Cons.}$: Fuel consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	0.989	0.990	1.014	1.008	1.015	1.006	0.935	0.936	0.919	0.916	0.997	0.984	1.022	1.007
$F_{Cons.}$	1		0.859		0.865		0.857		0.939		0.948		0.899		0.886	
EI_{agg}	1	1	0.765	0.820	0.782	0.816	0.765	0.820	1.467	1.457	1.640	1.681	0.916	1.012	0.753	0.843

Figure 2-5 Share of costs in the German and Colombian manufacturing industries at the two- digit level



**Energy intensive sectors.*

b. The relationship between capital intensity, labour intensity and energy intensity. In the industrial sector, intensity effects might depend on three strong interactions, where energy and labour and capital and labour are substitutes while energy and capital are complements (Hudson and Jorgensosn, 1998). The results of decomposition analysis showed that intensity effects have induced changes in the aggregate energy intensity performance in both countries and that the values of energy intensity were higher in the Colombian industrial sector than in the German industrial sector (on average, Colombia needs 2.4 or 1.5 times more energy than Germany to produce a unit of gross production or value added respectively, measured as exchange rates[39]). In order to explain these results, the relationships between energy and capital intensity and energy and labour intensity in both countries were analysed. Hence, German industries are clustered at a higher level in terms of capital intensity and an intermediate level in terms of labour intensity, whereas Colombian industries are clustered around an intermediate level in terms of capital intensity and a higher level in terms of labour intensity[40]. To explain these relationships, a correlational analysis was performed for several years (see Table 2.4).

Table 2-4 Correlation coefficients between capital-energy intensity and labour-energy intensity in the German and Colombian manufacturing sectors, (1998-2005)

Correlation factor	1998	1999	2000	2001	2002	2003	2004	2005
Germany								
Capital - energy intensity	0.401	0.467*	0.500*	0.479*	0.460*	0.458*	0.426	0.415
Labour - energy intensity	-0.008	-0.018	-0.011	-0.015	-0.044	0.047	0.008	0.030
Colombia								
Capital - energy intensity	0.497*	0.492*	0.560*	0.509*	0.487*	0.399	0.464*	0.541*
Labour - energy intensity	-0.381	-0.395	-0.348	-0.306	-0.355	-0.376	-0.335	-0.301

** Significant at the 0.05 level.*

In both countries, the relationship between capital and energy intensity was medium and direct, and the most capital-intensive sectors were also the more energy intensive. In fact, the analysis showed the expected positive and relatively high correlation coefficients[41]. Likewise, in the majority of the industrial sectors, a decrease in energy intensity corresponded to a decrease in the capital intensity, and the results of the intensity effects and the capital intensity showed similar behaviour. However, comparing the results of the two countries revealed that Germany is more capital intensive and less energy intensive than Colombia, and this fact might mean that the capital of the industrial sector of a country is related to better technology and could indirectly involve less energy consumption. These results could lead to the conclusion that capital

[39] With the use of purchasing power parities in the Colombian case, the magnitude of energy intensity indicators decreased 40%, showing similar results with German indicators, which require a careful analysis to avoid misleading interpretations.

[40] Capital intensity was measured using the ratio of capital stocks to be value added; labour intensity was measured as a ratio between the number of employees and value added, and energy intensity was measured as a ratio between energy consumed and value added. The three measures were applied for each sector at a 2 digit-level and also included the sectors of cement, steel and aluminium.

[41] Several studies have showed the relationship between energy intensity and capital intensity, e.g., Miketa (2001) found that capital formation has the effect of increasing energy intensity, and this effect is stronger where sectoral output is larger; Papadogonas et al. (2007) proved that in the Hellenic manufacturing sector, firms that are more capital intensive are also more energy intensive; and Wing and Eckaus (2004) showed the association between the accumulation of capital and increases in energy demand where a shift in the energy-output ratio is associated with additional units of capital, implying a change in the energy use characteristics of capital relative to its contribution to output.

intensity is one of the variables that could determine energy intensity performance in the industrial sector at the macro and meso levels and that energy and capital have a complementary interaction in the industrial sector[42]. For this reason, it is important to develop strategies to improve the technology in the industrial sectors of developing countries with the aim of increasing productivity and optimising energy consumption because significant opportunities exist to enhance the use of existing efficient technologies. Often, technology transfer and deployment are inhibited by the lack of an appropriate enabling framework. More needs to be done to drive increased technology transfer of today's efficient technologies and to provide broader markets for innovative technologies in the future (ICC, 2007).

On the other hand, the relationship between labour and energy intensity is more complex because sectors with high labour intensity are expected to be low energy intensity. The inverse correlation is reflected by the negative sign of the correlation factor for several years. However, this relationship is unclear in the German case, so the correlation factor was calculated by dividing the German industrial sectors into energy intensive sectors (EISs) and non-energy intensive sectors (NEISs)[43]. It was found that EISs had an inverse relationship between energy and labour intensity (negative sign and relatively high correlation coefficients), whereas NEISs showed a direct relationship (positive sign and relatively high correlation coefficients; see table 2.5). Therefore, the changes in energy intensity should not directly depend on the changes in labour intensity.

Table 2-5 Correlation coefficients between capital-energy intensity and labour-energy intensity in the German and Colombian manufacturing sectors, (1998-2005)

Correlation factor	1998	1999	2000	2001	2002	2003	2004	2005
EISs								
Labour - energy intensity	-0.691	-0.641	-0.692	-0.676	-0.639	-0.628	-0.662	-0.653
NEISs								
Labour - energy intensity	0.488	0.491	0.543	0.503	0.495	0.520	0.558	0.586

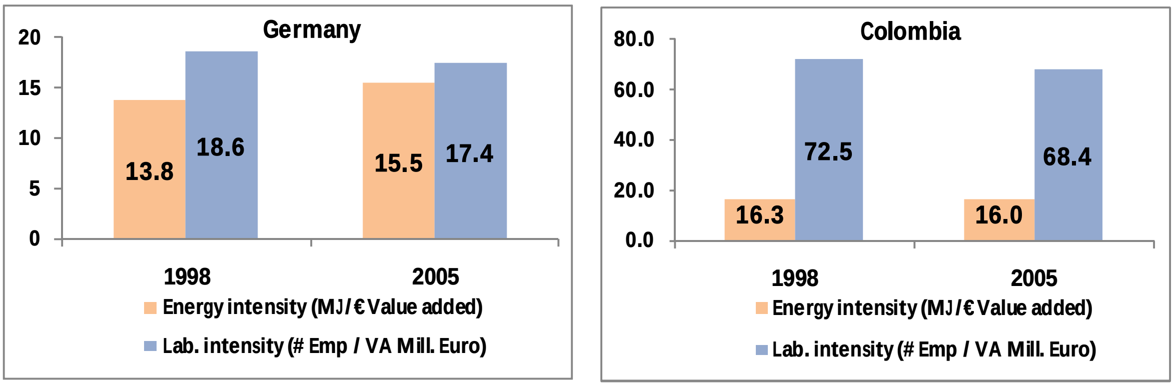
Comparing the results of both countries, it can be observed that there is a direct relationship between labour and energy intensity because German industry had lower energy and labour

[42] Wing and Eckaus (2004) demonstrated that technological changes embodied in industries' capital stocks have contributed importantly to reductions in energy intensity and that a significant portion of the energy-saving technical changes observed were the result of innovations that were intended to accelerate production, reduce both labour and capital costs, or make use of alternative materials. Jollands and Aulkah (1997) showed that investment in new technology would affect energy intensity. If the technical change served to reduce energy intensity, it could be concluded that there was an improvement in energy efficiency and vice versa.

[43] EISs and NEISs were clustered taking into account Germany's Ecological Tax Reform (See literal a).

intensity than Colombian industry. Moreover, the results of structural effects coincided partially with labour intensity, indicating that energy intensity performance does not have a clear dependence on changes in labour intensity. Nevertheless, it is clear that in the industrial sectors of both countries, energy intensity had a lower increase or slower decrease, whereas the labour intensity decreased in the majority of industrial sectors[44] (see figure 2.6), which might suggest that the energy consumed per employee tends to increase over time. Therefore, countries or industrial sectors with intermediate or lower levels of labour intensity require more effort to improve energy efficiency because in several cases these improvements will depend on changes in work behaviour and habits[45]. Hence, the results indicate that higher growth rates of energy intensity do not necessarily mean higher or lower rates of labour intensity, and therefore, the changes in energy intensity should not directly depend on the changes in labour intensity[46].

Figure 2-6 Changes in energy intensity and labour intensity in German and Colombian industrial sectors, 1998-2005



Finally, it is possible to conclude that capital intensity has a stronger relationship to energy intensity performance than labour intensity and that changes in labour intensity do not determine changes in energy intensity in the industrial sectors of both countries. However, because developing countries possess higher labour intensity than developed countries, the

[44] Kreith and West (1996) projected that between 1993 and 2010, industrial energy intensity might decrease on average 0.9% annually, and labour productivity might increase by an average rate of 3.9% per year.
[45] The "efficiency paradox" in energy consumption suggests that a substantial amount of investment in energy efficiency is not spontaneously undertaken by actors due to the presence of strong energy-inefficient habits, and therefore the behaviour, habits and preferences are important determinates in the improvement of energy efficiency in the industrial sector. Changes in work habits require time and resources to guarantee their adoption and maintenance over time (Marechal and Lazaric, 2007).
[46] Grott and Mulder (2004) found labour productivity growth to be higher on average than energy productivity growth and that technology changes contributed to the energy-efficiency improvements. In contrast, labour changes only play a minor role in explaining aggregate energy intensity developments.

strategies to improve energy efficiency at the micro level ought to include training programs related to labour standards and energy efficiency.

c. Substitution of fuels. During the sample period, the industrial sector in Germany increased its use of electricity, gas and renewable energy, whereas other fuels (coal and mineral oil) decreased their total share by the same amount (Figure 2.3). In Colombia, the situation is similar except for a large increase in the consumption of natural gas (10%). During this period, more than 50% of Colombian industries fed their boilers with natural gas, meaning that a change in the fuel used from low to high quality (i.e., from oil to natural gas) can influence energy efficiency (Hall et al., 1986). Much of the decline in the energy intensity in the industrial sector has been due to the ability to expand the use of higher quality fuels (Ramos and Ortege, 2003). Hence, the results show that the increase in electricity use and the decrease in use of other fuels in both countries generated a decrease in the aggregate energy intensity, measured as production value, of other fuels, and the total aggregate energy intensity had a minor role[47]. Moreover, it is important to note that in both countries, the substitution of fuels has been intended to increase the use of clean fuels or of those generating less greenhouse gas emissions.

d. Energy prices. The development of energy prices in the German and Colombian industrial sectors shows similar behaviour between 1998 and 2005 (see figure 2.7). In general, it is assumed that energy efficiency is important during periods of high energy prices from a cost minimisation of output perspective. This situation might motivate improvements in the process and appropriate substitution of other inputs for energy (Mukherjee, 2008). The results show that in both countries the increases in prices of other fuels precipitated the substitution of these fuels by natural gas and renewable energy. As for energy efficiency performance, one might deduce that during the sample period, energy prices influenced energy efficiency performance because decreases in aggregate energy intensity occurred in the years in which energy prices increased[48]. This fact was more noticeable in the decomposition analysis of other fuels, which

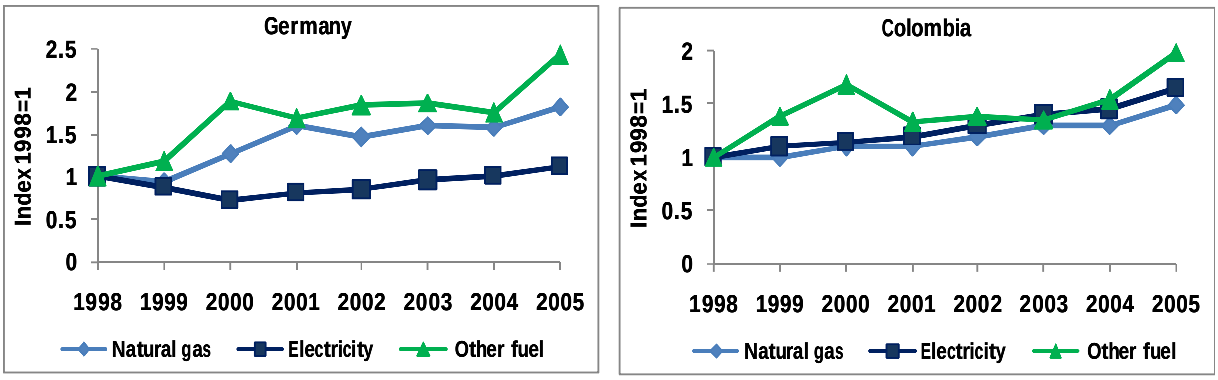
[47] The results of decomposition analysis showed that the contribution of intensity and structure to the aggregate energy intensity were the same (Germany: $F_{str1998-2005}$=0.992 and $F_{int1998-2005}$=0.992, and Colombia: $F_{str1998-2005}$=1.005 $F_{int1998-2005}$=0.992).

[48] Between 2003 and 2005, the German and Colombian industrial sectors decreased the aggregate energy intensity as production value 8% and 6% respectively, whereas the energy prices increased on average 20% and 22% respectively, and the aggregate fuel intensity decreased on average as production value 12% and 15% respectively.

had a higher increase than electricity. Therefore, an increase in prices over time leads to a decrease in energy intensity[49].

Moreover, the difference in energy prices between Germany and Colombia is meaningful[50] and might explain the better energy efficiency performance of Germany than Colombia. The size of the energy bill might have great influence on the application of new alternatives and strategies to improve energy consumption per unit produced, and taking this into account, Germany developed a policy instrument (German energy tax law) that has as its aim to encourage the cost-effectiveness of energy efficiency. Hence, an appropriate combination of policy instruments in the industrial sector of a given country might guarantee energy efficiency improvement.

Figure 2-7 Energy price developments for the German and Colombian industrial sectors



e. Use of VP or VA. In both countries, the results showed that the energy intensity indicator using value added as its output measure is relatively more vulnerable to economic change (e.g., between 2001 and 2004) than value production as the output measure. Likewise, the Colombian indicators showed similar behaviour in comparison with the German indicators. (To measure this vulnerability, the coefficients of variation were calculated for both indicators in both countries. The average coefficients of variation for the energy intensity indicators during the sample period for the German industrial sector were 2.5% for energy per unit of value of production and 5% for energy per unit of value added. For the Colombian industrial sector, these values were 7.4% and 8.1% respectively). These results may indicate that value of production as an energy intensity indicator provides a better description of energy intensity in

[49] Similar results were found by Cornillie and Fakhauser (2002), Hudson and Jorgenson (1998), Brown et al (1998) and Holdren (2001).
[50] During the sample period, the average prices of electricity and natural gas in Germany were 5.6 and 1.9 cent euro/Kwh respectively, and in Colombia, 4.1 and 1.2 cent euro/Kwh respectively.

the industrial sectors of both countries and that the industrial sector of a developing country, such as the Colombian case, might be more vulnerable to economic change than the industrial sector of a developed country, such as the German case. Finally, it can be concluded that during the sample period, the industrial sectors in both countries showed a slight increase in energy intensity (Germany: 0.61% and Colombia: 4%)[51].

f. Use of exchange rates or purchasing power parities. As shown throughout this chapter, the use of purchasing power parities generated meaningful decreases in energy intensity indicators in the Colombian case, whereas in the German case these indicators did not show relevant changes[52]. In both countries the trends were similar. Therefore, the PPP approach has limitations because in the comparisons between developed and developing countries, the latter would be more energy efficient. However, intuition and all the evidence indicate otherwise,[53] so the energy intensity results with this method may not reflect reality and could be misleading (Birol and Okogu, 1995). The use of PPP requires a careful interpretation with respect to the magnitude of indicators, and the use of this method depends on the aim and context of the study. However, the use of PPP is adequate to analyse projections, scenarios and trends between regions because this method will provide accurate estimates of the growth factors required for countries in a region to attain the same output and price structures (Nordhaus, 2007 and Vuuren and Alfsen, 2007).

2.5 Conclusions

In this chapter, energy efficiency development in the industrial sector of two countries in different stages of economical and technological development was examined with the aim of analysing several factors that might affect the changes in energy intensity. Hence, it was found that the industrial sectors of both countries during the sample period increased their energy consumption by 2.3% in Germany and 5.5% in Colombia and also decreased their aggregate energy intensity (12% and 6% respectively). By decomposing the effects of changes in structure, production and energy intensity in the industrial sector, it was found that I) the

[51] If value added were used as the measure of output, the increase would be 11% in the German case and 10% in the Colombian case in comparison with value of production.
[52] The average of energy intensity indicators were, for Germany and Colombia with exchange rate, 4.26 MJ/€ and 9.39 MJ/€ as production value and 14.09 MJ/€ and 21.47 MJ/€ as value added, respectively, whereas with PPP 4.22 MJ/€ and 3.08 MJ/€ as production value and 13.96 MJ/€ and 6.92 MJ/€ as value added, respectively.
[53] The technology factor explains why industrial countries tend to be more efficient than less-industrialised countries, and generally, developing countries tend to have older capital stock that is less efficient, not only because it is older technology but also because such equipment tends to lose efficiency with age and poor maintenance.

decrease in aggregate energy intensity shown by the German and Colombian industrial sectors was driven by the decrease of the energy intensity in EISs, II) several industrial sectors showed output growth and at the same time decreases in energy consumption, indicating that the trend of the industrial sectors in both countries is to increase energy productivity by producing more with less energy, III) in Germany, structural and intensity effects contributed to the results of the aggregate energy intensity. In the first case, the contribution could be due to improvements in technology or production standards, and the second case was due to the decrease of production in energy intensive sectors (e.g., the textile and glass industries, with an average of 8% and 5%, respectively), IV) in Colombia, intensity effects dominated over structural effects. This might be attributed to fact that during the sample period, a concentration process generated improvement in production standards and process optimisation (mainly in the chemical, food, basic metal, and glass industries), and V) the role of substitution of fuels has been minor in the decrease of aggregate energy intensity, especially in Germany. However, the results show that the increase in electricity use and the decrease in use of other fuels in both countries generated a decrease in the aggregate energy intensity, measured as production value, of other fuels.

All of these points are important in the formulation of energy policies for the industrial sector of a country, taking into account that energy efficiency performance has several differences at the different levels of aggregation. Likewise, it is important to consider key strategies for every level of aggregation, taking into account the variables that might generate effective energy efficiency improvements and reduction of carbon dioxide emissions in the industrial sector.

Moreover, the results also showed that the differences observed between the two countries might be explained by the relationship between capital intensity, labour intensity and energy intensity. It was found that capital intensity has played an important role in energy intensity improvements. Comparing the results of the two countries revealed that Germany is more capital intensive and less energy intensive than Colombia, and this fact might mean that the capital of the industrial sector of a country is related to better technology and could indirectly involve less energy consumption. These results could lead to the conclusion that capital intensity is one of the variables that could determine energy intensity performance in the industrial sector at the macro and meso levels and that energy and capital have a complementary interaction in the industrial sector.

On the other hand, changes in labour intensity did not show a clear relationship with the results of energy intensity indicating that higher growth rates of energy intensity do not necessarily mean higher or lower rates of labour intensity, and therefore, the changes in energy intensity should not directly depend on the changes in labour intensity.

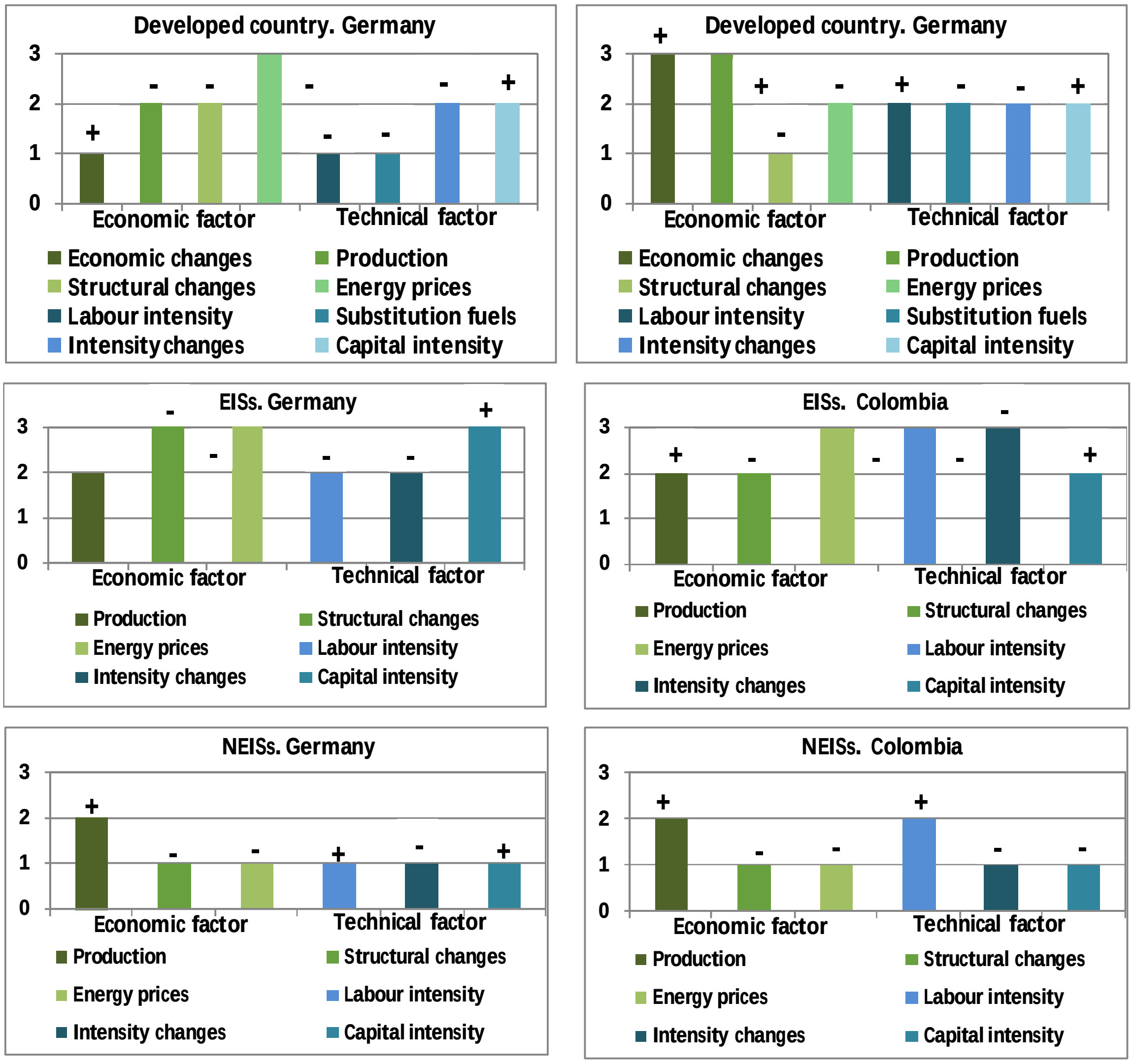
Moreover, energy prices were also important in energy intensity improvements. The results showed that in both countries the increases in prices of other fuels precipitated the substitution of these fuels by natural gas and renewable energy. As for energy efficiency performance, one might deduce that during the sample period, energy prices influenced energy efficiency performance because decreases in aggregate energy intensity occurred in the years in which energy prices increased.

Finally, figure 2.8 summarises the results of the analysis and confirms the hypotheses formulated in Chapter 1 concerning the differences at the macro and meso levels and the influence of economic and technical factors on energy intensity performance.

All findings of this chapter are of particular interest in the formulation and development of energy policies for the industrial sector to improve energy efficiency and reduction of carbon dioxide emissions. These policies should include different strategies and instruments, taking into account the key elements—an appropriate combination of policy instruments that encourage and the barriers that inhibit improving energy efficiency in EISs and NEISs.

In developing countries, it is important to develop strategies to improve the technology in the industrial sectors with the aim of increasing productivity and optimising energy consumption because significant opportunities exist to enhance the use of existing efficient technologies. Likewise, the micro level ought to include training programs related to labour standards and energy efficiency through energy management systems.

Figure 2-8 Summary of results at macro and meso levels of industrial sector



Note: The sign indicates the type of correlation, (+) direct and (-) inverse.

1, 2, 3 imply influence at the low, middle and high levels, respectively.

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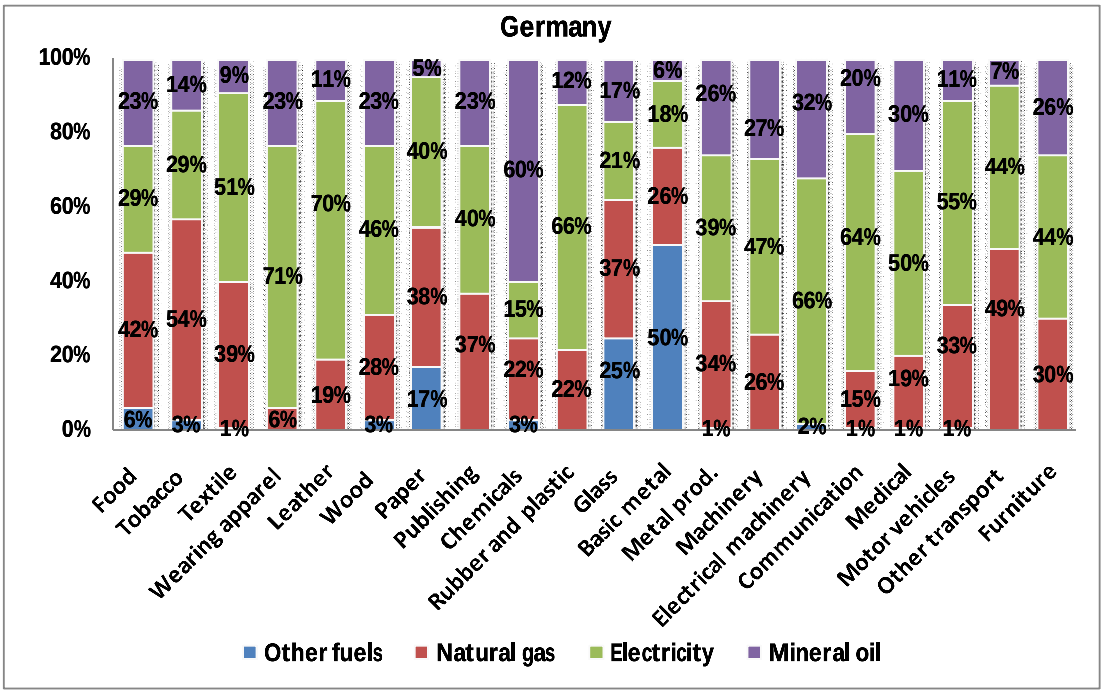
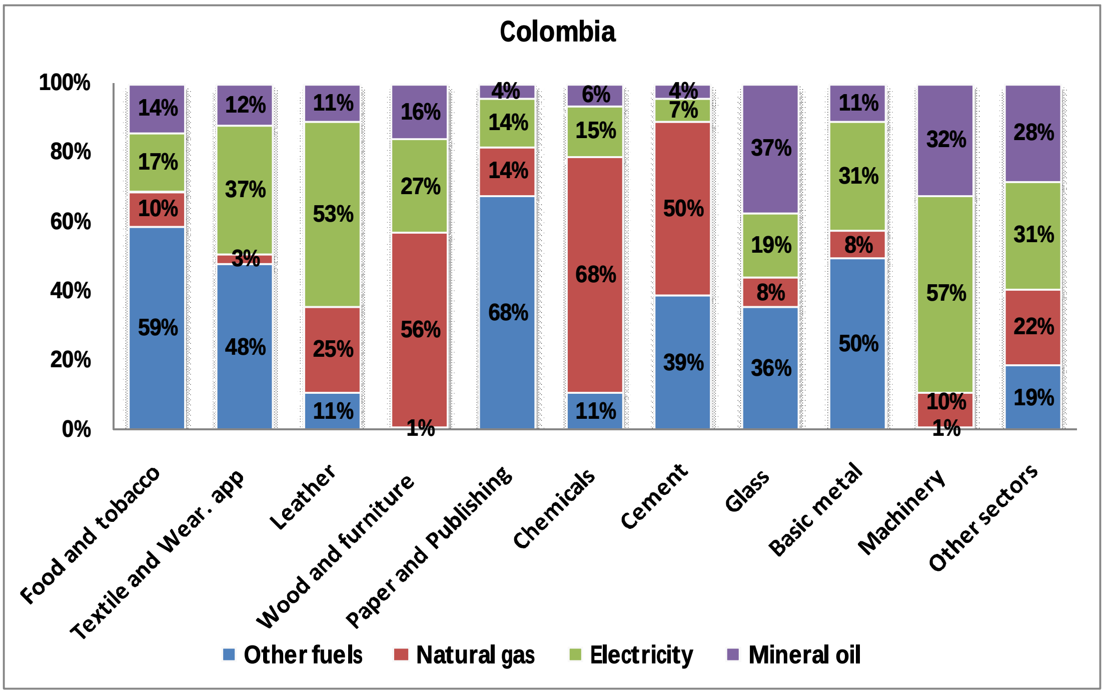
Appendix

Appendix 1 Distribution of fuel sources in energy consumption in the German and Colombian manufacturing sectors.





Appendix 2 Decomposition analysis at purchasing power parities

Table 1 Decomposition of aggregate energy intensity, electricity intensity and fuel intensity for the German and Colombian industrial sectors into structural (F_{str}) and intensity (F_{int}) effects using production value (PV) and value added (VA) as measures of economic output at purchasing power parities.

German industrial sector. Energy																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.997	1.001	0.995	0.999	0.995	0.999	0.993	0.998	0.992	0.997	0.988	0.992	0.988	0.992
F_{int}	1	1	1	0.998	0.991	0.993	0.994	0.997	0.995	0.996	0.999	0.999	0.995	0.996	0.990	0.992
EI_{agg}	1	1	1	1	0.920	0.978	0.920	0.951	0.934	0.973	0.949	0.984	0.891	0.995	0.858	0.918
Colombian industrial sector. Energy																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.998	0.997	0.998	0.997	1.001	1.001	1.002	1.003	1.006	1.005	1.014	1.011	1.016	1.011
F_{int}	1	1	0.981	0.980	0.955	0.960	0.945	0.952	0.954	0.960	0.964	0.975	0.962	0.977	0.957	0.976
EI_{agg}	1	1	0.871	0.894	0.824	0.845	0.806	0.844	0.863	0.897	0.946	1.007	0.981	1.059	0.945	1.005
German industrial sector. Electricity																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.999	1.001	0.992	1.001	0.991	0.996	0.993	0.994	1.001	1.003	0.989	0.991	0.988	0.991
F_{int}	1	1	0.997	0.998	1.001	0.999	0.999	1.005	0.995	1.006	1	1.010	1	1.011	0.996	1.011
EI_{agg}	1	1	1	1	0.933	1.001	0.941	0.996	0.933	1.001	0.963	1.012	0.939	1.006	0.927	1.012
Colombian industrial sector. Electricity																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.998	0.996	0.997	0.996	0.997	0.996	0.998	0.996	1	0.996	1.005	1.004	1.004	1.003
F_{int}	1	1	0.997	0.997	0.983	0.989	0.987	0.978	0.987	0.996	1.001	1.016	1.011	1.025	1.008	1.023
EI_{agg}	1	1	0.841	0.886	0.873	0.898	0.841	0.886	0.913	0.955	1.011	1.085	1.132	1.232	1.095	1.210
German industrial sector. Fuel																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.999	1.001	0.993	1.001	0.980	0.995	0.994	0.995	1.001	1.003	0.989	0.991	0.988	0.991
F_{int}	1	1	0.995	0.996	0.993	0.992	1.002	1.003	0.986	0.992	0.997	1.005	0.994	1.005	0.990	1.001
EI_{agg}	1	1	1	0.990	0.913	0.959	0.895	0.990	0.913	1.085	0.971	1.079	0.925	0.990	0.890	1.007
Colombian industrial sector. Fuel																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{str}	1	1	0.998	0.996	0.997	0.996	0.997	0.996	0.998	0.996	1	0.996	1.005	1.004	1.004	1.004
F_{int}	1	1	0.973	0.973	0.936	0.953	0.933	0.941	0.946	0.954	0.957	0.971	0.953	0.966	0.946	0.959
EI_{agg}	1	1	0.819	0.816	0.732	0.699	0.611	0.643	0.913	1.001	0.945	1.004	0.976	1.002	0.713	0.787

Table 2 Decomposition of energy consumption, electricity consumption and fuel consumption for the German and Colombian industrial sectors into production (F_{pdn}) and intensity (F_{int}) effects using production value (PV) and value added (VA) as measures of economic output at purchasing power parities.

German industrial sector. Energy ($E_{Cons.}$: Energy consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	1.014	1.002	1,015	1.006	1.016	1.006	1.012	1.005	1.011	1.001	1.016	1.006	1.019	1.008
$E_{Cons.}$	1		1.006		1.004		1.029		1.025		1.038		1.015		1.011	
EI_{agg}	1	1	1	1	0.920	0.978	0.920	0.951	0.934	0.973	0.949	0.984	0.891	0.995	0.858	0.918
Colombian industrial sector. Energy ($E_{Cons.}$: Energy consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	0.999	1	1.025	1.020	1.039	1.032	1.034	1.028	1.027	1.017	1.033	1.018	1.041	1.022
$E_{Cons.}$	1		0.877		0.876		0.923		0.951		0.988		1.002		1.021	
EI_{agg}	1	1	0.871	0.894	0.824	0.845	0.806	0.844	0.863	0.897	0.946	1.007	0.981	1.059	0.945	1.005
German industrial sector. Electricity ($El_{Con.}$: Electricity consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	1.004	1.001	1.014	1.005	1.015	1.003	0.992	0.982	0.996	0.989	1.016	1.002	1.020	1.001
$El_{Con.}$	1		1		1.030		1.039		1.015		1.029		1.050		1.053	
EI_{agg}	1	1	1	1	0.933	1.001	0.941	0.996	0.933	1.001	0.963	1.012	0.939	1.006	0.927	1.012
Colombian industrial sector. Electricity ($El_{Con.}$: Electricity consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	0.989	0.991	1.014	1.008	1.016	1.006	0.934	0.935	0.920	0.917	0.997	0.984	1.022	1.007
$El_{Con.}$	1		0.974		1.056		1.099		1.138		1.181		1.286		1.301	
EI_{agg}	1	1	0.841	0.886	0.873	0.898	0.841	0.886	0.913	0.955	1.011	1.085	1.132	1.232	1.095	1.210
German industrial sector. Fuel ($F_{Cons.}$: Fuel consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	1.004	1.001	1.014	1.005	1.015	0.999	0.993	1.022	1.006	1.030	1.016	1.027	1.020	1.003
$F_{Cons.}$	1		1		0.992		1.010		1.016		1.013		1.007		1.014	
EI_{agg}	1	1	1	0.990	0.913	0.959	0.895	0.990	0.913	1.085	0.971	1.079	0.925	0.990	0.890	1.007
Colombian industrial sector. Fuel ($F_{Cons.}$: Fuel consumption)																
	1998		1999		2000		2001		2002		2003		2004		2005	
	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA	PV	VA
F_{pdn}	1	1	1.028	0.990	1.080	1.018	1.033	1.025	1.069	1.023	1.069	1.010	1.060	1.010	1.060	1.014
$F_{Cons.}$	1		0.834		0.822		0.799		0.889		0.916		0.875		0.846	
EI_{agg}	1	1	0.819	0.816	0.732	0.699	0.611	0.643	0.913	1.001	0.945	1.004	0.976	1.002	0.713	0.787

Chapter 3.

Energy efficiency development in the German and Colombian manufacturing sectors at different aggregation levels: A non-parametric analysis[*]

Abstract

This study approaches the measurement of energy efficiency development in the manufacturing sector at different aggregation levels from a production-theoretic structure, using the method of Data Envelopment Analysis (DEA). Using data from the German and Colombian Annual Surveys of Industries for the years 1998 to 2005, the analysis compares the energy efficiency performance in the German and Colombian manufacturing industries between energy intensive sectors (EISs) and non-energy intensive sectors (NEISs) at three and two levels of aggregation, respectively, and then applies several alternative models. The results show considerable variation in energy efficiency performance in the EISs and NEISs of both countries. Comparing the results across models, it was found that, in the German manufacturing industry the three measures of energy efficiency were similar, indicating that an appropriate combination of technical efficiency and cost minimisation are necessary for energy efficiency improvement. In the Colombian manufacturing industry, the highest energy efficiency measured was from the cost minimisation model, suggesting that the relative energy prices have not generated the right incentives to improve energy efficiency. A second-stage regression analysis reveals that, in German EISs, energy costs and investments have played an important role in energy efficiency performance and decrease CO_2 emissions. In Colombian EISs, inter-fuel substitution was the most significant variable. In German and Colombian NEISs, labour productivity and investments were fundamental to the results for energy efficiency. Finally, the results of DEA models show a significant correlation with the traditional energy efficiency measure, indicating that the energy efficiency measured through DEA could be complementary to the energy intensity in analysing other key elements of energy efficiency performance in the industrial sector. In addition, energy efficiency is one of the quickest and the most efficient strategies for reducing energy demand and CO_2 emissions.

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[*] The section of German and Colombian EISs is published as chapter of book in Energy and Sustainability II, Section 6: Energy efficiency 499-511. The section of German and Colombian NEISs is in press in the Journal Energy Efficiency.

3.1 Introduction

A key component of the energy policy in some countries has been increasing energy efficiency and productivity, thereby guaranteeing sustainable development. Different researchers have developed indicators to measure and evaluate the development and outlook of energy efficiency performance within economic sectors or across countries or regions. The main systems to measure, analyse, and evaluate energy efficiency have been developed by international energy agencies or international organisations like the IEA (2001, 2008), ODYSEE (2007), World Energy Council (2008), and others.

Improving energy efficiency has become an important element of different perspectives that guarantee consumption and sustainability as key elements of economic development. The main objectives for improving energy efficiency on a macroeconomic level are to maintain reserves of fossil fuels, enhance energy security, prevent global warming, and improve environmental quality. On a microeconomic level, achieving energy efficiency's main objectives are cost minimisation, reduction of energy use when prices increase, and seeking substitutes or clean energy.

This analysis seeks to measure energy efficiency development from a production theoretic framework, and uses Data Envelopment Analysis (DEA) to present several alternatives models for measuring energy efficiency performance in German and Colombian industries. In both countries, the manufacturing industry is divided between energy intensive sectors (EISs) and non-energy intensive sectors (NEISs) to obtain comparable decision-making units (DMUs) at three and two aggregate levels between 1998 and 2005. Moreover, to explain variations in energy efficiency development across manufacturing industries, we use regression analysis involving several key factors that might have influenced the energy efficiency performance in EISs and NEISs in both countries. In German and Colombian EISs, the results reveal that basic chemical, iron, and steel industries demonstrated the highest energy efficiency performance, whereas some textile and glass sectors had the worst performance according to DEA models. In German and Colombian NEISs, food and chemicals emerged as the most energy efficient industries, whereas furniture and metal products were the worst performers according to DEA models.

Four alternative models were assessed in this study. The first two models measure the potential reduction in energy use when maintaining output levels and without including additional amounts of other inputs (technical efficiency); a third model (cost efficiency) considers energy efficiency based on the objective of minimising total input costs (these models were developed by Mukherjee, 2008 in the US manufacturing sector). The fourth model analyses the energy mix effects for energy efficiency and calculates Malmquist indices for the total factor of productivity (TFP), technological change (TC), and technical efficiency up to the output level (desirable output) and CO_2 emissions (undesirable output)[54] in German and Colombian industries. This chapter attempts to answer the following questions: (1) What have been the key factors influencing energy efficiency performance in the German and Colombian manufacturing industries?; (2) What are the differences in energy efficiency performance at different levels of aggregation in the manufacturing industries of a developed country (the German case) and a developing country (the Colombian case)?; The rest of this chapter is organised as follows: Section 2 provides a review of the literature on energy efficiency and DEA analysis in the manufacturing industry. Section 3 presents the methodology of DEA and the models used to measure energy efficiency development from different perspectives in the German and Colombian manufacturing industries. In section 4, we present the data, the empirical application in the countries' manufacturing sectors (EISs and NEISs), and the main findings from the analyses. Section 5 concludes.

3.2 A brief review of the literature on energy efficiency and Data Envelope Analysis

The most common definition of energy efficiency is energy intensity, defined as the quantity of energy required per unit of output or activity. According to the Directive 2006/32/EC of the European Council and the Parliament on energy end-use efficiency and energy services, energy efficiency is the ratio between an output of performance, service, goods, or energy and an energy input. These concepts show that when the relations between *E/O* (where *E* total energy is consumed and *O* total output is produced at the time) decrease over time, energy efficiency has improved. Researchers in many fields have used various approaches to measure energy efficiency in the industrial sector. These fields include engineering, economics, industrial ecology, operations research, and others. These analysis techniques were grouped into four

[54] Similar applications were developed by Ramanathan (2006) in the context of the relationships among world GDP, energy consumption and carbon dioxide emissions and Zhou and Ang, (2008) to measure economy-wide energy efficiency performance.

types: energy trend decomposition methods, econometric methods, ‘Top-down’ and ‘Bottom-up’ models, and industry-specific micro-economic analyses (Greening, et al., 2007). We next present a brief explanation of each method.

- Energy trend decomposition methods analyse the impacts of structural changes and energy efficiency (or other factors) on a country’s aggregate energy or emissions trends (e.g., the survey of index decomposition analysis in energy (Ang and Zhang, 2000), comparison of energy intensities in European Union countries (Alcantara and Duarte, 2004), and the decomposition of manufacturing energy use in IEA countries (Unander, 2007).
- Econometric methods are typically used to evaluate the effects of prices, emissions taxes, or energy demand, and these methods can vary in complexity from very simple to relatively sophisticated, and apply to data of varying temporal, spatial, and sectoral detail. Some analysis methods are single equations models (Sorell and Dimitropoulos, 2008), simultaneous equations models (Lescaroux, 2008), and time series (Lee and Oh, 2006).
- ‘Top-down’ and ‘Bottom-up’ (or engineering) models. Top-down models are used to measure and evaluate industrial technology policies and the impacts of technological change, while bottom-up models can be used in complex (e.g., World scope) or simple settings (e.g., individual countries). This type of model analyses the relationship between technology and energy consumption through hybrid models, optimisation, and simulation tools (e.g., Frei et al., 2003, Berglund and Söderholm, 2006, Wing and Eckaus, 2004, Böhringer and Rutherford, 2008).
- Industry-specific micro-economic analyses. These studies are applied to specific industries or processes using simulation models, as well as statistical and optimisation techniques (Babusiaux and Pierru, 2007, Lund, 2007, Henning and Trygg, 2008).

In the last few years, some researchers have analysed energy efficiency within a framework with inputs and outputs, where energy is an input in the productive process that can be analysed to determine the relation between energy intensity and the level of productivity (Boyd and Pang, 2000). Moreover, energy as an input generates desirable outputs (good) and undesirable outputs (as CO_2 emissions). These studies have used the DEA methodology. For instance, Schuschny (2007) and Zhou and Ang (2008) applied DEA models to analyse CO_2 emissions in Latin American and 21 OECD countries, respectively. Sarica and Or, (2007) assessed efficiency in Turkish power plants. Mukherjee (2008) presented several DEA models to analyse energy use efficiency in U.S. manufacturing and an interstate analysis of Indian manufacturing.

In Germany, DEA models have been applied mainly in studies of efficiency or electricity distributions companies (Hess and Cullman, 2007), benchmarking studies about the performances of universities (Fandel, 2007), and the development of software (Scheel, 2000). In Colombia, DEA models have also been applied in studies of the performance and efficiency of power distribution systems (Pombo and Taborda, 2006), production costs (Lopez, et al., 2007), and the analysis of ranking Colombian research groups (Restrepo and Villegas, 2007).

With this background, the present study seeks to analyse energy efficiency development in German and Colombian manufacturing, using several models to identify the multiple inputs into production, which is the role and effect of technical and economic factors (e.g., energy use, substitutions of inputs and fuels, and other factors) in terms of the results for energy efficiency development at different aggregation levels in the manufacturing industry of both countries.

3.3 Measuring energy efficiency development with DEA

Data Envelopment Analysis (DEA) allows for the measurement of relative efficiency for a group of decision-making units (DMU) that use resources (inputs) to produce products (outputs). This methodology involves the use of linear programming methods to build a non-parametric piecewise frontier over data, so as to be able to calculate efficiencies relative to this frontier. Furthermore, DEA allows for the identification and quantification of inefficient DMUs when it has several inputs and outputs. The definition of efficiency in DEA consists of three components: *technical efficiency*, which reflects the ability of a firm to obtain maximal output from a given set of inputs, *allocative efficiency*, which reflects the ability of a firm to use inputs in optimal proportions, given their respective prices, and *scale efficiency*, which, according to the features of performance scale, brings about the DMU. These three measures are then combined to provide a measure of total *economic efficiency* (Farrell, 1957 and Coelli, 1996 and Coelli et al., 2005)[55]. Moreover, this methodology has been applied in energy and environmental modelling in recent years, mainly because of the flexibility and ability of DEA to adapt to varying situations (Zhou and Ang, 2008). Following Mukherjee (2008) for models 1, 2, and 3 and Zhou and Ang, (2008) and Ramanathan (2006) for model 4, this study uses DEA to estimate energy efficiency

[55] Charnes et al., (1994) and Coelli et al., (2005) may be consulted for further details and bibliographies about DEA.

as a normative measure rather than just a descriptive measure of energy intensity, and to analyse the effects of input and fuel substitution on energy efficiency performance in the industrial sector at different aggregation levels.

Consider an industry producing a single output *y* from a vector of *n* inputs $x = (x_1, x_2, \ldots, x_n)$. Let y_i represent output and the vector x_i represent the input package of the *ith* DMU. Suppose that input–output data are observed for m DMUs. Then, the technology set can be completely characterised by the production possibility set *S = {(x, y):y can be produced from x}* based on a few regularity assumptions of feasibility for all observed input–output combinations, free disposability with respect to inputs and outputs, and convexity. If, in addition, a constant return to scale is assumed, then this implies that all radial expansions, as well as (non-negative) contractions of the feasible input–output combinations, are also considered feasible.

The input-oriented technical efficiency measure is defined as the ratio of the optimal (i.e., minimum) input package to the actual input package of a DMU for a given level of output, holding input proportions constant (*technical efficiency*). The CCR DEA[56] model for measuring the input-oriented technical efficiency of a DMU with the input–output package (x_0, y_0) is presented in model (1) below, comprising (1a) through (1d):

DEA model 1:

$\theta^* = \min \theta,$ (1a)

subject to

$\sum_{i=1}^{n} x_{ji} \lambda_i \leq \theta_{xi0} \; (j = Capital, Labour, materials, energy)$ (1b)

$\sum_{i=1}^{n} y_i \; \lambda_i \geq y_0 \; (output)$ (1c)

$\lambda_i \geq 0, \; i = 1,2, \ldots, n$ (1d)

$\theta = Total\ inputs$

$n = the\ number\ of\ DMUs$

$x_{ji} = the\ amount\ of\ input\ j\ of\ DMU\ n$

$y_i = the\ amount\ of\ output\ of\ DMU\ n$

$\lambda_i = Non\ negative\ multipliers\ that\ define\ the\ target\ operation\ point\ as\ a\ linear$
$combination\ of\ the\ sample\ observations$

[56] The first development of non-parametric approach DEA was by Charnes, Cooper, and Rhodes (CCR, 1978) to measure the efficiency of individual DMUs.

The objective of model 1 is to reduce all inputs to the largest extent possible by the same proportion, so as to accommodate any potential complementarily between energy and other inputs. Moreover, the inequality (1c) ensures that the resultant output is no lower than what is actually being produced. An efficient DMU will have $\theta^* = 1$, implying that no equi-proportionate reduction in inputs is possible, whereas an inefficient DMU will have $\theta^* < 1$. In this model, the optimal value of θ shows the radial contraction in all inputs that is possible for the process, while still producing the given output[57]. If the constraint associated with a specific input (in this case energy) in model 1 is non-covering, this would mean that it is possible to decrease this input even further without causing a reduction in output or requiring additional amounts of any other input. In the case of a particular input (e.g., energy) in this model, it is possible to reduce this input even further without causing a reduction in output or requiring additional amounts of any other inputs. Hence, there is no slack associated with this input in the optimal solution to model (1). In the rest of this chapter, we will refer to this measure of efficiency for a particular input as ε, and $\varepsilon = \theta$ in the case where there is no slack associated with the energy input.

The purpose is to know the maximum possible reduction in the energy input only, and that this maintains or increases the output level without requiring any additional amounts of other inputs. The CCR-type DEA model can be used to measure energy efficiency for a DMU with an input-output package (x_0, y_0) through the model 2 developed by Mukherjee (2008), where the input vector x_0 is divided explicitly into every input component - in this study, Capital (K), Labour (L), materials (M), and energy (E)– Moreover, inequalities (2b) and (2d) ensure that the other inputs not be increased at the optimal solution and inequality (2f) ensures that the output produced is no lower than what is actually being produced.

DEA model 2:

$\beta^* = \min \beta,$ (2a)

subject to

$\sum_{i=1}^{n} K_i \lambda_i \leq K_0 \ (Capital)$ (2b)

$\sum_{i=1}^{n} L_i \lambda_i \leq L_0 \ (Labour)$ (2c)

$\sum_{i=1}^{n} M_i \lambda_i \leq M_0 \ (Materials\ inputs)$ (2d)

$\sum_{i=1}^{n} E_i \lambda_i \leq \beta E_0 \ (Energy)$ (2e)

$\sum_{i=1}^{n} y_i \lambda_i \geq y_0 \ (output)$ (2f)

$\lambda_i \geq 0, \ i = 1,2,\dots,n$ (2g)

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57 This is the concept of technical efficiency of the firm according to Debreau (1951) and Farrel (1957).

Models 1 and 2 can be used to measure energy efficiency when the underlying objective is the conservation of energy and maintenance of environmental quality by reducing energy use and maintaining the level of output. However, the energy efficiency measure obtained from model 1 is appropriate when the energy input is strongly complementary to other inputs and may be limited to the extent that energy savings at the optimal solution are due to the simultaneous reduction of all inputs. On the other hand, model 2 allows us to assess the potential reduction of energy input without requiring any additional other inputs and while maintaining the observed level of outputs (or more).

Another objective for achieving energy efficiency is based on the economic objective of minimising costs during periods of relatively high energy prices, under which achieving cost effectiveness would typically lead to substituting other inputs for energy. Suppose that the given input price vector for the DMU under evaluation is w_0. The DEA model for cost minimisation can be written as in the model (3) below, which comprises (3a)–(3d).

DEA Model 3:

$$C^* = min w'_0\, x \;(Total\ input\ cost) \qquad (3a)$$

Subject to

$$\sum_{J=1}^{n} x_{ij}\,\lambda_j \;\le\; x_i \;(i = capital, labour, materials, energy) \qquad (3b)$$

$$\sum_{J=1}^{n} y_j\;\lambda_j \;\ge\; y_0 \;(output) \qquad (3c)$$

$$\lambda_j \;\ge\; 0,\; J = 1,2,\ldots,n \qquad (3d)$$

In model 3, the objective is to minimise the total input cost. The inequalities (3b) and (3c) ensure that the optimal input bundle is chosen, so as to minimise the total cost, but such that it can still produce the output bundle y_0. The ratio of minimum cost (C*) to the actual cost (C) obtained from this model gives a measure of cost efficiency for the DMU, i.e., CE = C*/C. Moreover, the model can compare energy use at the optimal solution to this problem to actual energy use in order to obtain a measure of energy use efficiency (μ^*) based on cost minimisation. Since this model allows other inputs to be substituted for energy, it can potentially generate greater reductions in energy beyond model (2). However, the objective of cost minimisation does not always lead to energy conservation. During periods when energy prices are relatively low compared to the prices of other inputs, cost minimisation may call for increased use of energy to substitute for those other inputs, in which case we would obtain $\mu^*>1$.

A common feature of the above three models is that energy consumption is an input within a production framework where energy and other non-energy inputs are used to produce good or desirable outputs. Nevertheless, energy use also generates some undesirable outputs, e.g., CO_2 emissions, as by-products of producing desirable outputs. Model 4 evaluates energy efficiency performance within a joint production framework, in which both desirable and undesirable outputs are considered simultaneously. Moreover, this model treats different energy sources as different inputs so that changes in energy mix can be accounted for in calculating indices of the total factor of productivity change (TFP), technological change (TC), and technical efficiency change (TEC)[58] through the application of Malmquist DEA methods[59].

Consider a production process in which desirable and undesirable outputs are jointly produced by energy inputs and non-energy inputs. Assume that *e, x,* and *y* are, respectively, the vectors of energy inputs, non-energy inputs and desirable and undesirable outputs, where energy inputs consist of *L* different energy sources. This model does not assume that all slack variables must be positive, which allows all the possible energy mix effects to be captured when evaluating energy efficiency. The model is as follows:

DEA model 4:

$$\phi^* = max\phi \tag{4a}$$

subject to

$$\sum_{j=1}^{n} x_{Lj}\,\lambda_j \;\le\; x_{L0}\ (L = energy\ consumption\ by\ source) \tag{4b}$$

$$\sum_{j=1}^{n} x_{mj}\,\lambda_j \;\le\; x_{mo}\ (m = non-energy\ inputs) \tag{4c}$$

$$\sum_{j=1}^{n} Y_{pj}\,\lambda_j \;\le\; \phi x_{p0}\ (p = desirable\ output\ and\ undesirable\ output) \tag{4d}$$

$$\lambda_j \ \ge 0, j = 1,2,\dots,n \tag{4e}$$

ϕ: $total\ outputs$

However, note that in this model the inputs and outputs are not specified in the traditional sense, because gross production and CO_2 emissions are not outputs that are only due to

[58] TFP growth measures how much productivity grows or declines over time. When there are more outputs relative to the quantity of given inputs, then TFP has grown or increased. TFP can grow when adopting innovations such as application of energy-efficient technologies (e.g., Heat recovery, cogeneration, high efficiency boilers, etc.) which it calls "technological change" (TC). TFP can also grow when industry uses their existing technology and economic inputs more efficiently; they can produce more while using the same inputs (e.g., capital, energy, labour and technology), or more generally by increases in "technical efficiency" (TE). TFP change from one year to the next is therefore comprised of technological change and changes in technical efficiency.

[59] For more information on Malmquist index see Fare et al., (1994) and Coelli et al., (1997).

energy consumption. This fact must be interpreted in this study as the representative outputs and inputs relevant for computing energy efficiency performance. Moreover, CO_2 emissions are a difficult problem because it is an undesirable output and creating more is not desirable. The literature suggests several methods to treat undesirable outputs in the context of DEA (e.g., to add a negative sign to output, to analyse it as an input, or to use the reciprocal value)[60]. Taking similar research into account in this study, undesirable outputs are introduced as their reciprocal values in the DEA model, and the objective of this model (4) is to study patterns of energy efficiency performance in terms of energy consumption by source (electricity, natural gas, petroleum products, and other), economic activity (output), and CO_2 emissions (as well as the links between fuel substitutions, CO_2 emissions, and TFP). When manufacturing industrial sectors have TFP equal to or above one, they are efficient, whereas scores below one mean lower efficiency. This indicates that a higher TFP in the manufacturing industrial sector produces more output and less CO_2 given the energy sources and non-energy input consumed. This may be because a relatively lower amount of energy inputs was consumed, or that energy efficiency was increased for fuel substitution or better energy use and, hence, a relatively lower amount of CO_2 was emitted from the manufacturing industrial sector over the sample period.

3.4 Application to the German and Colombian manufacturing sector

3.4.1 Data construction and model application

The model was applied to inter-sectoral data from the German and Colombian manufacturing sectors from 1998 to 2005. The data for the manufacturing industry in both countries come from each country's respective static offices[61]. The study covered EISs at three digits of aggregation level and NEISs at two digits of aggregation level. It conceptualised a desirable output (measured by the gross value of manufacturing, deflated by the wholesale price index) and four input production technology factors: labour (measured by the total number of persons employed); energy (measured by energy consumed[62] in every sector in terajoules for model 1 and model 2, primary energy consumption in terajoules for model 4, and the expenditure on

[60] The undesirable output may be analysed as an input because it has the characteristic of an input (less of it is preferable), but it is difficult the interpretation of results (Schuschny (2007) used this method to analysis energy sector and CO_2 emissions in Latin American and the Caribbean); another possibility is to assign a negative sign to undesirable outputs. However, this method also shows difficulties because many DEA models are not invariant with respect to adding different signs between inputs and outputs (Lowell and Pastor, 1995), and another method may be using the reciprocals of undesirable output to incorporate the feature that less undesirable outputs are preferred and this method solves the difficulties of previous methods (Ramanathan (2006) and Zhou and Ang, (2008) used this approaches in their models to evaluate energy efficiency and emissions).

[61] Germany by the Statisches Bundesamt Deutschland (German Bureau of Statistics) and Colombia by the Departamento Nacional de Estadística (Colombian Department of Statistics, DANE).

[62] Including final energy consumption as soon as transformation input, consumption of the energy sector and final non-energy consumption.

fuels for model 3); capital (measured as a stock by taking the value of fixed–capital); and materials (measured by the expenditure on materials). In model 3, all inputs are measured by the appropriate quantity indices, with 1998 as the base year and price indices for individual inputs used as the relevant input prices. Model 4 considers four categories of energy consumption by source as inputs, namely electricity, petroleum products, gas, and other energy. It also considers as undesirable output the reciprocal of CO_2 emissions[63] (in million tons). Appendix 1 shows the summary of the main variables used.

Next, it is necessary to consider the construction of the production frontier[64], on which efficiency can be measured. In this study, we used the inter-temporal frontier, where the production possibility set is defined as $S' = \{(x,y): x \geq \sum_{i=1}^{n}\sum_{t=1}^{t}\lambda_i^t\, x_i^t; y \leq \sum_{i=1}^{n}\sum_{t=1}^{t}\lambda_i^t\, y_i^t\}$ when there are *n* units observed over *T* periods of time at which the DMU is being evaluated. This frontier was selected because it captures overall efficiency change and, under constant returns to scale, (CRS) productivity and efficiency measures are equivalents (Ray, 2004). Using this frontier also assumes technical progress or regress.

Furthermore, DEA evaluates the relative efficiency of a set of comparable entities with multiple inputs and outputs. In this study, the industrial sector in both countries was divided between EISs and NEISs[65], taking into account German energy tax law and using cluster analysis[66] to apply models (1), (2), and (4). In the case of model (3), EISs was divided between higher-energy intensive sectors (HEISs) and lower-energy intensive sectors to achieve better comparisons, again applying cluster analysis[67] with final criteria (See table 3.1 and appendix 1).

[63] CO_2 emissions were calculated using the following IPCC carbon emission factors: Natural gas 15,3 tC/TJ, petroleum products: tC/TJ, Other fuel: 22,9, and electricity by Germany according to Federal Environment Agency (2007) and by Colombia according to Resolution 181401/2004.
[64] DEA analysis defines three types of frontiers: a) the contemporaneous builds from only the cross-section data from a given period, b) the sequential considers all current and past observations as feasible, and c) the inter-temporal uses observations from all the periods in the sample (Tulkens and Eeckaut., 1995).
[65] Several studies have classified the industrial sectors depending on energy intensity. For instance, heavy industries (EISs) and light industries (NEISs); strategic (with lower energy intensity and higher value added) and non strategic; high energy consumer, high value added consumers and low energy consumers (Eichhammer and Mannsbart, 1997; and United States Department of Energy, 1995). The problem with these definitions is that no define the criteria to classify between EISs and NEISs and these criteria could be determined arbitrary form.
[66] German energy tax law defines the EISs as the sectors where the cost of energy is above 3% of total costs. Moreover, to confirm this criterion applied cluster analysis using as criteria the energy intensity, the share of energy cost and energy consume by every industrial sector at the 2and 3-digit level.
[67] HEISs are identified in the results with (σ).

Table 3-1 Results of cluster analysis in German and Colombian industrial sectors

EISs at 3 digit level	
Germany	**Colombia**
156 Grain mill and starch products;	
171 Spinning of textile fibres;	171 Spinning of textile fibres;
172 Weaving of textiles;	172 Weaving of textiles;
173 Finishing of textiles;	173 Finishing of textiles[σ];
	174 Made-up textile articles;
	175 Other textiles n.e.c.;
202 Veneer sheets;	202 Veneer sheets[σ];
211 Pulp, paper and paperboard[σ];	211 Pulp, paper and paperboard;
241 Basic chemicals[σ];	241 Basic chemicals;
247 Man-made fibres;	
	251 Rubber products;
	252 Plastics products;
261 Glass and glass products[σ];	261 Glass and glass products[σ];
262 Non-structural non-refractory ceramic ware;	262 Non-structural non-refractory ceramic ware[σ];
263 Refractory ceramic products[σ];	263 Refractory ceramic products[σ];
264 Structural non-refractory clay and ceramic products[σ];	264 Structural non-refractory clay and ceramic products[σ];
265 Cement, lime and plaster[σ];	265 Cement, lime and plaster[σ];
266 Articles of concrete, cement and plaster;	266 Articles of concrete, cement and plaster;
267 Cutting, shaping and finishing of stone;	267 Cutting, shaping and finishing of stone;
268 Other non-metallic mineral products n.e.c.;	268 Other non-metallic mineral products n.e.c.;
271 Basic iron and steel[σ];	271 Basic iron and steel[σ];
274 Basic precious and non-ferrous metals;	274 Basic precious and non-ferrous metals.
275 Casting of metals.	
NEISs at 2 digit level	
Germany	**Colombia**
15 Manufacture of food products and beverages[σ];	15 Manufacture of food products and beverages[σ];
17 Manufacture of textiles[σ];	
18 Manufacture of wearing apparel; dressing and dyeing of fur;	18 Manufacture of wearing apparel; dressing and dyeing of fur;
19 Tanning and dressing leather; manufacture of luggage, handbags, saddler, and footwear;	19 Tanning and dressing leather; manufacture of luggage, handbags, saddler, and footwear;
20 Manufacture of wood and of products of wood and cork, except furniture[σ];	20 Manufacture of wood and of products of wood and cork, except furniture;
21 Manufacture of pulp, paper and paper products[σ];	21 Manufacture of pulp, paper and paper products[σ];
22 Publishing, printing and reproduction on record media[σ];	22 Publishing, printing and reproduction on record media;
24 Manufacture of chemicals and chemical products[σ];	24 Manufacture of chemicals and chemical products;
25 Manufacture of rubber and plastic[σ];	
27: Manufacture of basic metal[σ];	
28 Manufacture of fabricated metal products, except machinery and equipments[σ];	28 Manufacture of fabricated metal products, except machinery and equipments[σ];
29 Manufacture of machinery and equipment;	29 Manufacture of machinery and equipment;
31 Manufacture of electrical machinery and equipments;	31 Manufacture of electrical machinery and equipments;
32 Manufacture of radio, television and communication equipment apparatus;	32 Manufacture of radio, television and communication equipment apparatus;
33 Manufacture of medical, precision and optical instruments, watches and clocks;	33 Manufacture of medical, precision and optical instruments, watches and clocks[σ];
34 Manufacture of motor vehicles, trailers and semi-trailers;	34 Manufacture of motor vehicles, trailers and semi-trailers;
35 Manufacture of other transport equipment;	35 Manufacture of other transport equipment;
36 Manufacture of furniture; manufacturing n.e.c.	36 Manufacture of furniture; manufacturing n.e.c. [σ]

[σ] *(HEISs and HNEISs)*

The results of the cluster analysis show that the German manufacturing industry has fewer EISs and more NEISs than the Colombian industrial sector[68]. There are two main reasons for this. First, more energy-intensive industrial processes tend to move from developed to developing countries[69], which, as suggested by the pollution haven hypothesis, assumes that polluting industries will relocate to jurisdictions with less stringent environmental regulations (Liddle, 2001). Second, as economies develop beyond a certain point, they may move into a "post-industrial" phase in which services become relatively more important in contrast with manufacturing, while capital and labour become more important in comparison with raw materials and energy (Bell, 1999). Therefore, it is necessary to pay specific attention to the manufacturing sectors of developing countries in order to encourage the importance of energy efficiency improvement through adequate policies and instruments, such as financial incentives, information programs, technology diffusion, regulations, and standards, among others.

3.4.2 Results from the DEA analysis of EISs and NEISs

Table 3.2 provides average results for energy intensity from the DEA models for German and Colombian EISs and NEISs, and appendix 2 provides results for energy intensity from the DEA models for each manufacturing industry during the sample period in both countries. First, the table shows the traditional measures of energy efficiency by computing energy intensities. The average energy intensity of EISs in Germany and Colombia during this period was 0.0151 and 0.0359, respectively, implying that in order to produce 1€ worth of output, the German and Colombian EISs used, on average, about 0.015 and 0.035 TJ of energy, respectively. In Germany, the average energy intensity for the iron and steel (271), cement (265), ceramic products (264), chemicals (247), and paper (211) were higher than that for overall EISs, and in the case of grain mills (156), articles of concrete (266), and casting metals (275), the average energy intensity was lower. In the Colombian case, the average energy intensity for ceramic products (264), cement (265), ceramic ware (262), and cutting of stone (267) were higher than that for overall EISs, whereas for rubber and plastic products (251 and 252) and non-ferrous metals (274), it was lower.

[68] In Colombian manufacturing industry all textile sector, rubber and plastic products are energy intensive industries whereas in Germany are non energy intensive sectors. Several Colombian EISs are 3 times more intensive than German EISs (e.g., glass products and cement).

[69] During 1980 – 2001, the reduction of energy intensity in the G-7 was the shift of many heavy industrial processes to the developing countries and Latin America's electricity intensity increased 63% during this period reflecting the region's industrialization, electrification, and emphasis on heavy industries (EIA, 2004).

Table 3-2 Average results of energy intensity and DEA models in German and Colombian EISs (3-digit level) and NEISs (2 digit level)

Manufacturing Sector	1998	1999	2000	2001	2002	2003	2004	2005	Annual Average
Germany									
Energy intensity (E/Y = TJ/Tsd. €1998)									
EISs	0.0147	0.0152	0.0144	0.0147	0.0149	0.0160	0.0152	0.0154	0.0151
NEISs	0.0024	0.0025	0.0023	0.0024	0.0024	0.0025	0.0025	0.0024	0.0024
Radial technical efficiency (Model 1-θ)									
EISs	0.929	0.918	0.931	0.919	0.919	0.922	0.919	0.916	0.922
NEISs	0.871	0.856	0.816	0.839	0.822	0.827	0.805	0.800	0.830
Energy efficiency derived from the technical efficiency model (1-ε)									
EISs	0.903	0.891	0.907	0.900	0.917	0.903	0.907	0.910	0.905
NEISs	0.871	0.856	0.816	0.839	0.822	0.827	0.805	0.800	0.830
Energy efficiency based on energy input minimisation (model 2-β)									
EISs	0.680	0.723	0.720	0.711	0.763	0.729	0.756	0.735	0.727
NEISs	0.761	0.747	0.748	0.779	0.770	0.784	0.755	0.739	0.760
Cost efficiency (model 3-CE)									
EISs	0.831	0.813	0.666	0.645	0.648	0.648	0.639	0.635	0.691
NEISs	0.853	0.822	0.730	0.724	0.727	0.722	0.722	0.720	0.752
Energy efficiency based on cost minimisation (model 3-μ)									
EISs	1.03	0.80	0.85	0.84	0.83	0.82	0.90	0.89	0.87
NEISs	0.702	1.083	1.071	0.960	0.947	0.938	0.938	0.934	0.947
Patterns of efficiency indexes based on model 4 (ϕ)									
	98-99			04-05			Average		
	TC	TE	TFP	TC	TE	TFP	TC	TE	TFP
EIS	0.99	1.12	1.10	1	1.04	1.04	1	1.10	1.08
NEISs	0.96	1.12	1.08	1.01	1.01	1.02	0.98	1.05	1.05
Colombia									
Energy intensity (E/Y = TJ/Tsd. €1998)									
EISs	0.0324	0.0354	0.0354	0.0380	0.0378	0.0407	0.0359	0.0318	0.0359
NEISs	0.0033	0.0031	0.0038	0.0034	0.0030	0.0038	0.0034	0.0029	0.0033
Radial technical efficiency (Model 1-θ)									
EISs	0.770	0.810	0.830	0.843	0.848	0.838	0.828	0.888	0.832
NEISs	0.821	0.819	0.826	0.825	0.822	0.774	0.758	0.744	0.799
Energy efficiency derived from the technical efficiency (model 1-ε)									
EISs	0.770	0.804	0.824	0.843	0.848	0.838	0.828	0.884	0.830
NEISs	0.808	0.812	0.806	0.812	0.809	0.760	0.744	0.737	0.786
Energy efficiency based on energy input minimisation (model 2-β)									
EISs	0.554	0.660	0.656	0.609	0.617	0.626	0.633	0.693	0.631
NEISs	0.603	0.623	0.615	0.607	0.618	0.582	0.565	0.557	0.596
Cost efficiency (model 3-CE)									
EISs	0.643	0.601	0.608	0.671	0.634	0.589	0.562	0.571	0.610
NEISs	0.759	0.779	0.737	0.766	0.764	0.755	0.751	0.779	0.761
Energy efficiency based on cost minimisation (model 3-μ)									
EISs	0.88	1.07	1.07	1.09	1.03	1.01	0.84	0.87	0.98
NEISs	1.240	1.091	1.022	1.146	1.169	1.023	1.036	1.046	1.10
Patterns of efficiency indexes based on model 4 (ϕ)									
	98-99			04-05			Average		
	TC	TE	TFP	TC	TE	TFP	TC	TE	TFP
EIS	0.98	0.95	0.94	1.02	1.18	1.20	1.00	1.03	1.03
NEISs	0.97	1.07	1.04	1.09	1.20	1.28	1.03	1.13	1.11

The average energy intensity for German and Colombian NEISs was 0.0024 and 0.0033, respectively, indicating that in order to produce 1€ worth of output, NEISs in both countries used, on average, 0.0024 and 0.0033 of energy, respectively. In Germany, the average energy intensity for the manufacture of rubber and plastic products (25) and chemicals (24) were higher than that for overall NEISs, whereas for manufacture of electrical machinery (31) and motor vehicles (34), the average energy intensity was lower. In Colombian NEISs, the manufacture of other articles of paper (212) and furniture and other manufactured items (36) had higher average energy intensity than that for overall NEISs, while in the case of manufacture of communication equipment (32) and other transport equipment (35), this indicator was lower.

During the sample period in Germany, energy intensity remained almost constant in both sectors (EISs and NEISs), whereas in Colombia it increased between 1998 and 2003 and declined thereafter in both sectors[70]. Moreover, the gap between German and Colombian NEISs is lower than for EISs, indicating that the productivity process and production standards are probably similar for NEISs due to energy use being confined mainly to processes of physical conversion and motor drive in those sectors, and where the gap in technology is lower in comparison to other productive processes of EISs. Moreover, in some cases, energy is used primarily for space heating in buildings rather than for manufacturing processes (EIA, 2004).

The first measures in the DEA model are radial measures of technical efficiency obtained from model (1), in which the value of θ represents the maximum proportional contraction for all inputs (including energy) that could be applied without reducing output. For Germany and Colombia, the average efficiency during the sample period was 0.92 and 0.832 in EISs, respectively, and 0.83 and 0.79 in NEISs, respectively. These results imply that, on average, the EISs in both countries could have produced the observed output levels by consuming 8% and 17% less of all inputs, respectively, and, in the case of NEISs, 17% and 21% less, respectively.

In German EISs, three sectors – Grain mill (156), basic chemicals (241) and ceramic ware (262) - had higher technical efficiency than the overall EISs, whereas the finishing of textiles (173) and iron and steel (271) sectors had lower technical efficiency than EISs. When examining performance over time, we find variation in trends across individual sectors. During the sample period, the glass (261), iron and steel (271), and non-ferrous metals (274) sectors exhibited increased technical efficiency, whereas the textile sector (171, 172, and 173) and paper industry

[70] These results suggests that the energy efficiency performance in the manufacturing industry is dependent on economic factors and that energy intensity performance is more sensitive to economic and political changes in Colombian NEISs due to the fact that industrial output is so closely linked to economic growth and prosperity which concurs with results of Cotte (2007) in the Colombian case.

(211) had declining technical efficiency. In Colombian EISs, while basic chemicals (241), rubber products (251), cement (265), and non-ferrous metals (274) demonstrated 100% technical efficiency each year, sectors like spinning of textile (171), glass (261), and cutting of stone (267) could have reduced their input use proportionately by as much as 35% and still produced the given output level. Moreover, the majority of sectors exhibited increased technical efficiency, except for paper (211) and ceramic products (264).

In case of German NEISs, while publishing (22) and communication equipment (32) demonstrated 100% technical efficiency each year, sectors like wood (20) and leather (19) could have reduced their input use proportionately by as much 30% and still produced the given output level. For Colombian NEISs, chemical (24) and publishing (22) had higher technical efficiency than the overall NEISs, whereas wood (20) and leather (19) had lower technical efficiency than NEISs. In both countries, NEISs' declining technical efficiency indicates (especially in the Colombian case) that technology levels in this sector are moderate, and the potential to adopt new technologies is higher in comparison with developed countries, where the improvements in technical efficiency are highly dependent on employment behaviour and adequate application of production methods.

Next, by accounting for the slack associated with the constraint on energy in model (1), we can obtain measures of energy efficiency. The average energy efficiency for the German and Colombian EISs over the sample period was 0.905 and 0.830, respectively, ands for NEISs, it was 0.83 and 0.78, respectively; these results imply that, on average, if energy output was reduced by 10% and 17% for the German and Colombian EISs, respectively, and for NEISs by 17% and 22%, respectively, it would still be possible to produce the observed output levels without increasing any inputs. This measure of energy efficiency may indicate that all purchased energy is not necessarily used efficiently; rather, there is some wastage, especially in Colombian industry. NEISs in both countries have potential to improve energy efficiency.

Comparing across industries in both countries, the results demonstrate similar behaviour without slack adjustment. Furthermore, it's important to stand out, as technological development and economic stability allow for improvements in energy efficiency across time, as in the German case. Likewise, these results could point to approaches for understanding the relation between productivity and energy use in manufacturing industry. The results of model 1 reflect how several sectors experienced technical progress (because the technical efficiency measure is based on an inter-temporal frontier), particularly in the sectors with the highest energy intensity in both countries. Further, in Colombian EISs, these improvements are meaningful. Hence, these results show the potential of EISs to improve technical efficiency, especially in Colombia. This fact was mentioned in the study of IEA (2007), where it was suggested that the technical efficiency improvement potential for the whole manufacturing industry ranged from 18-26%, taking into account both process improvement and technological change; this is similar in NEISs, where, in both countries, the possibilities for improving energy efficiency are higher in comparison with EISs. Moreover, greater opportunities exist for significant technical efficiency improvements in developing countries that will help them meet their goals for energy efficiency improvement and sustainable development (UNF, 2008).

While the objective in model (1) is to conserve all inputs, the objective could also be to simply minimise energy use without increasing any other inputs or reducing output. The energy efficiency measured in this model was lower than that from model (1), because the optimal solution to this model allows for a limited substitution of other inputs for energy without requiring any additional inputs other than the observed amounts. The average energy efficiency of German and Colombian EISs over the 8-year sample period was 0.727 and 0.631, respectively and for NEISs was 0.76 and 0.59, respectively. In German EISs, we saw that the grain mill (156) and basic chemical (241) industries had energy efficiency of more than 90%, whereas finishing of textiles (173), non-ferrous metals (274), and cement (265) were the worst performers by this measure of energy efficiency. The Colombian case showed that rubber products (251), veneer sheets (202), and finishing of textiles (173) were the best performers by this measure of energy efficiency, whereas glass (261), cutting of stone (267), and other non-metallic products (268) had efficiency of less than 42%. However, in both countries, the great majority of manufacturing industries improved on this measure during the sample period, demonstrating that energy input is an important variable within the production structure and a key element in technology development[71].

German NEISs' results revealed that communication equipment (32) and the automotive industry (34) were the best performers by this measure or energy efficiency, whereas leather (19) and furniture and other manufactured items (36) had efficiency of less than 42%. For

[71] Any change in technology will have an impact on energy efficiency through the substitution of factors of production and goods (Birol and Keppler, 2000) and Technology innovations play a central role by enabling reductions in energy use, and such innovations change the amounts of various inputs (energy, material, labour) in the production function required to produce a given level of satisfaction (utility). Typically, technology innovations create opportunities to save energy, save other inputs, or increase utility (IAC, 2007).

Colombian NEISs, we saw that chemical (24) and the automotive industry had efficiency of more than 85%, whereas wood (20) and furniture and other manufactured items (36) were the worst performers. Moreover, in both countries, several NEISs declined on this measure during the sample period, indicating that energy savings for this sector are of secondary importance due to the fact that energy is a minor cost item in relation to labour, and the fact that capital is instead used in order to save on labour costs (Kander and Schön, 2005).

In the German case, the two measures of energy efficiency were similar in both sectors, indicating that energy efficiency improvement is necessary to achieve technical efficiency. On the other hand, in the Colombian case, we saw that the energy efficiency results in both sectors were lower than in the German case, meaning that in Colombia with an emerging and expanding industrial infrastructure have great potential to improve their energy efficiency. They also have a particular opportunity to mitigate GHG emissions while increasing their competitiveness by applying energy-efficient best practices, technologies, and innovations (UNIDO, 2008).

From an economic perspective, it is insufficient to simply achieve technical efficiency. To achieve cost efficiency, a firm needs also to be efficient in its allocation of inputs, given input prices. Over time, since prices of different inputs need not change at the same rate, a DMU would need to change input proportions in response to changes in relative prices in order to achieve minimum costs. Model (3) allows for the measurement of cost efficiency for a DMU. The cost efficiency measure ranged from an annual average of over 90% in the German EISs' case for grain mills (156), paper (211), and chemicals (241), and in NEISs' case for food (15), communication equipment (32), and the automotive industry (34). The measure reached about 50% in EISs' finishing textiles (173), cutting of stone (267), and casting metals (275) industries, and to about 60% in NEISs' metal products (28) industry, with an overall average across manufacturing industries of 69% in EISs and 75% in NEISs. For Colombian EISs, we saw that basic chemicals (241), iron and steel (271), and non-ferrous metals (274) had energy efficiency of more than 90%, which was also true in NEISs' case for food (15), chemicals (24), and the automotive industry (34). In EISs, the textiles (172 and 175), rubber products (251), and glass (264, 265 and 267) industries had energy efficiency of less than 50%, and, in NEISs, leather (19) and furniture and other manufacturing (36) had energy efficiency of less than 60%, with the average across manufacturing industries approximately 61% for EISs and 76% for NEISs.

Regarding cost minimising inputs, model (3) analysed input prices. The ratio of the optimal amount of energy (as obtained from the cost minimisation model) to the actual amount of energy used allows us to obtain a measure of energy efficiency (μ) based on cost minimisation. If the current input–output combination is allocatively inefficient, then cost minimisation would require changing input proportions, which implies input substitution (it is possible that the measure of energy efficiency (μ) is greater than, equal to, or less than the measured cost efficiency due to input substitution). In the German case, the average energy efficiency for EISs and NEISs over the entire sample period was 87% and 95%, respectively. When we examine the average for each sector, we find that, in EISs, grain mills (156), textiles (171 and 172), and chemicals (241 and 247) emerge as the most energy efficient manufacturing industries. The analogous NEISs' industries were food (15) and chemicals (24). For EISs, ceramic products (264) and cement (265) were the worst performers, while, for NEISs, furniture and other manufacturing (36) and metal products (27) were the worst performers. In Colombia, the average energy efficiencies overall for EISs and NEISs during the sample period were 98% and 110%, respectively. In EISs, basic chemicals (241) and iron and steel showed the greatest energy efficiency, while, for NEISs, food (15), chemicals (24), and the automotive industry showed the greatest energy efficiency. For EISs, ceramic products (264) and cement (265) were the worst performers, while, for NEISs, metal products and furniture and other manufacturing were the worst performers.

In German and Colombian EISs and NEISs, the results showed that when input prices were taken into consideration, the annual average energy efficiency across EISs was higher than the measured cost efficiency, suggesting that, for cost minimising over a set of inputs, industries should be conserving more of other inputs rather than energy. Furthermore, the overall average energy efficiency from this model was higher than that obtained from model (2). The measured energy efficiency from model (3) should be higher than that from model (2) only if the optimal solution to the cost minimisation model (based on input prices) calls for more energy consumption than at the optimal solution for model (2), where the model minimised energy input without increasing the amount of other inputs. In fact, for many manufacturing industries in both countries, the energy efficiency from this model exceeded 100%, meaning possibly that, in order to minimise costs, the manufacturing industries should use more energy than is actually being used, by substituting energy for other inputs[72].

[72] Nwaokoro (2003) found evidence of substitutability among inputs where workers, materials and energy are substitutes according to cost minimisation and Metcalf (2008) found that higher energy prices contributes to declines

In the German case, the three measures of energy efficiency were similar, indicating that energy efficiency improvement is necessarily an appropriate combination of technical efficiency and cost minimisation. On the other hand, in the Colombian case, we saw that the highest energy efficiency measured was from the cost minimisation model, suggesting that the relative price of energy in Colombian manufacturing industry does not reflect the real cost of using energy. As such, energy is the relatively cheaper input. Therefore, it is worthwhile to note that, in Germany, especially over the last years, energy prices have brought about energy efficiency improvement, whereas, in the Colombian case, energy prices have not generated the proper incentives to improve energy efficiency. Moreover, in both countries, energy efficiency based on cost minimisation was higher in NEISs, demonstrating that energy prices in this sector are not the key variable for improving energy efficiency. This is due to the low share of energy costs, where it is preferable to change other inputs instead of energy. Likewise, manufacturers and industry analysts say that the most important factor in determining whether or not to implement energy savings measures is price and cost of energy (Halpern et al., 2007), and this fact coincides with the results of model (3).

The efficiency index calculated using model (4) combines output, CO_2 emissions, non-energy inputs, and energy consumption by sources of the EISs and NEISs during the sample period. For German and Colombian EISs and NEISs, the TFP improved, indicating that the output increased; alternately, CO_2 emissions decreased during the sample period due to a positive contribution of technical progress, mainly by application of energy-efficient technologies or adoption of new technologies[73]. This upward improvement reflects the conscious efforts made by the industrial sectors in both countries to increase efficiency of energy consumption and production processes. However, in both sectors, technical efficiency was also important (i.e., the enhancement of their productivity), specifically the effective use of inputs and the adoption of new production methods[74]. Note that, in the German case, the results were higher in EISs than in NEISs, indicating that technical changes in NEISs possibly did not have energy efficiency improvement as their main aim. On the other hand, in the Colombian case, the results were just the opposite, meaning probably that NEISs had higher levels of technology than did EISs.

in energy intensity, primarily through improvements in energy efficiency and where the substitution among inputs become a key factor.

[73] In Colombian these results were mainly for the change of fuels in boilers from petrol products to natural gas during the sample period where the use of petrol products decreased 8% and the use of natural gas increased 6% in EISs.

[74] The reduction of GHG emissions in the manufacturing industry has direct relationship with the productivity due to increased production and product quality, improved maintenance, and operating cost, an improved working environment, among other benefits (Metz and Worrel, 2007), which is consistent with the results of the model 4 where manufacturing industries with the highest TFP achieved also decreased CO_2 emissions.

However, comparing the results from both countries shows that German manufacturing industry displayed higher values in indices than did Colombian manufacturing industry, which demonstrates that, in the Colombian case, the technology level is still moderate, and technological adoption will be much easier to achieve in the industrial sector. Moreover, restrictions on greenhouse gas emissions (GHG) are not feasible without significant productivity growth and a transfer of technologies from advanced to emerging countries (Ark, 2008)[75].

3.5 Analysing inter-industrial variations in energy efficiency development

To explain the observed variation in energy efficiency across EISs and NEISs in both countries over sample period, regression analysis was used to obtain results for technical efficiency (model 1-ε and model 2-β) and energy efficiency from the cost minimisation (model 3-μ) perspective. The three alternative measures of energy efficiency (model 1-ε, model 2-β, and model 3-μ) assessed in the previous section were defined as dependent variables in several regression models that included different evaluation parameters in order to determine the differences and factors that could have influenced the results for energy efficiency performance (see equation 5). The variables used in this study are as follows:

$$\Delta EE_i = \gamma_0 + \gamma_1 * VAGP + \gamma_2 * LAPRO + \gamma_3 * ENSI + \gamma_4 * ELE + \gamma_5 * KL + \gamma_6 * EC + \gamma_7 * INV + u \quad (5)$$

where:

$\Delta EE_i = The\ changes\ in\ energy\ efficiency\ \ (model\ 1-\varepsilon, model\ 2-\ \beta\ and\ model\ 3-\ \mu)$

- The manufacturing value added, *VAGP,* is a measurement of output, and this measure represents the contribution of manufacturing industry to GDP. The variable *VAGP* was measured as the share of value added in the total gross production for each manufacturing industry. Furthermore, energy saving technologies and increased energy efficiency may bolster growth in manufacturing value added (Soytas and Sari, 2007). We would expect a higher value on this variable to be associated positively with energy efficiency.
- The labour quality (in terms of labour productivity), is labelled *LAPRO* (i.e., manufacturing output per worker). For each manufacturing industry, the average annual labour productivity

[75] For instance, Germany to be leader in energy efficiency technology consider that he has responsibility to support the efforts to increase energy efficiency undertaken by emerging and developing countries in particular (BMWI, 2008).

(gross production per worker) over the sample period was used. We hypothesise that a higher quality labour force has a direct relationship with improvement in energy efficiency[76].

- The enterprise size variable, ENSI, has a direct relationship with capital and the potential investments in every manufacturing sector branch, and likewise these two elements are highly complementary with improvement in energy efficiency (Kander and Schön, 2007). The variable ENSI was measured as the share of gross production in medium and large enterprises for each manufacturing industrial sector, by year[77]. We expect higher levels of production in medium and large enterprises to be associated with greater energy efficiency because higher output in medium and large enterprises leads to higher levels of energy efficiency, which could explain the fact that the management and staff resources of small and medium enterprises (SMEs) are more constrained. In addition, they typically do not have dedicated energy or facilities managers (DEFRA, 2006).
- The share of electricity, *ELE,* in total energy (fuel) consumed by the manufacturing industrial sector during the study period is also analysed as a variable in evaluating differences in inter-fuel composition and the role of substitution fuels in the development of energy efficiency performance. Energy efficiency improvements in the manufacturing industry could be the result of a shift in the structure of energy sources from lower-end use of efficiency fuels like coal and petroleum products to greater-end use efficiency fuels like gas and electricity (UNEP, 1976). It expects that this variable will have more of an impact in Colombian EISs due to the fact that, during the sample period, Colombian EISs had an inter-fuel substitution (from petroleum products to natural gas in industrial boilers). Such inter-fuel substitution is low within German companies during sample period because these substitutions were carried out mainly in the 1980s and the beginning of the 1990s, and the effects of fuel substitutions are seen in the short run for aggregate energy efficiency performance (Söderholm 2000 and Tauchman, 2006). We expect higher electricity consumption to be associated with improvements in energy efficiency, especially in Colombian manufacturing industry.
- The capital input, *KL,* is measured by the capital-labour ratio. The average ratio over the sample period is used. In the last chapter, we provide evidence across industries regarding the substitutability/complementarity between energy and capital, and also between energy and labour. Therefore, this variable may have either a positive or negative coefficient.

[76] Gowdy (1992) demonstrated that the labour and energy productivity have a positive relationship and these two factors are key to improve productivity efficiency.
[77] This variable was calculated taking into account the categories established by German and Colombian statics office based in number of workers and output levels for every industrial sector.

- The change in energy costs, EC, is measured by indexing the annual energy cost in Euros to 1998 for each manufacturing industrial sector over the sample period. This variable could determine the relationship between the energy efficiency measure and changes in energy prices. We expect that the higher the energy costs or prices, the higher the energy efficiency.
- The investments, *INV,* are measured as the share of investments[78] in gross production. Several investments in the industrial sector have relationships with energy efficiency improvement. When these investments are assessed and implemented properly, the returns can be high and the technical risks relatively low. Such investments can help reduce energy consumption and may also have other positive effects, such as improved product quality. Benefits can also be gained through environmental improvements and through a demonstration effect on the business community (CEU, 2005). We expect a higher investment to be positively associated with energy efficiency.

The multiple regression for energy efficiency results (model 1-ε, and model 2-β) are estimated using the Tobit procedure, which is the appropriate method when the dependent variable is censored (the energy efficiency results in these models are censored because 1 is equal to the actual score whenever the actual score is <1, and if the score is $\geq$ 1, the efficiency is 1)[79]. On the other hand, the energy efficiency measure obtained from the cost minimisation model (μ) is estimated by an OLS procedure and the dependent variable here is not censored.

The results from the regression models are shown in tables 3.3a, 3.3b, and 3.3c. For each energy efficiency measure, an initial regression was run with all 7 explanatory variables. A second model was then run retaining only those variables that were significant at the 10% level or higher. As can be seen, the results are robust[80] across all three energy efficiency measures.

As expected, in Germany and Colombia, the ENSI variable had a positive influence on energy efficiency for EISs, implying that higher output in medium and large enterprises lead to higher energy efficiency, which could explain the fact that small and medium enterprises' (SMEs) management and staff resources are more constrained, and they typically do not have dedicated energy or facilities managers (DEFRA, 2006). Alternately, in the case of NEISs, this variable was not significant in both countries, meaning that the size of companies does not

[78] The investments include machinery and equipments, property and buildings.
[79] Mukherjee (2008) uses a similar model in the context of the Indian manufacturing sector.
[80] A model is robust when the statistical test (Log likelihood) has high value, the variables have expected sign and the majority of variables have high significance level.

greatly influence energy efficiency performance in this sector, probably because production processes and technology levels have similar features in both large enterprises and SMEs due to the specific requirements of products, such as machinery, computers and electronics, and transportation equipment.

Table 3-3a Results of Tobit regressions for explaining energy efficiency performance in German and Colombian EISs and NEISs (energy efficiency (ε) dependent variable)

Parameter	EISs					
	Germany-Colombia		Germany		Colombia	
	Estimate					
	(1)	(2)	(1)	(2)	(1)	(2)
Intercept	0.512*** (9.92)	0.574*** (12.67)	0.507*** (9.05)	0.655*** (12.28)	0.408*** (5.94)	0.458*** (7.78)
VAGP	0.043 (1.07)		0.137 (0.69)		0.215** (2.04)	0.179** (1.99)
LAPRO	0.0004*** (4.36)	0.0004*** (4.67)	0.0003*** (3.19)	0.0004*** (4.75)	0.002*** (5.52)	0.002*** (5.42)
ENSI	0.107*** (3.79)	0.119*** (4.20)	0.066** (2.25)	0.058** (2.02)	0.076** (2.14)	0.049** (2.04)
ELE	0.533*** (9.49)	0.538*** (8.36)	0.121 (1.39)		0.732*** (9.94)	0.728*** (9.83)
KL	0.004*** (5.86)	0.004*** (5.67)	-0.009 (1.45)		-0.0002 (0.128)	
EC	0.042** (2.38)	0.038** (2.33)	0.118*** (3.88)	0.136*** (4.14)	0.029* (1.64)	0.096** (1.96)
INV	0.045*** (2.75)	0.044*** (2.71)	0.077** (2.55)	0.079** (2.51)	0.017 (0.83)	
Log likelihood	259.65	256.85	190.59	176.85	124.17	123.10
Cross sections	39	39	19	19	20	20

Parameter	NEIs					
	Germany-Colombia		Germany		Colombia	
	Estimate					
	(1)	(2)	(1)	(2)	(1)	(2)
Intercept	0.130* (1.87)	0.138 (1.99)	0.243* (1.92)	-0.078 (0.93)	-0.055 (0.49)	0.029 (0.26)
VAGP	0.799*** (5.54)	0.801*** (5.69)	0.972*** (4.21)	1.467*** (7.97)	0.827*** (4.01)	0.771*** (3.91)
LAPRO	0.001*** (3.69)	0.001*** (6.25)	0.0016*** (4.45)	0.0021*** (8.18)	0.005*** (5.56)	0.006*** (8.79)
ENSI	0.374*** (6.70)	0.396*** (7.56)	0.001 (0.02)		0.301 (1.20)	
ELE	0.178** (2.45)	0.215** (2.47)	0.001 (0.19)		0.126* (1.76)	0.021 (1.23)
KL	-0.0009 (1.44)		-0.017 (0.54)		-0.0002 (0.33)	
EC	0.070* (1.83)	0.076** (2.10)	0.033* (1.66)	0.007 (1.60)	0.131** (2.57)	0.173*** (3.29)
INV	0.002 (0.059)		0.05 (0.89)		0.117 (0.65)	
Log likelihood	187.93	186.88	159.73	152.37	79.20	71.53
Cross sections	33	33	18	18	15	15

Figures in parentheses are z-statistic.
, **, * imply significance at the 10%, 5%, and 1% level, respectively.*

Table 3-3b: Results of Tobit regressions for explaining energy efficiency in German and Colombian EISs and NEISs (energy efficiency (β) dependent variable)

Parameter	EISs					
	Germany-Colombia		Germany		Colombia	
	Estimate					
	(1)	(2)	(1)	(2)	(1)	(2)
Intercept	0.165*** (2.82)	0.257*** (5.66)	-0.262** (2.68)	-0.098 (1.12)	0.092 (1.07)	0.111 (1.36)
VAGP	0.145 (1.43)		0.444 (1.28)		0.449*** (3.41)	0.410*** (3.80)
LAPRO	0.0004*** (3.14)	0.0005*** (4.93)	0.001*** (5.77)	0.001*** (5.36)	0.003*** (6.03)	0.002*** (9.82)
ENSI	0.164*** (3.91)	0.199*** (5.002)	0.320*** (6.25)	0.305*** (5.93)	0.001* (1.57)	0.008 (1.37)
ELE	0.813*** (9.81)	0.763*** (9.42)	0.232 (1.52)		1.078*** (11.72)	1.073*** (11.74)
KL	0.007*** (5.92)	0.006*** (5.40)	-0.021 (1.38)		-0.011 (0.17)	
EC	0.026* (1.67)	0.009* (1.68)	0.146*** (2.75)	0.214*** (4.01)	0.022* (1.65)	0.012* (1.95)
INV	0.037* (1.76)	0.060** (2.38)	0.101* (1.91)	0.223*** (4.61)	0.009 (0.35)	
Log likelihood	131.71	128.76	100.37	88.22	88.50	86.25
Cross sections	39	39	19	19	20	20

Parameter	NEIs					
	Germany-Colombia		Germany		Colombia	
	Estimate					
	(1)	(2)	(1)	(2)	(1)	(2)
Intercept	0.062 (0.84)	0.059 (0.79)	0.080 (0.53)	-0.241** (2.38)	-0.086 (0.79)	0.101*** (0.92)
VAGP	0.796*** (5.17)	0.784*** (5.24)	1.163*** (4.24)	1.703*** (7.75)	0.938*** (4.74)	0.552*** (2.86)
LAPRO	0.002*** (5.87)	0.002*** (10.32)	0.002*** (5.44)	0.002*** (9.61)	0.006*** (7.69)	0.005*** (8.15)
ENSI	0.295*** (4.95)	0.291*** (5.21)	0.133 (1.24)		0.23 (1.60)	
ELE	0.174** (2.51)	0.161** (2.52)	0.142 (1.63)		0.246** (2.51)	0.135* (1.77)
KL	-0.0004 (0.56)		-0.022 (1.31)		-0.0002 (0.258)	
EC	0.050* (1.74)	0.241* (1.76)	0.031* (1.71)	0.017 (1.61)	0.031* (1.67)	0.073* (1.68)
INV	0.013 (0.33)		0.026 (0.50)		0.618 (0.27)	
Log likelihood	169.93	169.73	133.57	122.57	84.59	74.45
Cross sections	33	33	18	18	15	15

Figures in parentheses are z-statistic.
, **, * imply significance at the 10%, 5%, and 1% level, respectively.*

Table 3-3c Results of OLS regressions for explaining energy efficiency in German and Colombian EISs and NEISs (energy efficiency (μ) dependent variable)

Parameter	EISs					
	Germany-Colombia		Germany		Colombia	
	Estimate					
	(1)	(2)	(1)	(2)	(1)	(2)
Intercept	1.129*** (3.50)	1.151*** (3.63)	-0.272* (1.52)	0.357** (2.19)	1.878 (1.27)	1.911 (1.30)
VAGP	0.345 (1.22)		0.423 (1.08)		0.831*** (3.82)	0.930*** (3.51)
LAPRO	0.0009*** (4.27)	0.0001*** (3.43)	0.0004*** (5.31)	0.001*** (4.43)	0.002*** (4.07)	0.002*** (4.08)
ENSI	0.050*** (3.47)	0.042*** (3.41)	0.284*** (3.52)	0.123*** (3.93)	0.206* (1.42)	0.008 (1.37)
ELE	0.075** (2.35)	0.063** (3.02)	0.372 (1.35)		0.415*** (4.29)	0.431*** (4.37)
KL	0.005* (1.63)	0.005* (1.77)	-0.015 (1.02)		-0.003 (0.38)	
EC	0.154** (2.30)	0.158** (2.45)	0.140*** (3.46)	0.215*** (4.15)	0.358* (1.74)	0.355* (1.77)
INV	0.076* (1.43)	0.070 (1.23)	0.167* (1.73)	0.070** (2.61)	0.006 (0.68)	
R^2	0.69	0.65	0.78	0.81	0.71	0.76
Durbin-Watson	1.69	1.69	1.75	1.66	1.72	1.70
F	2.44	2.07	8.83	4.21	2.87	4.06
Cross sections	39	39	19	19	20	20

Parameter	NEIs					
	Germany-Colombia		Germany		Colombia	
	Estimate					
	(1)	(2)	(1)	(2)	(1)	(2)
Intercept	1.696*** (9.99)	1.663*** (9.69)	1.087** (3.08)	0.706** (3.10)	1.296*** (4.55)	1.749*** (5.90)
VAGP	1.305*** (3.70)	1.478*** (4.26)	0.934*** (3.45)	0.965*** (4.94)	1.251*** (3.43)	1.020*** (3.86)
LAPRO	0.002*** (3.79)	0.003*** (7.11)	0.002*** (3.46)	0.001*** (4.72)	0.003*** (3.58)	0.005*** (3.99)
ENSI	1.015*** (7.44)	0.985*** (7.62)	0.503 (1.39)		0.195 (1.25)	
ELE	0.821** (2.17)	0.692* (1.67)	0.530 (1.30)		0.668** (2.61)	0.009 (1.37)
KL	-0.004 (1.05)		-0.038 (1.29)		-0.004 (1.24)	
EC	0.185* (1.78)	0.163* (1.81)	0.229* (1.84)	0.269* (2.15)	0.111* (1.66)	0.015 (1.18)
INV	0.192 (1.04)		0.010 (0.85)		0.544 (1.21)	
R^2	0.63	0.64	0.73	0.72	0.76	0.78
Durbin-watson	1.97	1.97	1.66	1.75	2.23	2.09
F	14.14	17.27	3.07	2.20	13.81	12.01
Cross sections	33	33	18	18	15	15

Figures in parentheses are t-statistic.
, **, * imply significance at the 10%, 5%, and 1% level, respectively.*

For both German and Colombian EISs and NEISs, the EC and LAPRO variables had significant influences on energy efficiency. EC had a positive influence on energy efficiency, meaning that a higher energy cost was associated with higher energy efficiency[81]. On the other hand, LAPRO had a positive coefficient, implying that sectors with higher quality of labour experience had higher energy efficiency. This suggests that growth in energy- and labour-productivity are complementary rather than substitutable; and industrial sectors that invest in new capital goods in order to expand or replace existing production facilities (or to increase labour productivity) simultaneously achieve energy efficiency improvements (Mulder and Groot, 2004). Also, the INV variable had a positive coefficient in both the German and Colombian industrial sectors. However, the results show that, in German EISs, these investments had direct relationships with energy efficiency improvements,[82] whereas in NEISs the investments probably did not have energy efficiency improvements as a main aim. Hence, energy savings in the NEISs are a side effect of investments in labour savings and technological changes in general. On the other hand, in Colombian manufacturing industry, the investment had a secondary effect of energy efficiency improvement because the industrial sector in developing countries likely prefers traditional investments like expansion of industrial plants or power generation. Furthermore, energy efficiency projects without large capital investments are often perceived as riskier and / or are too small to attract multilateral financial institution lending (UNIDO, 2007).

In German EISs, the LAPRO, ENSI, and EC variables were the variables most important to the energy efficiency performance, whereas in Colombia the inter-fuel substitution variable (ELE) was the most significant variable for EISs, indicating that inter-fuel substitution could be a variable that determines a country's development level. This is because a large degree of technical change and substitution fuels an increase in the use of higher quality energy and reduced use of lower quality energy, meaning that technical change has been 'embodied' in the fuels and their associated energy converters. These changes have increased energy efficiency in energy extraction processes, and have allowed an apparent 'decoupling' of energy use from economic output, and have thereby been major factors behind increasing energy efficiency in the production of output, especially in developed countries (Cleveland et al., 2000 and Fleay, 2005). The challenge is to achieve the use of higher quality energy, improve energy efficiency, and decrease CO_2 emissions in developing countries.

[81] An increase in prices over time leads to a decrease in energy intensity (Cornellie and Fankhauser, 2002).
[82] The energy intensive manufacturing sectors have already made significant investments to reduce energy use in Europe (IFIEC Europe, 2000).

In the case of NEISs, VAGP, LAPRO, and EC were the most significant variables predicting energy efficiency in both countries. The effect of capital input (KL) was not significant in the German and Colombian manufacturing industries, and the difference in the signs of the coefficients between countries suggests that this variable could be substitutable or complementary in the production framework.

In short, the results obtained from regression analyses are as follows:

In German and Colombian EISs, all variables had positive effects on energy efficiency performance. The main variables that determined energy efficiency performance were LAPRO, ENSI, ELE, and KL, whereas EC and INV showed lower significance levels and VAGP was not statistically significant. In contrast, for German and Colombian NEISs, all variables had positive effects except the KL variable. Energy efficiency performance in NEISs as determined, in order of importance, by VAGP, LAPRO, ENSI, ELE, and EC; the KL and INV variables were not statically significant.

These results could indicate that, for improvements in energy efficiency performance in the manufacturing industry, both economic and technical factors play important roles and, therefore, energy policy ought to mix economic and technical instruments to achieve increases in energy efficiency and decreases in CO_2 emissions. By the same logic, policy should recognise that NEISs require special attention to encourage the energy efficiency.

In German EISs, all variables had positive effects on energy efficiency performance except the KL variable. In order of importance, LAPRO, EC, INV, and ENSI were the variables with the highest statically significant effects on energy efficiency performance, whereas the VAGP, ELE, and KL variables did have not statistically significant effects. In Colombian EISs, the sign of variables was the same as in German EISs. However, the variables with the most statically significant effects, in order of importance, were LAPRO, ELE, VAGP, ENSI, and EC, whereas KL and INV did not have statically significant effects on energy efficiency performance.

These results demonstrate that, in the German EISs, the main factor behind improvement in energy efficiency is the economic factor, whereas in Colombian EISs the technical factor is the key strategy to improve energy efficiency. This is due to the technological differences between developed and developing countries. Therefore, it is important to design energy policies with the participation of both developed and developing countries, policies that seek to generate possibilities for technology transfer in order to improve energy efficiency in developing countries.

In German NEISs, the signs on variables were the same as for EISs. However, VAGP and LAPRO were the most statically significant variables, whereas the other variables did not show statically significant effects on energy efficiency performance. Likewise, in Colombian NEISs, the signs of coefficients were the same as for EISs. Nevertheless, in addition to VAGP and LAPRO, ELE, and EC also had statically significant effects on energy efficiency performance, whereas the ENSI, KL, and INV variables did not have statically significant effects.

Hence, these results show that, for NEISs in both countries, the economic variables like investments or energy costs have not influenced energy efficiency performance, probably because energy consumption is lower than other inputs in terms of production costs. Therefore, NEISs do not see energy efficiency as a strategy to improve general productive efficiency.

Finally, we analysed the relationship between the traditional measure of energy efficiency (energy intensity), energy efficiency scores obtained from DEA models, and emissions intensity in order to determine whether the measures from DEA models are an adequate approach for measuring energy efficiency. The results are shown in the table 3.4. As can be seen, the results are robust for the majority of energy efficiency measures in both countries. As expected, the correlation between energy intensity and the four energy efficiency measures are negative and significant, implying that the measure of energy efficiency from DEA models is an alternative for assessing energy use in the industrial sector. This is because this method allows analyses at different levels of aggregation and analyses of energy efficiency performance from different approaches like technical efficiency, cost efficiency, and the effects of energy mix in CO_2 emissions. These analyses take into account the role of input substitutions and the ability of DEA analysis to assess the energy efficiency indices considering several variables and models, which cannot be evaluated with a traditional measure of energy intensity.

Moreover, the correlation between energy intensity and emissions intensity was positive and significant, indicating that higher energy intensity is associated with higher emissions intensity. These results suggest that cost-effective measures for energy efficiency are those with the quickest and the most efficient means of reducing energy demand, as well as those that increase energy security in order to reduce green house gas emissions. This is in line with the climate change objectives, while also enhancing the competitiveness of businesses, making it a fundamental strategy for developing countries (CEU, 2005 and Figueres and Bosi, 2006).

Table 3-4 Correlation between energy intensity, emissions intensity and energy efficiency based on DEA models

	Correlation of energy intensity with emissions intensity	Correlation of energy intensity with ε	Correlation of energy intensity with β	Correlation of energy intensity with μ	Correlation of energy intensity with TFP
			Germany		
EISs	0.8282**	-0.1609*	-0.1534	-0.4934**	-0.1604*
NEISs	0.8782**	-0.3476**	-0.4020**	-0.056	-0.0774
			Colombia		
EISs	0.2933**	-0.5915**	-0.5092**	-0.6260**	-0.085
NEISs	0.9492**	-0.1051	-0.1479	-0.3039**	-0.1402

**, ** imply significance at the 5%, and 1% level, respectively.*

3.6 Conclusions

This chapter approaches the measurement of energy efficiency from a production theoretic framework and uses DEA to measure energy efficiency for German and Colombian EISs and NEISs over the period between 1998 and 2005. Four measures of energy efficiency were estimated (Technical efficiency (model 1-ε), energy input minimisation (model 2-β), cost minimisation (model 3-μ) and Patterns of efficiency indexes (model 4-ϕ). The appropriate measure depends on what policy objective is at stake. The first two measures are useful when the objective of the analysis is that of energy conservation and reduction in energy-related environmental degradation. The third measure is appropriate from the economic objective of cost minimisation and maintaining low output prices. The fourth measure is designed for the study of patterns of energy efficiency performance in terms of energy consumption (by source) and CO_2 emissions.

During the sample period in Germany, energy intensity remained almost constant in both sectors, whereas in Colombia it increased between 1998 and 2003 and declined thereafter in both sectors. Moreover, the gap between German and Colombian NEISs is lower than for EISs, indicating that the productivity process and production standards are probably similar for NEISs due to energy use being confined mainly to processes of physical conversion and motor drive in those sectors, and where the gap in technology is lower in comparison to other productive processes of EISs.

In the German case, the two measures of energy efficiency from model 1 and 2 were similar in both sectors, indicating that energy efficiency improvement is necessary to achieve technical efficiency. On the other hand, in the Colombian case, we saw that the energy efficiency results in both sectors were lower than in the German case, meaning that developing countries with an emerging and expanding industrial infrastructure have a great potential to improve their energy efficiency. Moreover, the results also demonstrated that energy input is an important variable within the production structure and a key element in technology development.

In German and Colombian EISs and NEISs, the results showed that when input prices (model 3) were taken into consideration, the annual average energy efficiency across sectors was higher than the measured cost efficiency, suggesting that, for cost minimising over a set of inputs, manufacturing industries should be conserving more of other inputs rather than energy. Moreover, for many manufacturing industries in both countries, the energy efficiency from this model exceeded 100%, meaning possibly that, in order to minimise costs, the industrial sector should use more energy than is actually being used, by substituting energy for other inputs. Moreover, in both countries, energy efficiency based on cost minimisation was higher in NEISs, demonstrating that energy prices in this sector are not the key variable for improving energy efficiency. This is due to the low share of energy costs, where it is preferable to change other inputs instead of energy.

The efficiency index calculated using the model (4) showed that for German and Colombian EISs and NEISs, the total factor of productivity change (TFP) improved, indicating that the output increased; alternately, CO_2 emissions decreased during the sample period due to a positive contribution of technical progress, mainly by application of energy-efficient technologies or adoption of new technologies. This upward improvement reflects the conscious efforts made by the manufacturing industry in both countries to increase efficiency of energy consumption and production processes. However, in both sectors, technical efficiency was also important (i.e., the enhancement of their productivity), specifically the effective use of inputs and the adoption of new production methods.

A second-stage regression analysis revealed that, for German EISs, energy costs and investments have played a significant role in energy efficiency performance, whereas in Colombian EISs, the inter-fuel substitution was the most significant variable behind improvements in energy efficiency performance and decreases in CO_2 emissions. In German and Colombian NEISs, labour productivity and investments were fundamental predictors of energy efficiency. Capital input variables have not played a significant role in energy efficiency performance in the manufacturing sector of either country.

We conclude the following for EISs: I) Energy costs, labour productivity and company size showed positive and significant influences on energy efficiency. II) The value added and electricity variables had positive influences, and these variables were more significant in Colombian EISs than in German EISs, whereas the investment variable was more significant in German EISs. III) There was evidence that the relationship between capital – energy and labour – energy can be substitutable or complementary, because contrary signs were found for German and Colombian EISs.

We conclude the following for NEISs: I) Energy costs, labour productivity and value added showed a positive and significant influence on energy efficiency. II) We could not identify a significant influence of the enterprise size, electricity, capital input, and investment variables on energy efficiency (the coefficients were statically insignificant).

The results of the company size variable in EISs implies that higher output in medium and large enterprises lead to higher energy efficiency, which could explain the fact that small and medium enterprises' (SMEs) management and staff resources are more constrained, and they typically do not have dedicated energy or facilities managers. Alternately, in the case of NEISs, this variable was not significant in both countries, meaning that the size of companies does not greatly influence energy efficiency performance in this sector, probably because production processes and technology levels have similar features in both large enterprises and SMEs.

The results of labour productivity imply that sectors with higher quality of labour experience had higher energy efficiency. This suggests that growth in energy- and labour-productivity are complementary rather than substitutable; and industrial sectors that invest in new capital goods in order to expand or replace existing production facilities (or to increase labour productivity) simultaneously achieve energy efficiency improvements.

The results of investment variable showed that, in German EISs, these investments had direct relationships with energy efficiency improvements, whereas in NEISs the investments probably did not have energy efficiency improvements as a main aim. Hence, energy savings in the

NEISs are a side effect of investments in labour savings and technological changes in general. On the other hand, in Colombian manufacturing industry, the investment had a secondary effect of energy efficiency improvement because the industrial sector in developing countries likely prefers traditional investments like expansion of industrial plants or power generation.

The results of the inter-fuel substitution variable (ELE) indicated that inter-fuel substitution could be a variable that determines a country’s development level. This is because a large degree of technical change and substitution fuels an increase in the use of higher quality energy and reduced use of lower quality energy, meaning that technical change has been 'embodied' in the fuels and their associated energy converters. The challenge is to achieve the use of higher quality energy, improve energy efficiency, and decrease CO_2 emissions in developing countries.

These results also demonstrated that, in the EISs of developed countries, the main factor behind improvement in energy efficiency is the economic factor, whereas in developing countries the technical factor is the key strategy to improve energy efficiency. This is due to the technological differences between developed and developing countries.

Moreover, the results of the DEA models showed a significant correlation with the traditional energy efficiency measure, indicating that the energy efficiency measured through DEA could be complementary to energy intensity in analyses of other key elements of energy efficiency performance in the industrial sector. Finally, the correlation of energy intensity with emissions intensity ilustrates that energy efficiency is one of the quickest and the most efficient strategies for reducing energy demand and CO_2 emissions.

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Appendix

Appendix 1: Summary of the main variables used for German and Colombian industrial sectors

Variable	Main sources
Germany	
Desirable output – Gross value of production in the industrial sector	Destatis (GENESIS-Table: 42251-0002)
Labour – Total number of persons employed	
Materials – expenditure on materials	
Energy – Expenditure on energy	
Capital – stock by taking the value of fixed capital	Destatis (Table: 3.2.16)
Value added – the share of value added in the total gross production (%)	Destatis (GENESIS-Table: 42251-0004)
Investments- the share of investments in gross production (%)	Destatis (GENESIS-Table: 42231)
Energy consumption (TJ)	Destatis Chapter 5-Table: 5.2.2.1-5.3.11
Electricity – the share of electricity in total energy consumed (%)	
Energy sources (electricity, natural gas, petroleum products, and other in TJ)	Destatis Chapter 5 – Table 5.2
CO_2 emissions - (t carbon eq.) IPCC carbon emission factors: Natural gas 15.3 tC/TJ, petroleum products: 20.1 tC/TJ, Other fuel: 22.9, and electricity according to Federal Environment Agency (2007)	Destatis Chapter 5 and author's calculations
Labour productivity – gross production per worker	Destatis (Table: 3.2.16, 42251)
KL- the capital-labour ratio	
Enterprise size – the share of gross production in medium and large enterprises for each industrial sector (%)	Destatis (Serie 4 – Vol. 4.3)
Colombia	
Desirable output - Gross value of production in the industrial sector	DANE (Table: 3.1)
Labour - Total number of persons employed	
Materials - expenditure on materials	
Energy - Expenditure on energy	DANE (Table: 5.3)
Capital - stock by taking the value of fixed capital	DANE (Table: 3.1)
Value added - the share of value added in the total gross production (%)	
Investments- the share of investments in gross production (%)	DANE (Table: 5.5)
Energy consumption (TJ)	UPME (Energy balance)
Electricity – the share of electricity in total energy consumed (%)	
Energy sources (electricity, natural gas, petroleum products, and other in TJ)	
CO_2 emissions - (t carbon eq.) IPCC carbon emission factors: Natural gas 15.3 tC/TJ, petroleum products: 19.9 tC/TJ, Other fuel: 22.3, and electricity according to Resolution 181401/2004.	UPME (Energy balance) and author's calculations
Labour productivity - gross production per worker	DANE (Table: 3.1, 5.3) and author's calculations
KL- the capital-labour ratio	
Enterprise size - the share of gross production in medium and large enterprises for each industrial sector (%)	DANE (Table: 3.2)

Appendix 2: Results of energy intensity and DEA models for EISs and NEISs

Table 1 Energy intensity in German and Colombian EISs at 3-digit level

Manufacturing Sector	E/Y 1998	E/Y 1999	E/Y 2000	E/Y 2001	E/Y 2002	E/Y 2003	E/Y 2004	E/Y 2005	Annual Average
Germany									
156 GMS	0.0062	0.0060	0.0057	0.0058	0.0057	0.0058	0.0060	0.0062	0.0059
171 STF	0.0067	0.0082	0.0073	0.0079	0.0080	0.0077	0.0074	0.0083	0.0077
172 WT	0.0052	0.0055	0.0052	0.0052	0.0060	0.0068	0.0071	0.0076	0.0061
173 FT	0.0116	0.0113	0.0130	0.0135	0.0129	0.0163	0.0169	0.0181	0.0142
202 VS	0.0076	0.0076	0.0079	0.0089	0.0084	0.0092	0.0087	0.0085	0.0084
211 PPP	0.0218	0.0228	0.0196	0.0205	0.0209	0.0219	0.0237	0.0248	0.0220
241 BC	0.0227	0.0212	0.0194	0.0193	0.0204	0.0209	0.0197	0.0193	0.0204
247 MMF	0.0186	0.0223	0.0186	0.0184	0.0229	0.0250	0.0252	0.0265	0.0222
261 GP	0.0138	0.0131	0.0117	0.0118	0.0122	0.0127	0.0093	0.0096	0.0118
262 NCW	0.0086	0.0086	0.0084	0.0088	0.0080	0.0085	0.0093	0.0079	0.0085
263 RCP	0.0183	0.0195	0.0212	0.0246	0.0223	0.0236	0.0207	0.0232	0.0217
264 CCP	0.0273	0.0257	0.0287	0.0308	0.0287	0.0311	0.0280	0.0282	0.0286
265 CLP	0.0367	0.0356	0.0337	0.0320	0.0354	0.0411	0.0384	0.0363	0.0361
266 ACC	0.0065	0.0063	0.0067	0.0067	0.0069	0.0074	0.0073	0.0081	0.0070
267 CSS	0.0047	0.0069	0.0057	0.0053	0.0062	0.0070	0.0070	0.0097	0.0066
268 ONM	0.0082	0.0088	0.0084	0.0079	0.0084	0.0078	0.0068	0.0094	0.0082
271 BIS	0.0337	0.0378	0.0343	0.0324	0.0336	0.0333	0.0293	0.0246	0.0324
274 NFM	0.0126	0.0130	0.0104	0.0106	0.0100	0.0107	0.0104	0.0098	0.0109
275 CM	0.0080	0.0087	0.0081	0.0079	0.0071	0.0073	0.0072	0.0069	0.0076
Average Total EISs	0.0147	0.0152	0.0144	0.0147	0.0149	0.0160	0.0152	0.0154	0.0151
Colombia									
171 STF	0.0272	0.0266	0.0194	0.0188	0.0229	0.0244	0.0226	0.0216	0.0229
172 WT	0.0201	0.0200	0.0147	0.0130	0.0168	0.0169	0.0161	0.0148	0.0166
173 FT	0.0106	0.0212	0.0140	0.0153	0.0156	0.0146	0.0114	0.0116	0.0143
174 MTA	0.0086	0.0066	0.0055	0.0054	0.0062	0.0068	0.0066	0.0057	0.0064
175 OT	0.0073	0.0123	0.0065	0.0062	0.0078	0.0090	0.0082	0.0068	0.0080
202 VS	0.0105	0.0106	0.0106	0.0117	0.0141	0.0162	0.0134	0.0127	0.0125
211 PPP	0.0192	0.0200	0.0214	0.0208	0.0239	0.0237	0.0213	0.0196	0.0212
241 BC	0.0209	0.0213	0.0205	0.0237	0.0260	0.0292	0.0247	0.0212	0.0234
251 RP	0.0031	0.0028	0.0024	0.0026	0.0033	0.0042	0.0038	0.0032	0.0032
252 PP	0.0036	0.0033	0.0028	0.0033	0.0043	0.0055	0.0049	0.0037	0.0039
261 GP	0.0973	0.1047	0.1097	0.1077	0.1166	0.1297	0.1209	0.0994	0.1108
262 NCW	0.0699	0.0753	0.0788	0.0834	0.0739	0.0830	0.0759	0.0652	0.0757
263 RCP	0.0441	0.0554	0.0579	0.0658	0.0681	0.0691	0.0562	0.0343	0.0564
264 CCP	0.0987	0.1062	0.1113	0.1146	0.1126	0.1238	0.1126	0.0874	0.1084
265 CLP	0.0606	0.0660	0.0699	0.0785	0.0852	0.0899	0.0820	0.1055	0.0797
266 ACC	0.0101	0.0109	0.0116	0.0123	0.0136	0.0149	0.0138	0.0121	0.0124
267 CSS	0.0682	0.0734	0.0768	0.1058	0.0698	0.0760	0.0594	0.0544	0.0730
268 ONM	0.0328	0.0353	0.0369	0.0354	0.0397	0.0464	0.0430	0.0384	0.0385
271 BIS	0.0293	0.0304	0.0314	0.0310	0.0319	0.0279	0.0191	0.0158	0.0271
274 NFM	0.0051	0.0053	0.0054	0.0049	0.0036	0.0027	0.0028	0.0028	0.0041
Average Total EISs	0.0324	0.0354	0.0354	0.0380	0.0378	0.0407	0.0359	0.0318	0.0359

Energy intensity (TJ / Tsd. €1998)

Note: GMS: 156 Grain mill and starch products; STF: 171 Spinning of textile fibres; WT: 172 Weaving of textiles; FT: 173 Finishing of textiles; MTA: 174 Made-up textile articles; OT: 175 Other textiles n.e.c. VS: 202 Veneer sheets; PPP: 211 Pulp, paper and paperboard; BC: 241 Basic chemicals; MMF: 247 Man-made fibres; RP: 251 Rubber products; PP: 252 Plastics products GP: 261 Glass and glass products; NCW: 262 Non-structural non-refractory ceramic ware; RCP: 263 Refractory ceramic products; CCP: 264 Structural non-refractory clay and ceramic products; CLP: 265 Cement, lime and plaster; ACC: 266 Articles of concrete, cement and plaster; CSS: 267 Cutting, shaping and finishing of stone; ONM: 268 Other non-metallic mineral products n.e.c.; BIS: 271 Basic iron and steel; NFM: 274 Basic precious and non-ferrous metals; CM: 275 Casting of metals

Table 2 Energy intensity in German and Colombian NEISs at 2-digit level

Manufacturing Sector	E/Y 1998	E/Y 1999	E/Y 2000	E/Y 2001	E/Y 2002	E/Y 2003	E/Y 2004	E/Y 2005	Annual Average
Germany									
15 Food	0.0030	0.0030	0.0029	0.0029	0.0029	0.0031	0.0031	0.0031	0.0030
17 Textile	0.0041	0.0040	0.0039	0.0040	0.0040	0.0044	0.0047	0.0046	0.0042
18 MWA	0.0013	0.0013	0.0014	0.0014	0.0014	0.0015	0.0014	0.0015	0.0014
19 Leather	0.0020	0.0020	0.0020	0.0020	0.0020	0.0021	0.0021	0.0022	0.0020
20 Wood	0.0030	0.0030	0.0030	0.0030	0.0028	0.0028	0.0027	0.0029	0.0029
21 Paper	0.0020	0.0019	0.0018	0.0019	0.0019	0.0020	0.0021	0.0022	0.0020
22 Publishing	0.0023	0.0022	0.0022	0.0023	0.0023	0.0024	0.0023	0.0023	0.0023
24 Chemical	0.0044	0.0055	0.0049	0.0051	0.0053	0.0048	0.0048	0.0045	0.0049
25 R&P	0.0038	0.0038	0.0038	0.0038	0.0037	0.0038	0.0040	0.0038	0.0038
27 MBM	0.0052	0.0064	0.0060	0.0060	0.0060	0.0067	0.0056	0.0045	0.0058
28 MP	0.0026	0.0025	0.0024	0.0025	0.0026	0.0029	0.0027	0.0026	0.0026
29 M&E	0.0012	0.0012	0.0011	0.0011	0.0011	0.0012	0.0012	0.0012	0.0012
31 EM&E	0.0010	0.0009	0.0009	0.0009	0.0009	0.0011	0.0010	0.0010	0.0010
32 R&TV	0.0013	0.0010	0.0008	0.0009	0.0009	0.0009	0.0009	0.0009	0.0010
33 MPI	0.0014	0.0013	0.0012	0.0012	0.0012	0.0012	0.0013	0.0012	0.0013
34 MVT	0.0011	0.0010	0.0009	0.0009	0.0009	0.0009	0.0010	0.0009	0.0010
35 OTE	0.0016	0.0015	0.0014	0.0013	0.0014	0.0014	0.0015	0.0013	0.0014
36 F&O	0.0018	0.0018	0.0017	0.0020	0.0019	0.0021	0.0020	0.0021	0.0019
Average Total NEISs	0.0024	0.0025	0.0023	0.0024	0.0024	0.0025	0.0025	0.0024	**0.0024**
Colombia									
15 Food	0.0054	0.0054	0.0047	0.0045	0.0051	0.0064	0.0058	0.0048	0.0053
18 MWA	0.0024	0.0022	0.0022	0.0020	0.0022	0.0025	0.0023	0.0019	0.0022
19 Leather	0.0039	0.0034	0.0031	0.0028	0.0035	0.0041	0.0040	0.0032	0.0035
20 Wood	0.0021	0.0021	0.0021	0.0026	0.0031	0.0056	0.0038	0.0031	0.0031
21 Paper	0.0044	0.0045	0.0195	0.0183	0.0053	0.0091	0.0089	0.0079	0.0097
22 Publishing	0.0027	0.0028	0.0034	0.0028	0.0035	0.0033	0.0030	0.0027	0.0030
24 Chemical	0.0035	0.0036	0.0034	0.0048	0.0054	0.0059	0.0057	0.0053	0.0047
28 MP	0.0039	0.0033	0.0025	0.0023	0.0027	0.0030	0.0028	0.0020	0.0028
29 M&E	0.0025	0.0021	0.0016	0.0014	0.0016	0.0018	0.0015	0.0014	0.0017
31 EM&E	0.0029	0.0024	0.0019	0.0016	0.0019	0.0023	0.0020	0.0015	0.0021
32 R&TV	0.0010	0.0009	0.0008	0.0010	0.0012	0.0017	0.0012	0.0010	0.0011
33 MPI	0.0019	0.0017	0.0015	0.0015	0.0021	0.0026	0.0025	0.0021	0.0020
34 MVT	0.0031	0.0040	0.0025	0.0016	0.0021	0.0027	0.0023	0.0021	0.0025
35 OTE	0.0005	0.0005	0.0004	0.0005	0.0005	0.0007	0.0005	0.0003	0.0005
36 F&O	0.0087	0.0081	0.0071	0.0036	0.0044	0.0052	0.0048	0.0037	0.0057
Average Total NEISs	0.0033	0.0031	0.0038	0.0034	0.0030	0.0038	0.0034	0.0029	**0.0033**

Energy intensity (TJ / Tsd. €1998)

Note: Food: 15 Manufacture of food products and beverages (In German case does not include grain mill and starch products); Textile: 17 Manufacture of textiles (In German case only includes 174 Made-up textile articles and 175 Other textiles n.e.c.); MWA: 18 Manufacture of wearing apparel; dressing and dyeing of fur; Leather: 19 Tanning and dressing leather; manufacture of luggage, handbags, saddler, and footwear; Wood: 20 Manufacture of wood and of products of wood and cork, except furniture (In both countries do not include 202 Veneer sheets); Paper: 21 Manufacture of pulp, paper and paper products (In both countries only include 212 other articles of paper and paperboard); Publishing: 22 Publishing, printing and reproduction on record media; Chemical: 24 Manufacture of chemicals and chemical products (In both countries do not include 241 basic chemicals and 247 man-made fibres); R&P: 25 Manufacture of rubber and plastic; MBM: 27: Manufacture of basic metal (In Germany only includes 272 tubes and 273 Other first processing of iron and steel); MP: 28 Manufacture of fabricated metal products, except machinery and equipments; M&E: 29 Manufacture of machinery and equipment; EM&E: 31 Manufacture of electrical machinery and equipments; R&TV: 32 Manufacture of radio, television and communication equipment apparatus; MPI: 33 Manufacture of medical, precision and optical instruments, watches and clocks; MVT: 34 Manufacture of motor vehicles, trailers and semi-trailers; OTE: 35 Manufacture of other transport equipment; F&O: 36 Manufacture of furniture; manufacturing n.e.c

Table 3a Radial technical efficiency (model 1-θ) EISs

Manufacturing Sector	θ 1998	θ 1999	θ 2000	θ 2001	θ 2002	θ 2003	θ 2004	θ 2005	Annual Average
Germany									
156 GMS	1	1	1	1	1	1	1	1	1
171 STF	0.853	0.776	0.858	0.833	0.849	0.852	0.868	0.836	0.841
172 WT	1	1	1	1	0.979	0.953	0.922	0.894	0.969
173 FT	0.751	0.721	0.719	0.694	0.684	0.694	0.677	0.693	0.704
202 VS	0.888	0.899	0.889	0.85	0.875	0.865	0.891	0.92	0.885
211 PPP	0.988	0.930	0.948	0.913	0.975	0.958	0.917	0.766	0.924
241 BC	1	1	1	1	1	1	1	1	1
247 MMF	1	0.94	1	1	0.889	0.838	0.782	0.740	0.899
261 GP	0.852	0.879	0.884	0.873	0.874	0.884	0.917	0.921	0.885
262 NCW	1	1	1	1	1	1	1	1	1
263 RCP	1	1	1	0.811	1	0.912	1	1	0.965
264 CCP	1	1	1	0.984	1	1	0.993	0.986	0.995
265 CLP	0.968	1	1	1	1	0.936	1	1	0.988
266 ACC	1	1	1	1	1	1	0.990	1	0.999
267 CSS	1	1	1	1	1	1	1	0.916	0.990
268 ONM	1	1	1	1	1	1	1	0.981	0.998
271 BIS	0.856	0.734	0.753	0.779	0.775	0.822	0.849	0.937	0.813
274 NFM	0.922	0.977	1	1	1	1	0.998	1	0.987
275 CM	0.887	0.868	0.900	0.904	0.962	0.986	0.952	1	0.932
Average Total EISs	0.929	0.918	0.931	0.919	0.919	0.922	0.919	0.916	**0.922**
Colombia									
171 STF	0.510	0.530	0.651	0.657	0.664	0.68	0.626	0.631	0.619
172 WT	0.554	0.579	0.709	0.751	0.762	0.767	0.718	0.785	0.703
173 FT	1	1	1	1	1	1	1	1	1
174 MTA	0.666	0.84	0.896	0.952	0.934	0.942	0.916	0.957	0.888
175 OT	0.77	0.48	0.817	0.878	0.824	0.831	0.822	0.923	0.793
202 VS	0.906	1	1	1	1	1	1	1	0.988
211 PPP	0.89	0.927	0.911	0.955	0.962	0.866	0.786	0.763	0.883
241 BC	1	1	1	1	1	1	1	1	1
251 RP	1	1	1	1	1	1	1	1	1
252 PP	1	0.956	0.958	0.974	0.895	0.894	0.916	0.988	0.948
261 GP	0.514	0.54	0.542	0.589	0.578	0.539	0.517	0.714	0.567
262 NCW	0.32	0.809	0.782	0.662	0.76	0.746	0.727	0.927	0.717
263 RCP	0.543	0.718	0.637	0.643	0.683	0.658	0.683	0.799	0.671
264 CCP	1	0.631	0.631	0.648	0.645	0.632	0.668	0.946	0.725
265 CLP	1	1	1	1	1	1	1	1	1
266 ACC	0.71	0.915	0.900	0.949	0.888	0.881	0.903	0.858	0.876
267 CSS	0.294	0.605	0.518	0.501	0.643	0.625	0.629	0.77	0.573
268 ONM	0.718	0.720	0.711	0.755	0.724	0.695	0.654	0.690	0.708
271 BIS	1	0.947	0.944	0.949	1	1	1	1	0.980
274 NFM	1	1	1	1	1	1	1	1	1
Average Total EISs	0.770	0.810	0.830	0.843	0.848	0.838	0.828	0.888	**0.832**

Table 3b Energy efficiency derived from the technical efficiency model (1-ε) EISs

Manufacturing Sector	ε 1998	ε 1999	ε 2000	ε 2001	ε 2002	ε 2003	ε 2004	ε 2005	Annual Average
Germany									
156 GMS	0.996	1	1	1	1	1	1	1	1
171 STF	0.853	0.776	0.858	0.833	0.849	0.852	0.868	0.836	0.841
172 WT	1	1	1	1	0.979	0.953	0.922	0.894	0.969
173 FT	0.751	0.721	0.719	0.694	0.684	0.694	0.677	0.693	0.704
202 VS	0.888	0.899	0.889	0.85	0.875	0.865	0.891	0.92	0.885
211 PPP	0.988	0.93	0.987	0.939	0.975	0.958	0.834	0.777	0.924
241 BC	1	1	1	1	1	1	1	1	1
247 MMF	1	0.94	1	1	0.889	0.838	0.782	0.74	0.899
261 GP	0.752	0.804	0.804	0.895	0.874	0.884	0.917	0.933	0.858
262 NCW	0.822	0.855	0.866	0.872	0.887	0.899	0.876	0.957	0.879
263 RCP	1	1	1	0.811	1	0.912	1	1	0.965
264 CCP	0.886	0.904	0.877	0.83	0.855	0.876	0.886	0.896	0.876
265 CLP	0.685	0.723	0.756	0.861	0.904	0.688	0.789	0.922	0.791
266 ACC	0.998	1	1	1	1	1	0.99	0.916	0.988
267 CSS	1	1	1	1	1	1	1	0.897	0.987
268 ONM	0.876	0.894	0.878	0.893	0.946	0.978	1	0.981	0.931
271 BIS	0.856	0.734	0.753	0.779	0.775	0.822	0.849	0.937	0.813
274 NFM	0.922	0.877	0.941	0.935	0.969	0.988	0.994	0.999	0.953
275 CM	0.887	0.868	0.9	0.904	0.962	0.958	0.952	1	0.929
Average Total EISs	0.903	0.891	0.907	0.900	0.917	0.903	0.907	0.910	**0.905**
Colombia									
171 STF	0.510	0.530	0.651	0.657	0.664	0.68	0.626	0.631	0.619
172 WT	0.554	0.579	0.709	0.751	0.762	0.767	0.718	0.785	0.703
173 FT	1	1	1	1	1	1	1	1	1
174 MTA	0.666	0.84	0.896	0.952	0.934	0.942	0.916	0.957	0.888
175 OT	0.77	0.48	0.817	0.878	0.824	0.831	0.822	0.923	0.793
202 VS	0.906	1	1	1	1	1	1	1	0.988
211 PPP	0.89	0.927	0.911	0.955	0.962	0.866	0.786	0.763	0.883
241 BC	1	1	1	1	1	1	1	1	1
251 RP	1	1	1	1	1	1	1	1	1
252 PP	1	0.956	0.958	0.974	0.895	0.894	0.916	0.988	0.948
261 GP	0.514	0.54	0.542	0.589	0.578	0.539	0.517	0.714	0.567
262 NCW	0.32	0.809	0.782	0.662	0.76	0.746	0.727	0.927	0.717
263 RCP	0.543	0.718	0.637	0.643	0.683	0.658	0.683	0.799	0.671
264 CCP	1	0.522	0.512	0.648	0.645	0.632	0.668	0.871	0.687
265 CLP	1	1	1	1	1	1	1	1	1
266 ACC	0.71	0.915	0.900	0.949	0.888	0.881	0.903	0.858	0.876
267 CSS	0.294	0.605	0.518	0.501	0.643	0.625	0.629	0.77	0.573
268 ONM	0.718	0.720	0.711	0.755	0.724	0.695	0.654	0.690	0.708
271 BIS	1	0.947	0.944	0.949	1	1	1	1	0.980
274 NFM	1	1	1	1	1	1	1	1	1
Average Total EISs	0.770	0.804	0.824	0.843	0.848	0.838	0.828	0.884	**0.830**

Table 4a Radial technical efficiency (model 1-θ) NEISs

Manufacturing Sector	θ 1998	θ 1999	θ 2000	θ 2001	θ 2002	θ 2003	θ 2004	θ 2005	Annual Average
Germany									
15 Food	0.853	0.809	0.767	0.739	0.736	0.733	0.794	0.651	0.745
17 Textile	0.708	0.714	0.698	0.711	0.697	0.700	0.694	0.676	0.700
18 MWA	0.934	0.872	0.832	0.881	0.844	0.852	0.795	0.783	0.849
19 Leather	0.720	0.714	0.682	0.665	0.653	0.689	0.666	0.668	0.682
20 Wood	0.711	0.697	0.683	0.682	0.658	0.701	0.667	0.641	0.680
21 Paper	0.802	0.796	0.771	0.786	0.746	0.780	0.769	0.742	0.774
22 Publishing	1	1	1	1	1	1	1	1	1
24 Chemical	1	1	1	1	0.993	1	0.988	1	0.998
25 R&P	0.786	0.815	0.771	0.784	0.763	0.755	0.743	0.718	0.767
27 MBM	0.790	0.747	0.687	0.688	0.686	0.691	0.745	0.814	0.731
28 MP	0.786	0.803	0.787	0.784	0.781	0.769	0.748	0.721	0.772
29 M&E	0.933	0.928	0.851	0.895	0.835	0.853	0.792	0.781	0.859
31 EM&E	1	1	0.878	0.975	0.980	0.898	0.910	0.880	0.940
32 R&TV	1	1	1	1	1	1	1	1	1.000
33 MPI	1	1	0.973	1	0.972	1	0.953	0.954	0.982
34 MVT	1	1	0.982	1	1	1	1	1	0.998
35 OTE	0.865	0.829	0.737	0.776	0.740	0.765	0.707	0.760	0.772
36 F&O	0.781	0.760	0.729	0.734	0.707	0.703	0.671	0.650	0.717
Average Total NEISs	0.871	0.856	0.816	0.839	0.822	0.827	0.805	0.800	**0.830**
Colombia									
15 Food	0.885	0.937	0.951	0.97	0.994	0.987	0.957	0.916	0.950
18 MWA	1	1	0.77	1	1	0.798	0.783	0.774	0.891
19 Leather	0.450	0.560	0.537	0.561	0.551	0.510	0.488	0.498	0.519
20 Wood	0.511	0.588	0.572	0.516	0.561	0.504	0.496	0.482	0.529
21 Paper	0.779	0.75	0.645	0.696	0.796	1	1	0.782	0.806
22 Publishing	1	1	1	1	1	1	1	1	1
24 Chemical	1	1	1	1	1	1	1	1	1
28 MP	0.557	1	1	0.756	0.763	0.722	0.679	0.667	0.768
29 M&E	0.728	0.777	0.796	0.852	0.856	0.500	0.515	0.668	0.712
31 EM&E	0.669	0.678	0.713	0.705	0.723	0.656	0.600	0.576	0.665
32 R&TV	1	0.794	0.794	0.724	0.769	0.715	0.659	0.664	0.765
33 MPI	0.729	1	1	1	0.781	0.706	0.700	0.669	0.823
34 MVT	1	0.588	1	1	1	1	1	1	0.949
35 OTE	1	1	1	1	1	1	1	1	1
36 F&O	1	0.608	0.608	0.6	0.543	0.509	0.497	0.462	0.603
Average Total NEISs	0.821	0.819	0.826	0.825	0.822	0.774	0.758	0.744	**0.799**

Table 4b Energy efficiency derived from the technical efficiency model (1-ε) NEISs

Manufacturing Sector	ε 1998	ε 1999	ε 2000	ε 2001	ε 2002	ε 2003	ε 2004	ε 2005	Annual Average
Germany									
15 Food	0.853	0.809	0.696	0.739	0.736	0.733	0.666	0.631	0.733
17 Textile	0.708	0.714	0.698	0.711	0.697	0.7	0.694	0.676	0.700
18 MWA	0.934	0.872	0.832	0.881	0.844	0.852	0.795	0.783	0.849
19 Leather	0.720	0.714	0.682	0.665	0.653	0.689	0.666	0.668	0.682
20 Wood	0.711	0.697	0.683	0.682	0.658	0.701	0.667	0.641	0.680
21 Paper	0.802	0.783	0.740	0.786	0.746	0.78	0.739	0.724	0.763
22 Publishing	1	1	1	1	1	1	1	1	1
24 Chemical	1	1	1	1	0.993	1	0.988	1	0.998
25 R&P	0.786	0.815	0.771	0.784	0.763	0.755	0.743	0.718	0.767
27 MBM	0.790	0.717	0.657	0.688	0.686	0.691	0.745	0.814	0.724
28 MP	0.786	0.803	0.787	0.784	0.781	0.769	0.748	0.721	0.772
29 M&E	0.933	0.892	0.851	0.895	0.835	0.853	0.792	0.781	0.854
31 EM&E	1	1	0.878	0.975	0.980	0.898	0.910	0.880	0.940
32 R&TV	1	1	1	1	1	1	1	1	1
33 MPI	1	1	0.973	1	0.972	1	0.953	0.954	0.982
34 MVT	1	1	0.982	1	1	1	1	1	0.998
35 OTE	0.865	0.829	0.737	0.776	0.74	0.765	0.707	0.760	0.772
36 F&O	0.781	0.760	0.729	0.734	0.707	0.703	0.671	0.650	0.717
Average Total EISs	0.871	0.856	0.816	0.839	0.822	0.827	0.805	0.800	**0.830**
Colombia									
15 Food	0.850	0.937	0.951	0.97	0.994	0.987	0.957	0.916	0.945
18 MWA	1	1	0.77	1	1	0.798	0.783	0.774	0.891
19 Leather	0.450	0.560	0.537	0.561	0.551	0.510	0.488	0.498	0.519
20 Wood	0.511	0.588	0.572	0.516	0.561	0.504	0.476	0.472	0.525
21 Paper	0.779	0.75	0.450	0.696	0.796	1	1	0.782	0.782
22 Publishing	1	1	1	1	1	1	1	1	1
24 Chemical	1	1	1	1	1	1	1	1	1
28 MP	0.507	1	1	0.656	0.663	0.622	0.579	0.567	0.699
29 M&E	0.628	0.677	0.696	0.752	0.756	0.400	0.415	0.668	0.624
31 EM&E	0.669	0.678	0.713	0.705	0.723	0.656	0.6	0.576	0.665
32 R&TV	1	0.794	0.794	0.724	0.769	0.715	0.659	0.664	0.765
33 MPI	0.729	1	1	1	0.781	0.706	0.700	0.669	0.823
34 MV	1	0.588	1	1	1	1	1	1	0.949
35 OTE	1	1	1	1	1	1	1	1	1
36 F&O	1	0.608	0.608	0.6	0.543	0.509	0.497	0.462	0.603
Average Total EISs	0.808	0.812	0.806	0.812	0.809	0.760	0.744	0.737	**0.786**

Table 5 Energy efficiency based on energy input minimisation (model 2-β) EISs

Manufacturing Sector	β 1998	β 1999	β 2000	β 2001	β 2002	β 2003	β 2004	β 2005	Annual Average
Germany									
156 GMS	0.765	0.932	0.904	0.903	1	1	1	1	0.938
171 STF	0.703	0.676	0.714	0.662	0.715	0.746	0.81	0.742	0.721
172 WT	0.905	1	1	1	0.951	0.843	0.838	0.811	0.919
173 FT	0.408	0.489	0.4	0.387	0.447	0.353	0.353	0.342	0.397
202 VS	0.623	0.726	0.652	0.591	0.684	0.626	0.687	0.722	0.664
211 PPP	0.837	0.855	0.948	0.895	0.975	0.958	0.834	0.777	0.885
241 BC	0.806	0.918	0.956	0.951	1	1	1	1	0.954
247 MMF	0.984	0.873	1	1	0.889	0.838	0.782	0.728	0.887
261 GP	0.345	0.425	0.442	0.444	0.472	0.452	0.641	0.644	0.483
262 NCW	0.552	0.643	0.616	0.599	0.717	0.678	0.640	0.785	0.654
263 RCP	1	1	0.875	0.748	0.912	0.886	0.952	0.832	0.901
264 CCP	0.669	0.76	0.647	0.597	0.709	0.674	0.705	0.683	0.681
265 CLP	0.498	0.547	0.55	0.574	0.575	0.509	0.514	0.531	0.537
266 ACC	0.731	0.881	0.775	0.781	0.838	0.776	0.814	0.765	0.795
267 CSS	1	0.805	0.903	0.993	0.932	0.823	0.847	0.638	0.868
268 ONM	0.576	0.631	0.616	0.662	0.686	0.735	0.872	0.656	0.679
271 BIS	0.542	0.515	0.54	0.567	0.607	0.630	0.674	0.783	0.607
274 NFM	0.376	0.426	0.500	0.494	0.573	0.539	0.572	0.632	0.514
275 CM	0.593	0.639	0.643	0.664	0.807	0.792	0.827	0.900	0.733
Average Total EISs	0.680	0.723	0.720	0.711	0.763	0.729	0.756	0.735	**0.727**
Colombia									
171 STF	0.369	0.369	0.445	0.439	0.473	0.559	0.502	0.537	0.462
172 WT	0.301	0.401	0.483	0.497	0.518	0.526	0.407	0.481	0.452
173 FT	0.953	0.901	0.854	0.867	0.869	1	1	1	0.931
174 MTA	0.357	0.581	0.678	0.687	0.633	0.638	0.616	0.689	0.610
175 OT	0.422	0.231	0.672	0.445	0.449	0.472	0.445	0.516	0.457
202 VS	0.595	1	1	1	0.964	0.903	0.847	0.911	0.903
211 PPP	0.523	0.731	0.685	0.566	0.568	0.516	0.481	0.591	0.583
241 BC	0.780	0.898	0.817	0.849	0.823	0.850	0.859	0.846	0.840
251 RP	1	1	1	1	1	0.832	0.825	0.884	0.943
252 PP	0.865	0.865	0.786	0.801	0.763	0.781	0.766	0.768	0.799
261 GP	0.336	0.397	0.387	0.392	0.340	0.358	0.355	0.545	0.389
262 NCW	0.168	0.668	0.569	0.395	0.537	0.559	0.566	0.726	0.524
263 RCP	0.243	0.536	0.438	0.353	0.382	0.372	0.347	0.482	0.394
264 CCP	0.832	0.342	0.332	0.309	0.352	0.375	0.382	0.432	0.420
265 CLP	0.840	0.934	0.829	0.845	0.765	0.817	0.825	0.825	0.835
266 ACC	0.306	0.746	0.680	0.456	0.412	0.421	0.826	0.761	0.576
267 CSS	0.148	0.413	0.338	0.335	0.468	0.461	0.474	0.630	0.408
268 ONM	0.398	0.544	0.495	0.374	0.374	0.357	0.346	0.438	0.416
271 BIS	0.844	0.794	0.779	0.738	0.726	0.724	0.794	0.796	0.774
274 NFM	0.808	0.841	0.844	0.833	0.917	1	1	1	0.905
Average Total EISs	0.554	0.660	0.656	0.609	0.617	0.626	0.633	0.693	**0.631**

Table 6 Energy efficiency based on energy input minimisation (model 2-β) NEISs

Manufacturing Sector	β 1998	β 1999	β 2000	β 2001	β 2002	β 2003	β 2004	β 2005	Annual Average
Germany									
15 Food	0.797	0.626	0.624	0.656	0.648	0.664	0.692	0.556	0.658
17 Textile	0.493	0.566	0.617	0.463	0.603	0.6467	0.675	0.566	0.579
18 MWA	0.792	0.816	0.764	0.759	0.769	0.842	0.776	0.762	0.785
19 Leather	0.477	0.574	0.591	0.624	0.612	0.648	0.612	0.506	0.581
20 Wood	0.679	0.527	0.616	0.633	0.627	0.679	0.576	0.551	0.611
21 Paper	0.767	0.726	0.698	0.749	0.726	0.769	0.701	0.701	0.730
22 Publishing	0.817	0.928	0.958	0.890	0.991	0.985	0.957	0.918	0.931
24 Chemical	0.952	0.843	0.873	0.969	0.935	0.926	0.964	0.976	0.930
25 R&P	0.725	0.696	0.685	0.749	0.665	0.732	0.623	0.669	0.693
27 MBM	0.687	0.495	0.603	0.635	0.609	0.604	0.638	0.784	0.632
28 MP	0.777	0.715	0.768	0.747	0.72	0.703	0.707	0.644	0.723
29 M&E	0.802	0.796	0.785	0.811	0.829	0.827	0.766	0.778	0.799
31 EM&E	1	1	0.852	0.975	0.98	0.884	0.901	0.78	0.922
32 R&TV	0.928	0.942	1	1	1	0.983	1	1	0.982
33 MPI	0.889	0.913	0.869	0.974	0.96	0.949	0.908	0.932	0.924
34 MVT	0.885	0.916	0.921	0.985	0.989	1	0.94	0.978	0.952
35 OTE	0.696	0.738	0.585	0.702	0.632	0.67	0.598	0.672	0.662
36 F&O	0.533	0.624	0.648	0.706	0.573	0.605	0.557	0.527	0.597
Average Total NEISs	0.761	0.747	0.748	0.779	0.770	0.784	0.755	0.739	**0.760**
Colombia									
15 Food	0.497	0.53	0.551	0.578	0.646	0.642	0.595	0.547	0.573
18 MWA	0.597	0.582	0.508	0.596	0.599	0.494	0.492	0.489	0.545
19 Leather	0.369	0.473	0.449	0.475	0.438	0.403	0.376	0.386	0.421
20 Wood	0.399	0.493	0.485	0.407	0.469	0.378	0.348	0.339	0.415
21 Paper	0.519	0.503	0.312	0.457	0.586	0.696	0.726	0.555	0.544
22 Publishing	1	1	0.771	0.778	0.794	0.806	0.795	0.798	0.843
24 Chemical	0.867	0.893	0.864	0.869	0.868	0.866	0.869	0.868	0.871
28 MP	0.397	0.771	0.796	0.495	0.486	0.457	0.426	0.439	0.533
29 M&E	0.519	0.581	0.607	0.653	0.664	0.466	0.476	0.593	0.570
31 EM&E	0.426	0.446	0.517	0.508	0.545	0.497	0.401	0.397	0.467
32 R&TV	0.767	0.543	0.548	0.483	0.507	0.465	0.409	0.426	0.518
33 MPI	0.607	0.793	0.798	0.796	0.652	0.5921	0.589	0.557	0.673
34 MV	0.882	0.547	1	1	1	1	1	1	0.929
35 OTE	0.682	0.671	0.668	0.673	0.675	0.653	0.668	0.658	0.669
36 F&O	0.512	0.351	0.353	0.344	0.334	0.319	0.308	0.297	0.352
Average Total NEISs	0.603	0.623	0.615	0.607	0.618	0.582	0.565	0.557	**0.596**

Table 7a Cost efficiency (model 3-CE) EISs

Manufacturing Sector	CE 1998	CE 1999	CE 2000	CE 2001	CE 2002	CE 2003	CE 2004	CE 2005	Annual Average
Germany									
156 GMS	0.743	1	1	1	1	1	1	1	0.968
171 STF	0.730	0.745	0.582	0.525	0.537	0.490	0.549	0.549	0.588
172 WT	0.809	0.777	0.571	0.562	0.529	0.486	0.481	0.481	0.587
173 FT	0.750	0.640	0.458	0.420	0.419	0.363	0.351	0.351	0.469
202 VS	0.731	0.809	0.669	0.670	0.693	0.673	0.685	0.685	0.702
211 PPP$^{\sigma}$	0.805	0.956	1	1	1	1	0.927	0.876	0.946
241 BC$^{\sigma}$	1	1	0.886	0.896	0.912	0.902	0.961	0.898	0.932
247 MMF	0.865	0.928	0.849	0.802	0.826	0.899	0.823	0.748	0.843
261 GP$^{\sigma}$	0.858	0.772	0.593	0.601	0.596	0.613	0.586	0.538	0.645
262 NCW	1	0.700	0.458	0.430	0.423	0.590	0.392	0.392	0.548
263 RCP$^{\sigma}$	0.843	0.685	0.512	0.499	0.530	0.391	0.538	0.505	0.563
264 CCP$^{\sigma}$	0.891	0.829	0.560	0.534	0.581	0.580	0.525	0.472	0.622
265 CLP$^{\sigma}$	0.810	0.935	0.718	0.663	0.625	0.634	0.670	0.647	0.713
266 ACC	0.942	0.859	0.588	0.544	0.534	0.492	0.501	0.501	0.620
267 CSS	0.908	0.658	0.431	0.405	0.391	0.393	0.362	0.362	0.489
268 ONM	0.890	0.823	0.608	0.568	0.564	0.530	0.515	0.515	0.627
271 BIP$^{\sigma}$	0.663	0.792	0.815	0.839	0.829	0.920	1	1	0.857
274 NFM	0.754	0.915	0.925	0.890	0.901	0.807	0.810	0.810	0.852
275 CM	0.792	0.618	0.431	0.412	0.418	0.384	0.383	0.383	0.478
Average Total EISs	0.831	0.813	0.666	0.645	0.648	0.648	0.639	0.635	**0.691**
Colombia									
171 STF	0.547	0.478	0.504	0.554	0.505	0.481	0.491	0.464	0.503
172 WT	0.544	0.459	0.476	0.572	0.482	0.464	0.457	0.453	0.488
173 FT$^{\sigma}$	1	0.339	0.51	0.57	0.54	0.446	0.39	0.325	0.515
174 MTA	0.556	0.628	0.587	0.683	0.601	0.551	0.502	0.493	0.575
175 OT	0.623	0.333	0.487	0.541	0.452	0.412	0.416	0.438	0.463
202 VS$^{\sigma}$	0.671	0.758	0.804	0.88	0.78	0.676	0.61	0.597	0.723
211 PPP	0.768	0.768	0.711	0.802	0.717	0.685	0.686	0.625	0.720
241 BC	0.818	1	1	1	1	1	1	1	0.977
251 RP	0.603	0.518	0.451	0.499	0.480	0.458	0.425	0.404	0.480
252 PP	0.674	0.678	0.615	0.698	0.634	0.587	0.575	0.607	0.634
261 GP$^{\sigma}$	0.641	0.681	0.740	0.950	0.855	0.670	0.492	0.544	0.697
262 NCW$^{\sigma}$	0.326	0.266	0.277	0.302	0.325	0.291	0.286	0.326	0.300
263 RCP$^{\sigma}$	0.641	0.593	0.640	0.633	0.613	0.442	0.375	0.457	0.549
264 CCP$^{\sigma}$	0.474	0.357	0.361	0.423	0.417	0.382	0.368	0.474	0.407
265 CLP$^{\sigma}$	0.495	0.311	0.324	0.338	0.372	0.421	0.46	0.495	0.402
266 ACC	0.558	0.788	0.724	0.877	0.794	0.821	0.839	0.866	0.783
267 CSS	0.342	0.477	0.405	0.472	0.565	0.547	0.455	0.469	0.467
268 ONM	1	0.672	0.577	0.668	0.565	0.494	0.481	0.473	0.616
271 BIS$^{\sigma}$	0.827	1	1	1	1	1	1	1	0.978
274 NFM	0.748	0.910	0.959	0.961	0.990	0.946	0.925	0.913	0.919
Average Total EISs	0.643	0.601	0.608	0.671	0.634	0.589	0.562	0.571	**0.610**

$^{\sigma}$ *(HEISs)*

Table 7b Energy efficiency based on cost minimisation (model 3-μ)

Manufacturing Sector	μ 1998	μ 1999	μ 2000	μ 2001	μ 2002	μ 2003	μ 2004	μ 2005	Annual Average
Germany									
156 GMS	1.47	1	1	1	1	1	1	1	1.06
171 STF	1.55	0.83	0.95	0.91	0.87	1.07	1.27	1.15	1.08
172 WT	1.33	1.19	1.32	1.34	1.19	1.12	1.23	1.24	1.25
173 FT	0.88	0.63	0.58	0.59	0.62	0.54	0.58	0.62	0.63
202 VS	1.06	0.90	0.89	0.85	0.76	0.67	0.73	0.80	0.83
211 PPP$^{\sigma}$	0.90	0.81	1.00	1.00	1.00	1.00	1.11	0.90	0.97
241 BC$^{\sigma}$	1.00	1.00	1.17	1.23	1.19	1.41	1.61	1.32	1.24
247 MMF	0.99	0.60	0.71	0.72	0.66	0.58	0.61	0.67	0.69
261 GP$^{\sigma}$	1.08	1.03	1.13	0.58	0.61	0.52	0.55	0.61	0.76
262 NCW	1.00	0.74	0.72	0.69	0.77	0.72	0.78	0.86	0.79
263 RCP$^{\sigma}$	0.56	0.72	0.67	0.67	0.71	0.74	0.89	0.72	0.71
264 CCP$^{\sigma}$	0.40	0.47	0.45	0.49	0.51	0.57	0.65	0.55	0.51
265 CLP$^{\sigma}$	0.42	0.37	0.40	0.46	0.45	0.49	0.51	0.46	0.45
266 ACC	1.96	1.10	1.03	0.99	1.01	0.89	0.98	1.01	1.12
267 CSS	1.17	1.03	1.14	1.24	1.17	0.93	0.91	0.91	1.06
268 ONM	1.12	0.77	0.79	0.82	0.81	0.82	0.91	1.00	0.88
271 BIP$^{\sigma}$	0.64	0.59	0.66	0.74	0.77	0.85	1.00	1.00	0.78
274 NFM	1.11	0.72	0.86	0.87	0.93	0.86	0.99	1.22	0.95
275 CM	0.98	0.63	0.71	0.75	0.79	0.71	0.76	0.83	0.77
Average Total EISs	1.03	0.80	0.85	0.84	0.83	0.82	0.90	0.89	**0.87**
Colombia									
171 STF	0.73	1.01	0.94	0.89	0.72	0.71	0.55	0.55	0.76
172 WT	0.71	1.02	0.96	0.98	0.77	0.85	0.61	0.57	0.81
173 FT$^{\sigma}$	1	0.91	0.79	1.01	1.11	1.05	0.76	0.64	0.91
174 MTA	1.37	1.65	1.69	1.6	1.61	1.62	1.1	1.25	1.49
175 OT	1.3	1.5	1.59	1.42	1.31	1.22	0.92	0.96	1.28
202 VS$^{\sigma}$	1.19	1.28	1.31	1.18	1.11	1.06	1.15	1.24	1.19
211 PPP	0.88	0.79	0.85	0.89	0.68	0.72	0.54	0.6	0.74
241 BC	0.66	1	1	1	1	1	1	1	0.96
251 RP	1.05	1.49	1.37	1.46	1.27	1.22	0.97	1.09	1.24
252 PP	1	1.39	1.45	1.47	1.49	1.46	1.04	1.21	1.31
261 GP$^{\sigma}$	0.7	0.84	0.74	0.85	0.9	0.76	0.69	0.62	0.76
262 NCW$^{\sigma}$	0.4	0.54	0.73	0.88	0.98	0.82	0.74	0.68	0.72
263 RCP$^{\sigma}$	1.06	1.32	0.91	1.23	1.14	1.22	0.86	0.9	1.08
264 CCP$^{\sigma}$	0.51	0.57	0.48	0.52	0.57	0.5	0.42	0.35	0.49
265 CLP$^{\sigma}$	0.33	0.44	0.4	0.45	0.47	0.46	0.41	0.43	0.42
266 ACC	1.69	1.7	1.78	1.79	1.5	1.53	1.41	1.58	1.62
267 CSS	0.4	0.55	0.89	0.61	0.82	0.86	0.68	0.78	0.70
268 ONM	1	1.18	1.22	1.25	0.98	0.89	0.67	0.75	0.99
271 BIS$^{\sigma}$	0.56	1	1	1	1	1	1	1	0.95
274 NFM	0.97	1.27	1.32	1.29	1.18	1.26	1.28	1.15	1.22
Average Total EISs	0.88	1.07	1.07	1.09	1.03	1.01	0.84	0.87	**0.98**

$^{\sigma}$ *(HEISs)*

Table 8a Cost efficiency (model 3-CE) NEISs

Manufacturing Sector	CE 1998	CE 1999	CE 2000	CE 2001	CE 2002	CE 2003	CE 2004	CE 2005	Annual Average
Germany									
15 Food$^{\sigma}$	0.804	1	1	1	1	1	1	1	0.976
17 Textile$^{\sigma}$	0.808	0.787	0.671	0.627	0.616	0.621	0.622	0.620	0.672
18 MWA	1	0.985	0.924	0.977	0.996	0.988	0.965	0.916	0.969
19 Leather	0.807	0.940	0.891	0.941	0.991	0.991	0.955	0.905	0.928
20 Wood$^{\sigma}$	0.769	0.758	0.633	0.593	0.642	0.667	0.673	0.688	0.678
21 Paper$^{\sigma}$	0.803	0.782	0.690	0.633	0.65	0.652	0.643	0.649	0.688
22 Publishing$^{\sigma}$	1	0.813	0.598	0.530	0.525	0.519	0.534	0.555	0.634
24 Chemical$^{\sigma}$	0.984	0.912	0.776	0.740	0.745	0.739	0.718	0.754	0.796
25 R&P$^{\sigma}$	0.836	0.778	0.619	0.580	0.602	0.608	0.616	0.627	0.658
27 MBM$^{\sigma}$	0.706	0.715	0.679	0.664	0.664	0.666	0.763	0.864	0.715
28 MP$^{\sigma}$	0.817	0.681	0.530	0.494	0.502	0.503	0.518	0.535	0.573
29 M&E	0.834	0.708	0.601	0.615	0.616	0.596	0.595	0.575	0.643
31 EM&E	0.875	0.772	0.645	0.668	0.635	0.630	0.623	0.580	0.679
32 R&TV	0.979	1	1	0.977	0.956	0.920	0.962	0.912	0.963
33 MPI	0.898	0.694	0.592	0.600	0.596	0.577	0.554	0.527	0.630
34 MVT	0.800	0.920	0.934	1	1	1	1	1	0.957
35 OTE	0.810	0.782	0.688	0.749	0.699	0.677	0.609	0.614	0.704
36 F&O	0.819	0.761	0.660	0.649	0.650	0.647	0.644	0.630	0.683
Average Total NEISs	0.853	0.822	0.730	0.724	0.727	0.722	0.722	0.720	**0.752**
Colombia									
15 Food$^{\sigma}$	1	1	1	1	1	1	1	1	1
18 MWA	0.578	0.658	0.616	0.698	0.659	0.691	0.696	0.767	0.670
19 Leather	0.615	0.632	0.539	0.584	0.542	0.549	0.519	0.494	0.559
20 Wood	0.486	0.714	0.709	0.703	0.756	0.574	0.647	0.748	0.667
21 Paper$^{\sigma}$	0.736	0.991	0.882	0.858	0.868	0.883	0.804	0.840	0.858
22 Publishing	0.857	0.690	0.647	0.733	0.731	0.735	0.678	0.732	0.725
24 Chemical	0.716	1	1	1	1	1	1	1	0.965
28 MP$^{\sigma}$	0.604	0.688	0.573	0.564	0.571	0.602	0.593	0.605	0.600
29 M&E	0.712	0.636	0.608	0.712	0.747	0.662	0.723	0.801	0.700
31 EM&E	1	0.695	0.674	0.736	0.753	0.725	0.811	0.893	0.786
32 R&TV	0.899	0.905	0.913	0.906	0.923	0.912	0.904	0.915	0.910
33 MPI$^{\sigma}$	0.764	0.678	0.577	0.607	0.570	0.597	0.568	0.579	0.618
34 MV	0.892	0.913	0.918	0.912	0.933	0.943	0.936	0.943	0.924
35 OTE	0.888	0.895	0.903	0.911	0.895	0.905	0.899	0.914	0.901
36 F&O$^{\sigma}$	0.639	0.594	0.496	0.560	0.514	0.545	0.493	0.449	0.536
Average Total NEISs	0.759	0.779	0.737	0.766	0.764	0.755	0.751	0.779	**0.761**

$^{\sigma}$ *(HNEISs)*

Table 8b Energy efficiency based on cost minimisation NEISs (model 3-μ)

Manufacturing Sector	μ 1998	μ 1999	μ 2000	μ 2001	μ 2002	μ 2003	μ 2004	μ 2005	Annual Average
Germany									
15 Food$^{\sigma}$	0.734	1	1	1	1.001	1	1	1	1
17 Textile$^{\sigma}$	0.539	0.790	0.861	0.825	0.828	0.880	0.890	0.914	0.816
18 MWA	1.002	1.728	1.500	1.121	1.109	1.198	1.207	1.138	1.250
19 Leather	0.774	1.108	1.101	0.846	0.840	0.772	0.771	0.789	0.875
20 Wood$^{\sigma}$	0.794	1.246	1.320	1.333	1.155	1.129	1.095	1.145	1.152
21 Paper$^{\sigma}$	0.509	0.744	0.850	0.758	0.711	0.791	0.782	0.790	0.742
22 Publishing$^{\sigma}$	0.998	1.500	1.530	1.673	1.631	1.301	1.392	1.344	1.421
24 Chemical$^{\sigma}$	0.912	1.123	1.169	1.096	1.062	1.227	1.239	1.290	1.140
25 R&P$^{\sigma}$	0.538	0.802	0.927	0.916	0.923	0.896	0.894	0.931	0.853
27 MBM$^{\sigma}$	0.427	0.588	0.686	0.675	0.683	0.747	0.859	0.999	0.708
28 MP$^{\sigma}$	0.398	1.104	1.208	1.208	1.170	1.135	1.175	0.422	0.977
29 M&E	0.696	1.075	1.101	0.751	0.793	0.745	0.711	0.789	0.833
31 EM&E	0.726	1.204	1.128	0.899	0.878	0.817	0.810	0.972	0.929
32 R&TV	0.614	0.998	1	0.715	0.779	0.740	0.720	0.718	0.786
33 MPI	0.803	1.320	1.314	0.985	0.938	0.891	0.861	0.936	1.006
34 MVT	0.885	1.407	0.526	1	1	1	1	1	0.977
35 OTE	0.721	0.867	1.154	0.852	0.920	0.942	0.885	0.956	0.912
36 F&O	0.567	0.896	0.895	0.632	0.628	0.667	0.597	0.681	0.695
Average Total NEISs	0.702	1.083	1.071	0.960	0.947	0.938	0.938	0.934	**0.947**
Colombia									
15 Food$^{\sigma}$	1	1	1	1	1	1	1	1	1
18 MWA	1.517	0.718	0.850	1.019	1.189	1.103	1.040	1.025	1.058
19 Leather	0.896	1.058	1.037	1.132	1.107	1.162	1.129	0.714	1.029
20 Wood	1.118	0.586	0.852	1.104	1.239	0.677	0.922	0.944	0.930
21 Paper$^{\sigma}$	0.372	1.926	0.812	0.654	1.668	0.707	0.753	0.794	0.961
22 Publishing	1.590	0.923	0.978	1.262	1.337	1.074	0.676	1.005	1.106
24 Chemical	1.480	1	1	1	1	1	1	1	1.059
28 MP$^{\sigma}$	0.714	0.838	0.836	0.707	0.690	0.765	0.877	0.903	0.791
29 M&E	1.122	0.688	0.736	0.817	0.942	0.639	0.615	0.910	0.809
31 EM&E	0.999	0.598	0.610	0.723	0.814	0.723	0.868	0.991	0.791
32 R&TV	2.595	1.955	1.137	1.020	1.211	1.204	1.258	1.137	1.440
33 MPI$^{\sigma}$	0.784	0.924	1.018	1.068	1.154	1.209	1.035	0.943	1.017
34 MV	1.770	1.938	1.860	2.549	1.740	1.520	1.760	1.700	1.855
35 OTE	1.850	1.468	1.990	2.552	1.880	1.920	1.900	1.900	1.932
36 F&O$^{\sigma}$	0.785	0.741	0.613	0.586	0.571	0.635	0.709	0.720	0.670
Average Total NEISs	1.240	1.091	1.022	1.146	1.169	1.023	1.036	1.046	**1.10**

$^{\sigma}$ *(HNEISs)*

Table 9 Patterns of efficiency indexes based on model 4 (ϕ) EISs

Manufacturing Sector	98-99			00-01			02-03			04-05			Average		
	TC	TE	TFP	TC	TE	TFP	TC	TE	TFP	TC	TE	TFP	TC	TE	TFP
Germany															
156 GMS	1	1.48	1.48	1	0.98	0.98	1	0.96	0.96	1	0.95	0.95	1	0.95	0.95
171 STF	1	0.91	0.91	1	0.96	0.96	1	0.92	0.92	1	0.95	0.95	1	0.95	0.95
172 WT	1	0.74	0.74	1	1.13	1.13	1	0.94	0.94	1	0.97	0.97	1	0.93	0.93
173 FT	0.87	1.02	0.89	0.97	1.01	0.98	0.89	0.85	0.75	0.94	0.96	0.90	0.95	0.93	0.89
202 VS	1	1.18	1.17	0.88	0.95	0.84	1.08	0.90	0.97	1.04	0.99	1.03	1	1	1.01
211 PPP	1	0.89	0.89	1	0.95	0.95	1	0.96	0.96	1	0.99	0.99	1	1.01	1.01
241 BC	1	2.73	2.73	1	2.32	2.32	1	1.14	1.14	1	1.65	1.65	1	1.95	1.95
247 MMF	1	1.20	1.20	1	0.89	0.89	1	0.74	0.74	1	1.13	1.13	1	1.04	1.04
261 GP	0.69	1.58	1.09	0.99	1.02	1.02	1.03	1.90	1.96	1	1.63	1.63	1.05	1.37	1.38
262 NCW	1	1.03	1.03	1.00	0.99	0.99	1	0.87	0.87	1	0.91	0.91	1	0.90	0.90
263 RCP	1.04	1.07	1.12	0.89	0.93	0.83	1	0.86	0.86	1	0.84	0.84	0.96	0.91	0.87
264 CCP	1.13	1.09	1.23	0.93	1.01	0.94	0.80	1.03	0.83	0.98	0.99	0.97	1	0.99	0.99
265 CLP	1.06	0.99	1.05	1.25	0.78	0.97	0.76	1.23	0.93	0.97	1.09	1.05	0.99	1.03	1.01
266 ACC	1	1.12	1.12	1.00	0.90	0.90	1	0.98	0.98	1	0.95	0.95	1	0.95	0.95
267 CSS	1	0.09	0.09	1	1.77	1.77	1	1.01	1.01	1	0.82	0.82	1	0.88	0.88
268 ONM	1.03	1.02	1.05	1.01	0.99	0.99	1	0.98	0.98	1	1.02	1.02	1.02	1	1.03
271 BIS	1	1.10	1.10	1	7.69	7.69	1	0.25	0.25	1	1.05	1.05	1	2.02	1.79
274 NFM	1	1	1	1	2.75	2.75	1	0.29	0.29	1	0.99	0.99	1	1.18	1.18
275 CM	1	1.10	1.10	1.10	0.94	1.04	1	0.95	0.95	1	0.97	0.97	1	0.88	0.89
Average Total EISs	0.99	1.12	1.10	1	1.52	1.52	0.98	0.93	0.91	1	1.04	1.04	**1**	**1.10**	**1.08**
Colombia															
171 STF	0.76	0.87	0.66	1.05	1.09	1.14	1.10	1.09	1.20	0.92	1.01	0.93	0.99	1.09	1.09
172 WT	1.03	1.08	1.11	1.04	1.04	1.97	0.98	0.99	0.97	1.00	1.26	1.26	1.00	0.99	1.12
173 FT	0.55	0.91	0.50	0.89	0.84	0.75	1.03	0.84	0.87	0.99	1.05	1.04	0.93	0.93	0.87
174 MTA	1	1.01	1.01	1	0.82	0.82	1	0.82	0.82	1	1.26	1.26	1	1.15	1.15
175 OT	0.88	0.73	0.64	1	0.67	0.67	0.95	0.83	0.79	1	1.41	1.41	1.01	0.96	0.98
202 VS	1	1.39	1.39	1	1.03	1.03	1	0.88	0.88	1	1.03	1.03	1	0.99	0.99
211 PPP	1	1.04	1.04	1.04	0.85	0.88	1	0.87	0.87	1	1.02	1.02	1	0.98	0.98
241 BC	1	0.97	0.97	1	0.94	0.94	1	1.16	1.16	1	1.44	1.44	1	1.21	1.21
251 RP	1	1.03	1.03	1	0.80	0.80	1	0.74	0.74	1	1.11	1.11	1	0.94	0.94
252 PP	1	1.07	1.07	1	1.04	1.04	1	0.93	0.93	1	1.05	1.05	1	0.95	0.95
261 GP	1.09	0.90	0.98	1.18	0.84	0.98	0.79	0.94	0.74	1.05	1.32	1.39	0.97	1	0.95
262 NCW	1.05	0.90	0.95	1.03	1.09	1.12	0.92	1.17	1.07	0.94	1.33	1.25	1.01	1.08	1.09
263 RCP	1.07	0.90	0.96	1	1.09	1.09	1	1.09	1.09	1	0.97	0.97	1.01	1.03	1.04
264 CCP	1.09	0.90	0.98	0.95	1.09	1.04	1	0.87	0.88	1.05	1.25	1.32	1.04	0.99	1.01
265 CLP	1	0.90	0.90	1.12	0.94	1.05	1	0.98	0.97	0.98	1.16	1.14	1	1.01	1.00
266 ACC	0.99	0.90	0.89	1.00	1.07	1.07	0.86	1.09	0.93	0.99	1.07	1.07	0.98	0.96	0.93
267 CSS	0.99	0.90	0.89	0.96	0.98	0.94	0.98	0.99	0.97	0.91	1.05	0.95	0.97	0.98	0.95
268 ONM	1.01	0.90	0.91	1.10	0.94	1.03	0.70	1.03	0.72	1.48	1.26	1.86	1.03	1	1.04
271 BIS	1.09	0.90	0.99	1	1.06	1.16	1.09	1.19	1.29	1	1.25	1.25	1.10	1.16	1.21
274 NFM	1.09	0.90	0.99	1	1.07	1.17	1.11	0.92	0.92	1	1.27	1.27	1.07	1.14	1.15
Average Total EISs	0.98	0.95	0.94	1.02	0.96	1.03	0.98	0.97	0.94	1.02	1.18	1.20	**1.00**	**1.03**	**1.03**

Table 10 Patterns of efficiency indexes based on model 4 (ϕ) NEISs

Manufacturing Sector	98-99			00-01			02-03			04-05			Average		
	TC	TE	TFP	TC	TE	TFP	TC	TE	TFP	TC	TE	TFP	TC	TE	TFP
Germany															
15 Food	0.93	1.06	0.98	1.00	1.05	1.05	1.01	1.02	1.03	0.95	1.04	1.00	0.96	1.04	1.00
17 Textile	0.94	1.06	1.00	0.96	1.03	0.99	1.00	1.02	1.02	0.97	1.04	1.01	0.97	1.04	1.01
18 MWA	1.00	0.89	0.89	0.87	0.98	0.85	1.00	0.74	0.74	1.00	1.00	1.00	1.00	0.93	0.94
19 Leather	1.00	2.51	2.51	1.00	1.26	1.26	1.00	0.79	0.79	1.00	0.45	0.45	0.99	1.48	1.48
20 Wood	1.00	0.84	0.84	0.88	0.82	0.72	0.91	0.99	0.89	1.02	0.96	0.99	0.94	0.97	0.89
21 Paper	0.91	1.06	0.96	0.84	0.98	0.82	1.00	0.88	0.88	1.48	1.14	1.68	1.02	1.00	1.06
22 Publishing	0.96	1.03	0.98	0.79	1.01	0.79	0.95	0.99	0.94	0.99	1.03	1.02	0.93	1.01	0.95
24 Chemical	0.99	1.06	1.05	0.96	1.05	1.01	0.85	1.02	0.87	1.02	1.04	1.06	0.98	1.04	1.03
25 R&P	0.97	1.06	1.03	0.95	1.05	0.99	0.98	1.02	1.00	0.99	1.04	1.03	0.98	1.04	1.02
27 MBM	0.65	0.99	0.64	1.53	2.68	4.10	0.63	0.52	0.33	0.91	1.06	0.96	1.01	1.17	1.35
28 MP	0.95	1.05	1.00	0.93	1.02	0.95	0.86	1.01	0.87	0.99	1.03	1.03	0.96	1.02	0.98
29 M&E	1.00	0.99	0.99	1.00	1.01	1.01	0.93	0.96	0.89	1.00	1.04	1.04	0.99	1.00	1.00
31 EM&E	1.00	1.07	1.07	1.00	0.79	0.79	1.00	0.78	0.78	1.00	1.03	1.03	0.99	0.95	0.95
32 R&TV	1.00	1.30	1.30	1.00	0.88	0.88	1.00	0.95	0.95	1.00	1.02	1.02	0.99	1.08	1.08
33 MPI	1.06	0.95	1.01	1.00	0.96	0.96	1.08	0.91	0.98	1.08	0.99	1.06	1.00	0.99	1.01
34 MVT	1.00	1.04	1.04	1.00	1.04	1.04	1.00	0.94	0.94	1.00	1.10	1.10	0.99	1.05	1.05
35 OTE	1.00	1.11	1.11	1.00	1.07	1.07	1.00	1.04	1.04	1.00	1.12	1.12	0.99	1.07	1.07
36 F&O	0.89	1.11	0.98	0.98	0.98	0.96	0.90	0.94	0.84	0.79	1.04	0.83	0.93	1.02	0.96
Average Total NEISs	0.96	1.12	1.08	0.98	1.09	1.12	0.95	0.92	0.88	1.01	1.01	1.02	**0.98**	**1.05**	**1.05**
Colombia															
15 Food	1.00	0.98	0.98	1.00	0.94	0.94	1.00	0.80	0.80	1.00	1.25	1.25	1.00	1.03	1.03
18 MWA	1.00	0.84	0.84	1.00	0.81	0.81	1.00	1.15	1.15	1.00	0.67	0.67	1.00	0.95	0.95
19 Leather	1.01	1.02	1.03	1.38	0.77	1.06	1.25	0.91	1.14	0.92	0.97	0.89	1.04	1.12	0.99
20 Wood	1.00	1.34	1.34	0.64	0.79	0.51	0.86	0.82	0.70	0.54	1.92	1.04	0.90	1.25	1.10
21 Paper	1.00	1.35	1.35	1.23	1.02	1.25	1.00	0.87	0.87	0.96	1.29	1.23	1.25	1.07	1.22
22 Publishing	1.00	0.97	0.97	1.20	0.77	0.93	1.00	0.90	0.90	1.00	2.45	2.45	1.03	1.23	1.22
24 Chemical	1.00	0.90	0.90	1.00	0.85	0.85	1.00	0.82	0.82	1.04	1.08	1.12	1.00	1.00	1.00
28 MP	0.88	0.98	0.86	0.79	0.90	0.71	1.00	1.44	1.44	1.52	0.78	1.19	1.06	1.00	1.05
29 M&E	0.93	1.19	1.10	1.31	0.62	0.82	1.00	0.82	0.82	0.70	0.72	0.50	1.01	1.09	1.05
31 EM&E	1.00	1.22	1.22	1.25	0.77	0.96	1.02	0.79	0.81	1.13	1.09	1.23	0.99	1.14	1.00
32 R&TV	1.00	1.10	1.10	1.00	1.03	1.03	1.00	0.62	0.62	1.00	1.96	1.96	1.00	1.08	1.08
33 MPI	1.00	1.13	1.12	0.94	1.10	1.04	0.95	0.90	0.86	0.58	1.09	0.63	0.91	1.08	0.98
34 MV	1.00	0.74	0.74	1.00	1.25	1.25	1.00	0.96	0.96	1.00	0.83	0.83	1.00	1.08	1.08
35 OTE	1.00	1.51	1.51	1.00	0.20	0.20	1.00	0.69	0.69	1.00	0.83	0.83	1.00	1.69	1.69
36 F&O	0.74	0.77	0.57	1.65	0.94	1.55	1.05	0.99	1.05	3.03	1.10	3.32	1.28	1.08	1.28
Average Total NEISs	0.97	1.07	1.04	1.09	0.85	0.93	1.01	0.90	0.91	1.09	1.20	1.28	**1.03**	**1.13**	**1.11**

Chapter 4.

Investments and energy efficiency in Colombian manufacturing industries*

Abstract

This chapter investigates the effects of investments on energy efficiency performance using data from Colombian manufacturing industries. These industries were analysed as a whole and as EISs and NEISs between 1998 and 2005. Using a simple factor demand model, we estimate the structural parameters of the model using both time-series and cross-sectional dimensions of the data, and we include the effect that investments have on energy efficiency in Colombian manufacturing industries. The results showed that in Colombian manufacturing industries overall, as well as in NEISs, the main variables that determine energy efficiency performance are energy prices, machinery and equipment investments and foreign investments. Whereas electricity prices show lower significance levels, investments in research and development (R&D) are not statistically significant. In contrast, for EISs, only energy prices and foreign investments are statistically significant. Therefore, these results demonstrate the close relationship between energy prices and investments with respect to energy efficiency improvements in Colombian manufacturing industries. These findings have important implications for policy makers aiming to encourage governments to adopt strategies that combine energy prices and technological change, as well as those policy makers wishing to strengthen foreign investment in order to improve technology development, productivity and energy efficiency in manufacturing industries.

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4.1 Introduction

Manufacturing industries are diverse in several areas, including economic activities, how energy is used and how investment decisions are made. Moreover, the differences seen in the manufacturing industries are due to the features of a particular industry, such as growth patterns, the wide-range use of technologies, the facility size and the diversity of the service demands met by that individual manufacturing industry.

The primary interest of the manufacturing industrial sector is to increase productivity and efficiency, to maximize production in a favourably-priced market while complying with quality, safety, labour and to meet environmental regulations in order to maintain operations. Investments that are directly related to these aspects of business operations have the highest priority. Investments related to the reduction of expenses do not currently receive the same amount of attention (Elliott, 2007). However, energy efficiency is part of reducing expenses, and unless other benefits, such as environmental or productivity improvements can be attributed to energy efficiency, these benefits may not be compelling enough for an industry to make these improvements. Yet many technologies that improve energy efficiency also offer benefits in productivity, safety and environmental performance. Improvements in productivity and quality contribute to the economic attractiveness of a given technology and may be the largest deciding factor in decisions regarding technology investments (Martin et al., 2000).

Energy efficiency is the quickest, cheapest and the most direct way to reduce energy demand and CO_2 emissions. With existing technologies, energy savings of up to 30% are already feasible (IEE, 2009). Improvements in energy efficiency applications could meaningfully reduce greenhouse gas emissions. However, the industrial sectors of developing countries generally do not make use of these enormous opportunities and do not exhibit any clear implementation of energy efficiency measures (Painuly et al., 2003). The main barriers to implementing energy efficient measures appear to be a lack of access to appropriate financing mechanisms, poor energy pricing policies, a lack of access to capital, the non-priority of energy efficiency investments, a lack of technical skills and staff awareness and poor information about energy efficiency opportunities (Araujo et al., 2005).

Several studies have examined the relationship between investments and energy efficiency with varying approaches and scopes, including: (I) a fairly broad-ranged, general approach

(Sanstand et al., 1995; Thompson, 1997; EPA, 1998; Clark, 2001); (II) an approach focused on developed and developing countries (Impetus, 2009, Siddayao, 1992; Fersen, 2008, Jackson, 2009); (III) a one-country approach (Yang, 2006 in the Indian context); (IV) an industrial approach (Wade et al., 2000 Worrel and Price, 2001; Sandberg and Soderstrom, 2003); (V) an approach based on specific industries (Axelsson et al., 2009 (in the EISs context) Svensson et al., 2009 (paper industry); Oda et al., 2007 (Iron and steel industry)); (VI) effects of particular policy strategy between energy efficiency and investments (Groot et al., 2001; Bjørner and Jensen, 2002; Laitner, 2009); (VII) an approach attentive to the barriers and obstacles to energy efficiency investments in the industrial sector (Brown, 2004; Elliot and Kaufman; 2009; Prindle et al., 2010); and (VIII) an approach focused on energy efficiency and technology investment (Worrell et al., 2001; Hanson and Laitner, 2004; Luiten and Block, 2004; CEC, 2009). These studies have mainly focused on the potential savings of energy or costs, the application of specific technologies, cost-benefit analysis and qualitative, rather than quantitative, aspects thereof. However, these studies do not include an analysis of the effects of different types of investments on energy efficiency over time, nor are they intended to study the development of investments and their effects on energy efficiency. Finally, they do not address manufacturing industrial sectors at an aggregate level.

In this context, the objective of this analysis is to determine the effect of investments on energy efficiency in manufacturing industries of a developing country such as Colombia[83]. Note that while an increase in the efficiency of energy use may be due to gains in production efficiency (i.e., better technology) or structural gains (i.e., changes in energy prices), the analysis conducted here analysis these two aspects.

The main contribution of this chapter is the analysis of the role of investments and energy prices on energy efficiency in Colombian manufacturing industries at different levels of aggregation between 1998 and 2005; note that for this period, existing economic research that employs quantitative analysis to determine these relationships is limited. The remainder of this paper is organized as follows. Section 2 describes the investment development and energy consumption in Colombian manufacturing industries. Section 3 presents the model, the underlying

[83] Colombia was chosen because within the Latin American context, and especially during the period being studied, this country showed strong and steady GDP growth (the industrial sector has grown on average 2% per year), energy intensity has decreased in the last 15 years 20%, it is an environmental leader among countries with comparable incomes, and the investment in the industrial sector has shown a sustained and dynamic growth (GTZ, 2003; Proexport, 2008; Ambrus, 2008).

methodology and data. The empirical results and discussion are presented in section 4. Concluding remarks are discussed in section 5.

4.2 The investment development and energy efficiency in Colombian manufacturing industries

In this section, we analyse investment developments and energy efficiency in Colombian manufacturing industries. Manufacturing industrial sector is a large energy-consuming sector of the Colombia economy, accounting for almost one-third of energy consumption. During the last decade, Colombian manufacturing industries have shown substantial improvements in reducing energy consumption and productivity. These improvements have been spurred by consumption, exportation and investment.

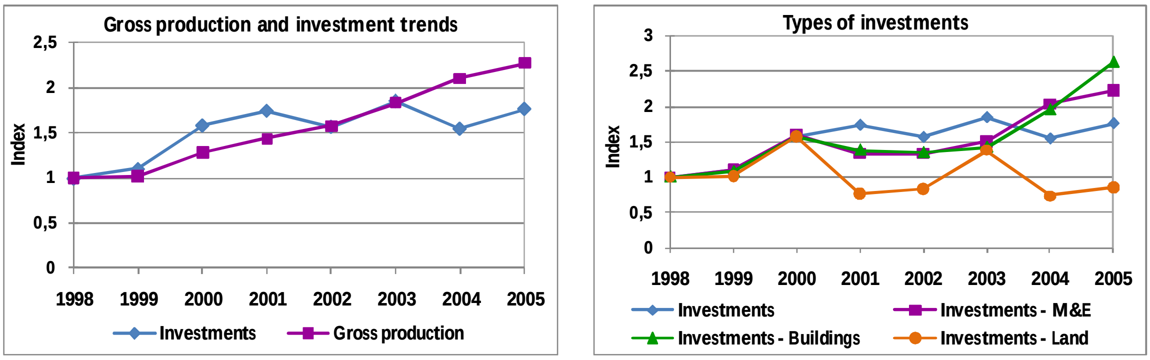
4.2.1 Investments in Colombian manufacturing industries

Investment is fundamental to the growth of a country, especially to its industrial sector. Several studies argue that the speed of development largely depends on the industrial investment level as well as the structure, orientation and efficiency of investments, whereas technology and innovation play a crucial role in the increase of productivity within manufacturing industrial sector and in the development and growth of a country (Romer, 1986; Landes, 1998, Bosworth and Collins, 2004).

During the sample period of 1998 to 2005, investments in the Colombian industrial sector have increased more than 50%; these investments have been particularly concentrated in machinery, equipment and buildings. In fact, building investments have grown at a higher rate than machinery and equipment investments, while land investments have declined in the last years (Figure 1). This trend is explained by the fact that the industrial sector prefers to purchase machinery and equipment or improve existing installations. These lines of purchase can lead to cost-savings through more technologically-advanced equipment and production plants, which in turn can lower costs and/or increase efficiency (Bradford, 1991; Hendricks, 2000).

Note that trends in gross production and investments are similar, indicating a direct relationship between industrial growth and investments (see figure 4.1). This is in line with Astorga (2009), who demonstrated the positive direct contribution of investments to economic growth in Latin American economies.

Figure 4-1 Investment development for Colombian manufacturing industries (Gross production, investment trends and types of investments)



Source: Dane

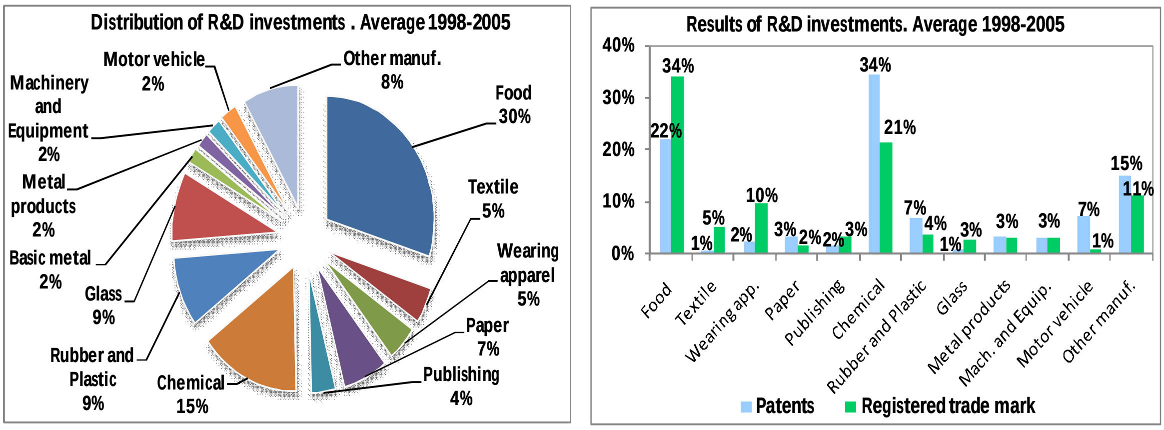
In the last several years, Colombian manufacturing industries have started to entertain investments in research and development (R&D). The average annual increase in R&D investments has ranged between 1% and 3% per year during the sample period of 1998 to 2005. These investments have mainly focused on production line and product improvements, the development of new products and production lines, management technologies and training. The industrial sectors with the most investments in R&D (as well as R&D results) include the chemical industry, the food industry, plastic products, and the cement industry (OCYT, 2005). Figure 4.2 plots R&D investments and results for Colombian manufacturing industries at the 2-digit level.

In terms of the growth of industrial sectors, another important factor is the development of foreign investment, which can contribute to economic development not only as a source of foreign capital but also as a source for employment opportunities, increasing competition and, most importantly, the transfer of skills and knowledge (i.e., spillover effects) (OECD, 2002; Kumar, 2007).

Gross production and foreign investment (FI) have shown consistent growth in Colombian manufacturing industries for the sample period of 1998 to 2005 (Figure 3). In 2005, FI grew 227%. These results are encouraging and can be linked to the recovery of the Colombian economy, improved security in the Colombian economy and policy reforms of Colombia's FI regulatory framework that has increased investor confidence (UNCTAD, 2006).

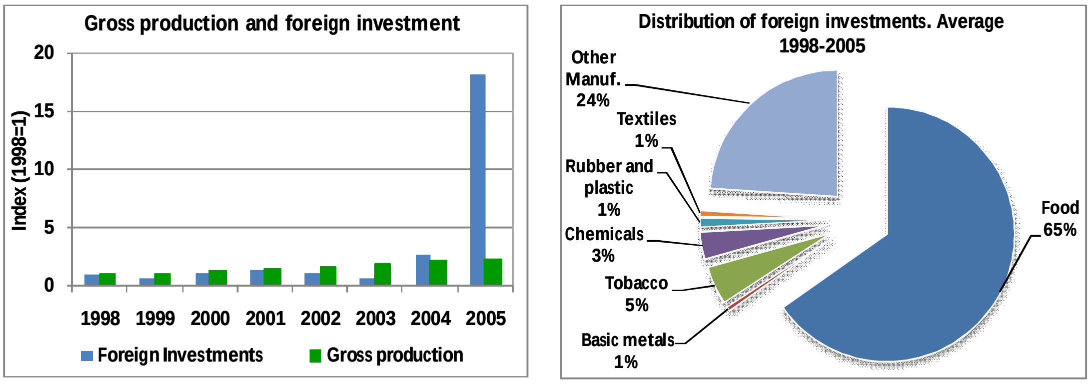
Manufacturing FI has focused on chemicals, metal and food products as well as the manufacturing of mineral and non-metal products. A number of foreign manufacturing firms have been established in Colombia that cater to both domestic and Andean markets. They operate in automotive assembly, food, beverages, tobacco, hygiene and cleaning products, chemicals and pharmaceuticals (Figure 4.3).

Figure 4-2 R&D investments and results for Colombian manufacturing industries at the 2-digit level (Distribution of R&D investments and results of R&D investments on average for 1998-2005)



Source: DANE and OCYT. Patents include granted patents, utility model patents and design patents.

Figure 4-3 Foreign investments in Colombian manufacturing industries[84] (Gross production, foreign investment and the distribution of foreign investments)

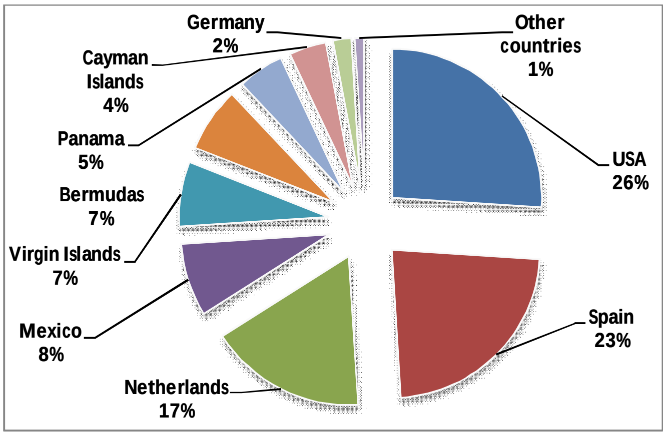


Source: DANE and DNP

[84] The increase of FI in 2005 is mainly due to Bavaria's acquisition by SABMiller. Bavaria is the largest Colombian company operating in the beverages sector, and it manufactures beer, mineral water, sweet drinks and milk. It is the second-largest South American brewer.

Figure 4.4 shows the FI distribution in Colombia by country of origin. The United States provides the most FI (26% of the total amount during the period 1998-2005), followed by Spain (23%) and the Netherlands (17%). Investments from these countries have been mainly directed towards oil and mining, manufacturing, public services and the financial sector.

Figure 4-4 Foreign investments distribution in Colombia by county of origin from 1998 – 2005



Source: Central Bank of Colombia and DNP

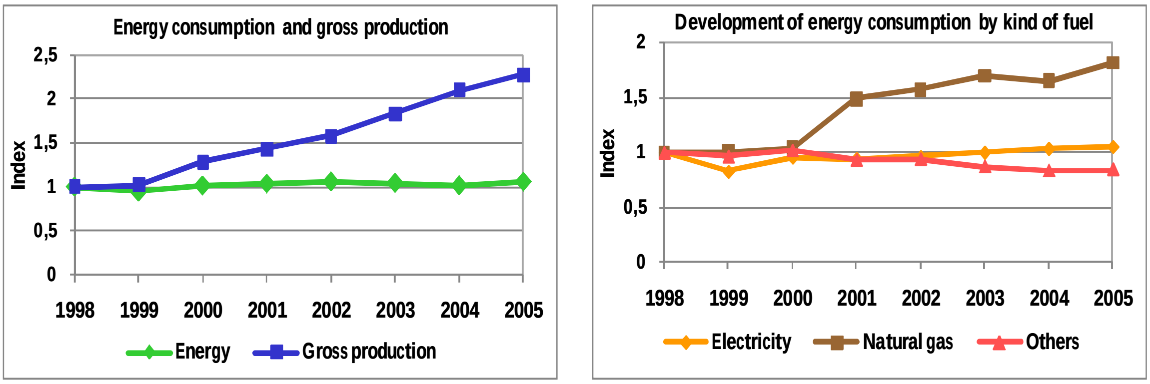
4.2.2 Energy consumption in Colombian manufacturing industries

Between 1998 and 2005, manufacturing industrial energy consumption in Colombia has increased 6%, while the gross production of Colombia's industrial sectors has increased 127% over the same period. The average inter-annual variation rate is 16% for gross production and 0.75% for energy consumption. The behaviour of energy intensity has been relatively homogeneous, with the decreasing trend a result of improvements in energy efficiency (UPME, 2009).

In terms of energy, in 2005, the total final consumption in the Colombian industrial sector was 6 mega tonnes oil equivalents (Mtoe), while primary energy supply (PES) had a relatively balanced mix of fuels. Over the sample period, the main fuel sources were electricity and natural gas, which increased their shares from 1998 to 2005. In fact, electricity and natural gas have grown, while other fuels declined substantially during this period. The trends in energy consumption and gross production show a disarticulation, although the trends themselves are similar (Figure 4.5).

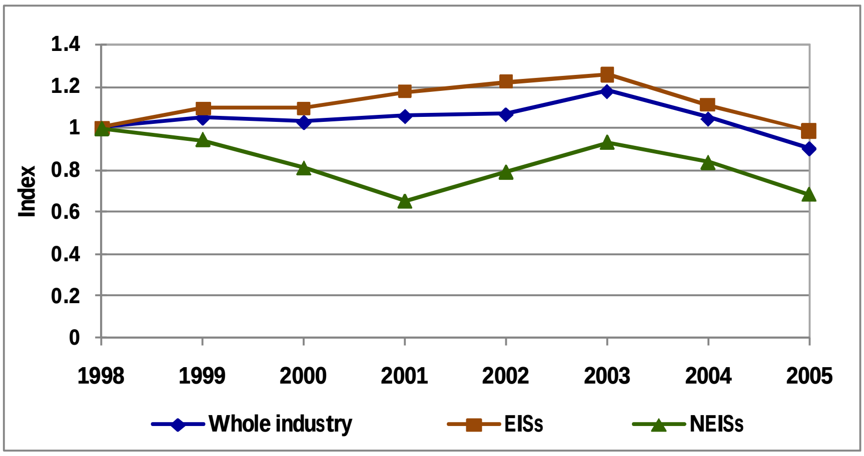
Figure 4.6 shows developments in average energy intensity for the Colombian manufacturing industry as a whole as well as for EISs and NEISs between 1998 and 2005. A quick glance at the figure indicates that energy intensity has decreased by 10% in the case of Colombian manufacturing industry as a whole, by 2% in the case of EISs and by 30% in the case of NEISs. This fact is reflected in most of the sub-sectoral results. Of the 81 industrial sectors analysed, only 26 showed some increase in energy intensity.

Figure 4-5 Trends in energy consumption in Colombian manufacturing industry, 1998-2005



Source: DANE and UPME

Figure 4-6 Energy intensity developments for Colombian manufacturing industry on the whole, EISs and NEISs, 1998 – 2005



4.3 Methods and data

The methods and data used to analyse the relation between energy efficiency and investment are discussed in this section.

4.3.1 Data

The model was applied to inter-sectoral data from Colombian manufacturing industries from 1998 to 2005. The study covers all industrial sectors and EISs at three digits of aggregation level as well as NEISs at two digits of aggregation level[85]. EISs and NEISs[86] were identified by taking into account German energy tax law and by using cluster analysis[87] (Table 4.1).

Table 4-1 Results of cluster analysis of Colombian manufacturing industries (According to ISEC classification of economic activities at the 2-3 digit levels of aggregation)

EIS at 3 digit level			
171	Spinning of textile fibres;	172	Weaving of textiles;
173	Finishing of textiles;	174	Made-up textile articles;
175	Other textiles n.e.c.;	202	Veneer sheets;
211	Pulp, paper and paperboard;	241	Basic chemicals;
251	Rubber products;	252	Plastics products;
261	Glass and glass products;	262	Non-structural non-refractory ceramic ware;
263	Refractory ceramic products;	264	Structural non-refractory clay and ceramic products;
265	Cement, lime and plaster;	266	Articles of concrete, cement and plaster;
267	Cutting, shaping and finishing of stone;	268	Other non-metallic mineral products n.e.c.;
271	Basic iron and steel;	274	Basic precious and non-ferrous metals.
NEISs at 2 digit level			
15	Manufacture of food products and beverages;	18	Manufacture of wearing apparel; dressing and dyeing ;
19	Tanning and dressing leather; manufacture of luggage, handbags, and footwear;	22	Publishing, printing and reproduction on record media;
28	Manufacture of fabricated metal products, except machinery and equipments;	29	Manufacture of machinery and equipment;
31	Manufacture of electrical machinery and equipments;	32	Manufacture of radio, television and communication equipment apparatus;
33	Manufacture of medical, precision and optical instruments, watches and clocks;	34	Manufacture of motor vehicles, trailers and semi-trailers;
35	Manufacture of other transport equipment;	36	Manufacture of furniture; manufacturing n.e.c.

Data necessary to conduct econometric analysis include energy consumption (E_t), gross output of production (Y_t), the price of electricity (P_{El}), the price of energy (P_E), production price (P_t), machinery and equipment investment (I_{MQ}) R &D investment (I_{RD}), foreign investment (I_F) and total investment (I_t). These data were provided by the Departamento Nacional de Estadística (Colombian Department of Statistics, or DANE) and the Unit of Mines and Energy Planning (UPME)[88].

[85] The database used is at the two and three-digit level of aggregation of the Colombian International Standard Economic Classification (ISEC). Colombian statistical data are reporting with this classification.
[86] Generally, the industrial sectors are classified depending on their energy intensity. For instance, categories include heavy industries (EISs) versus light industries (NEISs); strategic (i.e., with lower energy intensity and higher value added) versus non-strategic; and high-energy consumer, high-value-added consumers and low-energy consumers (Eichhammer and Mannsbart, 1997; United States Department of Energy, 1995).
[87] German energy tax law defines EISs as the sectors for which the cost of energy is above 3% of total costs. Moreover, to confirm this criterion, cluster analysis is applied using energy intensity, the share of energy cost and energy consumed by each industrial sector at the 2and 3-digit level as criteria.
[88] See Appendix (1) for more details on the data.

4.3.2 Model

Following the work of Collard et al. (2005) and Beckmann and Sato (1969), we propose a simple factor demand model to generate an interpretable relation between energy efficiency and technological progress. We assume that the production function of the typical firm is a nested constant elasticity of the substitution CES function:

$$Y_t = \left[\omega \{\otimes_t E_t\}^{\frac{1-\sigma}{\sigma}} + (1-\omega)\{F(X_{kt}K_t, X_{Lt}L_t, X_{Mt}M_t)\}^{\frac{1-\sigma}{\sigma}}\right]^{\frac{\sigma}{1-\sigma}} \quad (1)$$

Note that σ is the substitution parameter ($-1 < \sigma < \infty$) denotes the elasticity of substitution between production factors. K is the capital stock of the firm; E is energy consumption; M is the material; and L is the employment level in the firm. We assume X_{kt}, X_{Lt}, and X_{Mt} are exogenous to the firm. The energy-augmenting technological progress, $\otimes_t$, is assumed to evolve as follows:

$$\text{Log}\,[\otimes_t] = \theta_0 - \sigma_{Elt}\text{Log}\left(\frac{P_{El,t}}{P_t}\right) \pm \alpha_{MQt}\text{Log}\left(\frac{I_{MQ,t}}{I_t}\right) \pm \beta_{RDt}\text{Log}\left(\frac{I_{RD,t}}{I_t}\right) \pm \varrho_{Ft}\text{Log}\left(\frac{I_{F,t}}{I_t}\right) \quad (2)$$

Implicit in this specification is that the energy content of production can be partially controlled by the firm, as it depends on the technology and production methods that are chosen to produce output. The endogenous change in the production process is proxied by two variables, namely, prices electricity price ($P_{El,t}/P_t$ = electricity price / production prices) and investment ($I_{MQ,t}/I_t$ = machinery and equipment investment / total investment, $I_{RD,t}/I_t$ = research and development investment / total investment, and $I_{F,t}/I_t$ = foreign investment / total investment). The relationship among prices, investments and energy efficiency could be explained by the fact that higher energy prices, for example, ought to encourage more rapid adoption of energy-saving technologies and thus lead to faster energy efficiency growth[89]. The model assumes perfect competition and profit maximization, which implies that factor prices are equal to marginal productivities. Therefore, the model is formally specified as follows:

$$\log\left[\frac{E_t}{Y_t}\right] = \sigma\log(\omega) - \sigma\log\left(\frac{P_{E,t}}{P_t}\right) + (1-\sigma)\log(\circledast_t) \quad (3)$$

[89] For industrial sectors, increasing energy prices drive up costs and decrease their added value. Successful, cost-effective investments into energy efficiency technologies and practices meet the challenge of maintaining high-quality product output despite reductions in production costs. This is especially important, as energy-efficient technologies often include additional benefits such as increasing productivity at the firm level (Worrel and Galitsky, 2008).

where $P_{E,t}$ is energy price and P_t is production price. The variable E_t/Y_t represents the energy content of production, or energy efficiency. Simple as this theory is, it provides us with a set of explanatory variables for the technical coefficient. Substituting (2) into (3) leads to a log-linear equation (4) from which estimates for the vector of structural parameters $\Phi \equiv (\sigma, \sigma_{Elt}, \alpha_{MQt}, \beta_{RDt}, \varrho_{Ft})$ can be obtained.

$$\log\left[\frac{E_t}{Y_t}\right] = \sigma \log(\omega) - \sigma \log\left(\frac{P_{E,t}}{P_t}\right) + (1-\sigma)\left[\theta_0 \pm \sigma_{Elt}\log\left(\frac{P_{El,t}}{P_t}\right) \pm \alpha_{MQt}\log\left(\frac{I_{MQ,t}}{I_t}\right) \pm \beta_{RDt}\log\left(\frac{I_{RD,t}}{I_t}\right) \pm \varrho_{Ft}\log\left(\frac{I_{F,t}}{I_t}\right)\right] \quad (4)$$

As can be seen from equation (3), E_t/Y_t is the dependent variable[90]. Hence, depending on the algebraic signs of the coefficients, the individual variables either have positive or negative effects on energy efficiency. The objective of the applied production function is the estimation of the signs and sizes of the coefficients. In the panel approach we adopt, which combines cross-sectional and time-series dimensions of the data, the production function is estimated using a panel model with fixed effects for the whole industry and EISs and random effects in NEISs[91] to determine the effect of prices and investments on energy efficiency in Colombian manufacturing industries.

4.4 Empirical results

Table 2 shows the estimation results for Colombian manufacturing industries for three estimations (i.e., all industrial sectors, EISs and NEISs) as well as for the explanatory variables, including the price of energy ($P_{E,t}$), the price of electricity ($P_{El,t}$) machinery and equipment investment ($I_{MQ,t}$) research and development investment ($I_{RD,t}$), and foreign investment ($I_{F,t}$), respectively. As can be seen from table 2, the three estimations show similar results, and the

[90] Energy efficiency is denoted as the inverse of energy intensity (that is, energy used per unit of economic production).

[91] The method of estimation of the production function at every level of aggregation of industrial sector was established using results of the Hausman test. To determine the robustness of the results, we apply the Wooldridge test for serial autocorrelation and modified Wald test for groupwise heteroskedasticity in the case of fixed effects and Breusch and Pagan Lagrangian multiplier test for random effects. These tests show that there are problems of autocorrelation and heteroskedacity. To solve these problems, we use in the case of fixed effects Driscoll and Kraay standard errors and Feasible Generalized Least Squares (FGLS) in the case of random effects. The results of these estimations show again that energy prices, machinery and equipment and foreign investments encourage a decrease in aggregated energy intensity in the Colombian manufacturing industries and some cases the significances are higher.

energy prices and foreign investment variables have a statistically significant effect on energy intensity. However, R&D investment is statistically insignificant.

For Colombian manufacturing industry as a whole and for NEISs, the main variables determining energy efficiency performance include energy prices, machinery and equipment investments and foreign investments, whereas electricity prices show lower significance levels. R&D is not statistically significant. In contrast, for EISs, only energy prices and foreign investments are statistically significant; electricity prices show a negative effect on energy efficiency, but it is not statically significant.

Table 4-2 Estimation results of production function in Colombian manufacturing industries

Parameter	Colombia		
	All manufacturing industries	EISs	NEIs
	Fixed Effects	Fixed Effects	Random Effects
Intercept	1.530*** (0.204)	1.596*** (0.287)	-0.158 (0.402)
Energy Price σ	-0.038*** (0.008)	-0.379*** (0.067)	-0.037*** (0.008)
Ele. Price σ_{Elt}	-0.110* (0.058)	0.061 (0.070)	-0.203* (0.112)
M&E Inv. α_{MQt}	-0.074** (0.032)	-0.013 (0.036)	-0.143** (0.061)
R&D Inv. β_{RDt}	-0.009 (0.012)	-0.013 (0.013)	-0.008 (0.027)
For. Inv. ϱ_{Ft}	-0.012** (0.004)	-0.011** (0.005)	-0.015** (0.006)
Hausman test. P value	0.000	0.000	0.193
Obs.	256	160	96

Notes: *Figures in parentheses are standard errors;*
, **, * imply significance at the 10%, 5%, and 1% levels, respectively.*
[a] *If Prob > chi2 < 0.05, reject random effects.*

The elasticities derived from the structural coefficients can be interpreted in such a way that, e.g., in Colombian manufacturing industry as a whole, a 1% increase in energy prices leads to a 0.038% decrease in energy intensity. In EISs, a 1% increase in foreign investment leads to a 0.015% decrease in energy intensity, while in NEISs, a 1% increase in machinery and equipment investments leads to a 0.148% decrease in energy intensity.

The results indicate that developments in energy efficiency are similar in Colombian manufacturing industry as a whole and NEISs, whereas EISs show a different trend. This fact might be explained by differences in production levels, since 70% of gross production is generated by NEISs. However, 73% of energy consumption occurs in EISs, indicating that aggregated energy intensity is highly dependent on the changes in EISs. This is in line with

Sahu and Narayanan in the context of Indian manufacturing and Cornillie and Fankhauser in the context of transition countries.

Electricity prices show a negative effect on energy efficiency in the EISs; this result can be explained by the relatively lower price of electricity with respect to other fuels (e.g., coal or petroleum products), which in turn generates an increase in electricity consumption and a decrease in energy efficiency. Lower overall intensity cannot be reached and maintained without a sufficiently high level of end-use electricity prices because increases in electricity prices tend to generate higher technological competitiveness (Verbruggen, 2006; Yang, et al., 2006). Therefore, the development of an adequate electricity price policy is important, especially for Colombian EISs aiming to increase energy efficiency and to improve productivity through technological change and best practices in energy use.

Energy prices show positive effects on energy efficiency in Colombian manufacturing industries. This fact can be explained by increases in energy prices at an average rate of 6.5% per year during the sample period, which led to a decrease in energy intensity by an average rate 1.95% per year. These results demonstrate that energy prices are the most important determinants of energy consumption and efficiency; as has been documented by other analyses, energy prices have been successfully used to promote energy savings in the last year in the industrial sector (Mure-Odyssee, 2006), and high energy prices motivate industrial facilities to secure the amount of energy required for operations at the lowest possible price (McKane et al., 2008).

The results also indicate that FI encourages a decrease in aggregated energy intensity in the Colombian industrial sector, which is in line with the increase of these investments by an average rate of almost 25% per year during the sample period due. This increase can be attributed mainly to changes in foreign direct investment legislation in the last years[92] as well as political and economical conditions.

[92] The purposes of foreign investments in Colombia are the following: (I) Be an instrument for job creation and attraction of new investments; (II) Be a development centre that promotes competitiveness in the regions where they are located; (III) Develop highly productive and competitive industrial processes, within the parameters of security, transparency, technology, clean production and sound corporate practices; (IV) Promote better exploitation of economies of scale; (V) Simplify procedures for the commercialization of goods and services to facilitate sales (Gomez, 2001; Fedesarollo, 2007).

Several studies have demonstrated that FI has helped Colombia diversify its economy from the production of traditional goods into several urban and industrial sectors; it has also encouraged the creation of jobs with better salaries, an increase in new programs aimed at protecting workers rights and the environment and new opportunities for technological transfers, which, on the one hand, increase productivity and, on the other hand, accelerate innovation and technological development. Moreover, FI has introduced new technologies and skills; research has found evidence of spillovers through backward linkages in the manufacturing sector (UNCTAD, 2006; Kalin, 2009).

Machinery and equipment investments show a positive effect on energy efficiency and are statistically significant for manufacturing industry as a whole and for the NEISs. These results should demonstrate that technological change is closely related with improvements in energy efficiency in manufacturing industries, and that in developing countries, it is necessary to encourage adequate technological transfers in order to increase energy efficiency and decrease CO_2 emissions. Current market developments show that there is a huge demand for technology transfers to developing nations to achieve energy efficiency and emissions reduction in their industrial sectors. However, it is important to realise that successful technologies must also meet a host of other performance criteria, including cost competitiveness, safety and regulatory requirements; these technologies must also achieve consumer acceptance (Worrel et al., 2009).

R&D investment shows a positive effect on energy efficiency, though this effect is not statistically significant, which can be partly explained by low R&D expenditures. The results of R&D investments emerge in the medium and long run, but R&D investment is a relatively recent phenomenon in Colombian manufacturing industries, where it is focused mainly on improving products and productions lines in Colombian manufacturing industries.

However, R&D investment is widely recognized as the linchpin of technological advancement, such that the growth rates and levels of R&D expenditures are viewed as reliable indicators of innovative capacity (Boskin and Lau, 1992). Given the multitude of technologies using energy in final-energy sectors and the vast number of options for improving the efficient use of energy in industry processes, machinery and equipment, the identification of promising energy efficiency potentials through R&D becomes a major challenge for today as well as the future (Jochem, 2004). For these reasons, it is important to encourage an increase in R&D activities to improve technological levels and innovative capacities, especially in Colombian manufacturing industry.

Moreover, these results indicate that a close relationship exists between energy prices and investments not only with respect to the improvement of energy efficiency, but also regarding additional benefits such as increases in productivity and competitiveness in Colombian manufacturing industry. This is in line with Pizer et al. (2002), who found that changes in energy prices may result in faster technological development and higher levels of energy efficiency in the context of manufacturing plants in the United States.

These results have important implications for policy makers, focusing their attention on the manufacturing industries of developing countries. The results suggest that such policy makers should encourage governments to adopt strategies that adequately combine energy prices and technological change by promoting technology transfers through an appropriate enabling framework. Policy makers should also try to enhance international cooperation to scale sustainable energy solutions as well as strengthen FI through policies aimed at improving technological development, productivity and energy efficiency in manufacturing industries. Likewise, it is important to encourage the adoption of energy-efficient technologies and management practices within industry.

4.5 Conclusions

In this chapter, the effects of investments on energy efficiency performance were investigated using data from Colombian manufacturing industries; these industries were analysed as a whole and as EISs and NEISs between 1998 and 2005.

During the sample period, the investments in Colombian manufacturing industries increased more than 50%; these investments were particularly focused in machinery, equipment and buildings. In addition, FI showed consistent growth for the sample period; these investments encouraged the diversification of the economy, job creation and new opportunities for technological transfers. Moreover, energy intensity decreased in Colombian manufacturing industries.

To analyse the effects of investments on energy efficiency, a factor demand model was estimated. Taking advantage of both time-series and cross-sectional dimensions of the panel, the model was estimated using a panel model with fixed effects for industry as a whole and EISs and with random effects for NEISs.

The results indicate that for Colombia's manufacturing industry as a whole and for NEISs, the main variables that determine energy efficiency performance are energy prices, machinery and equipment investments and foreign investments, whereas electricity prices show lower significance levels. R&D is not statistically significant. In contrast, for EISs, only energy prices and foreign investments are statistically significant; electricity prices show a negative effect on energy efficiency is not statically significant. Therefore, energy prices and investments have a close relationship not only with improvements in energy efficiency but also with additional benefits such as increased productivity and competitiveness.

These findings have important implications for policy makers focusing their attention on the industrial sectors of developing countries. The results suggest that such policy makers should encourage governments to adopt strategies that adequately combine energy prices and technological change and to strengthen FI with policies aimed at improving technological developments, productivity and energy efficiency in manufacturing industries. In the future, these results should be further scrutinized by using data on other sectors and other countries.

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Appendix

Appendix 1 Summary of the main variables used for Colombian manufacturing industries

Variable	Main Sources
Monetary gross output of production	DANE (Table: 3.1)
Energy consumption (TJ)	UPME (Energy balance)
The price of energy – Relationship between expenditure on energy and energy consumption	DANE, UPME and author's calculations
The price of electricity - Relationship between expenditure on electricity and electricity consumption	
Production price	DANE (Table: 0.26)
Total investment	DANE (Table: 5.5)
Machinery and equipment investment	
Research and development investment	DANE (Table: 5.5 and report: Innovation and technology development in the manufacturing industries)
Foreign investment	Central Bank of Colombia and DNP (Table 3 and 2 respectively)
The series were transformed as follows. First, the variables were deflated using the respective wholesale price index. Second, we used exchange rates to account for monetary variables in Euros. Third, we used an average exchange rate of $ Colombian peso. 1Euro = $2422.39 during the sample period. Fourth, the variables E_t/Y_t, $P_{E,t}/P_t$, $P_{El,t}/P_t$, $I_{MQ,t}/I_t$, $I_{RD,t}/I_t$, $I_{F,t}/I_t$ were taken in logs.	

PART II.

ANALYSIS OF ENERGY EFFICIENCY DEVELOPMENTS IN SPECIFIC INDUSTRIAL SECTORS IN GERMANY AND COLOMBIA

What we need to do is really improve energy efficiency standards,
develop in full scale renewable
and alternative energy and use the one resource
we have in abundance, our creativity.
Lois Capps

Chapter 5.

Analysis of energy efficiency development in the German and Colombian food industries*

Abstract

In this chapter, we conduct a cross country and cross sector analysis of energy consumption and energy efficiency in German and Colombian food industries. The main goal of this chapter is twofold. Using data at the three-digit level of aggregation, the study compares energy efficiency across sectors of the food industry for the period 1998-2005. Energy efficiency is analysed using the energy intensity indicator as well as a decomposition analysis. To determine the factors that have influenced energy efficiency performance, we employ regression and correlation analysis. The results showed that both countries' food industries improved energy efficiency. During the period of study, energy consumption in the German food industry increased by an average of 1.3% per year and the energy intensity decreased 7%, whereas the Colombian food industry decreased its energy consumption by an average of 1.9% per the year and the energy intensity decreased 11%. However, Colombian food industry needs 2.2 times more energy than German food industry to produce a unit of gross production. A decomposition analysis indicated that economic and technical factors have played an important role in the energy efficiency performance because increases in economic growth and technology improvements increase the industrial sector's ability to improve energy efficiency. In order to determine the effects of different factors in energy efficiency performance across sectors and countries a regression analysis was performed in terms of several key characteristics of food industry. This analysis reveals that the variables such as energy price and index of production have positive influence in energy efficiency; and size enterprises have played an important role in energy efficiency performance in Colombian food industry. The results of correlation analysis for the concentration process variable indicated that this variable had played an important role in the reduction of energy intensity in the Colombian food industry, and the investment variable had a significant correlation with the improvements in energy efficiency performance in both countries.

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5.1 Introduction

In recent times, one of the main goals of the global environmental agenda is the decrease of emissions of carbon dioxide for the effects that they can have on the earth's climate pattern and for their potential consequences in the environmental, societal and economic realms. The increase of atmospheric carbon dioxide has driven the design and development of policy whose main challenge is the control of climate change. To this end, energy efficiency is one of the chief strategies to control the production of greenhouses gases (e.g., the European Commission on the 2006 green paper, "A European Strategy for Sustainable, Competitive and Secure Energy", has considered energy efficiency the most important and effective policy instrument to achieve energy policy goals, and a 2001 report by the International Panel for Climate Change finds that improvements in energy efficiency have the potential to reduce global CO_2 emissions by 30% below year 2000 levels using existing technologies at a cost of less than 30 US$/t$CO_2$). These elements suggest the importance of measuring energy efficiency and monitoring its changes in order to verify the improvement and effectiveness in the policies applied.

In this context, assessing the energy efficiency[93] of some economic activity generally uses energy intensity, which is defined as the ratio of energy used per unit of output. Several studies have analysed the advantages and disadvantages of different methodologies for measuring the changes and improvements of energy efficiency, taking into account the impact of policies, energy prices and technological development (e.g., Boyd et al., 1988, International Energy Agency, 1997, Phylipsen et al., 1996, Diekmann et al., 1999, World Energy Council, 2001), and their conclusions suggest that, to measure energy efficiency performance, a good approach is the design and use of indicators that show the relationship between energy consumption and output while accounting for economic and technical influences.

Studies on the food industry and its energy use have mainly examined the application of new technologies and their potential energy savings for specific factories such as meat, dairy, beer, and others (Mirza, 2008; Klemes and Stehlik, 2007, Fritzson and Berntsson, 2005, Burfoot, et al. 2004, Banga et al., 1994), the application of energy management and clean production (Muller et al., 2007, Kumar et al., 2003, Hyde et al., 2001, Henningsson et al., 2001, Kramer et al., 1999) and rationale use of energy and innovative technology (Sieberger et al., 2001). This

[93] Energy efficiency is measured as the inverse of energy intensity, and it refers to improvements in fuel economy, power plant heat rates, building operations, industrial processes, etc. (Shipper and Grubb, 2000; Hanson and Laitner, 2004 and Baksi and Chris, 2007).

again indicates the relative lack of attention paid to the analysis of energy use across sectors of food industry as well as the lack of studies determining the factors that have affected energy consumption and energy efficiency performance using cross-country and cross-sectoral comparisons.

In order to address this deficiency, the main goal of this chapter is twofold. The first is to examine in detail energy efficiency performance of German and Colombian food industries (ISEC 15) using the energy intensity indicator as well as a decomposition analysis. The second is to explain the factors that have influenced energy efficiency performance with empirical analysis using regression and correlation analysis. We carry out the analysis for the period 1998-2005 and at a 3-digit level of aggregation.

The structure of this chapter is as follows. The first section briefly describes the food industry, its importance in both countries' economies and the features of energy use in this sector. The second section provides a description of the methodology and data used. The third section exposes the main results of energy intensity and decomposition analysis. The following section provides an application of the regression and correlation analysis and a discussion of the results. Finally, conclusions are drawn in the last section.

5.2 The German and Colombian food industries and energy use

Food manufacturing transforms livestock and agricultural products into a diverse set of products for intermediate or final consumption by humans (or by animals as animal feed) and includes all sorts of technical, trading and service activities related to storage and processing, packaging, transport, distribution of food, and catering. In Germany and Colombia, the food sector represented about 7% and 19%, respectively, of the total energy consumed by the manufacturing sector in the year 2005[94] (Destatis, 2007 and UPME, 2007). In the same year, with a total of 4,958 establishments in Germany and 1,553 in Colombia, this sector accounted for about 10% and 22%, respectively, of industrial employment and 7.3% and 26.4%, respectively, of the industrial value added. In terms of costs, however, energy only amounted to about 2% to 3% of gross production in the food manufacturer industry. The food industry can be

[94] It does not include agriculture and mining.

broken down into 10 three-digit ISEC[95] industry sectors in accordance with raw materials (generally of animal or vegetable origin) and their processing into food products. This industry is highly diversified and dominated by large-scale and capital-intensive firms. Figure 5.1 shows the energy demanded by the food sector in comparison to the total manufacturing industry and its distribution by food sub-sector in both countries.

Energy is an essential input to ensure that processes function properly and that food and beverages are safe and can be preserved and stored under controlled conditions[96]. Manufacturers of other food products (ISEC 158)[97] and manufacture of beverages (ISEC 159) were the largest energy consumers in 2005 in both countries. The energy sources used during the period of study by food industry were relatively constant except for electricity and natural gas, which in both countries increased while fuel oil and coal decreased, e.g., in 2005: in Germany and Colombia, 44% and 10%, respectively, of the energy used by factories came from natural gas, 32% and 18%, respectively, from electricity, 21% and 16%, respectively, from fuel oil, and 3% and 45%, respectively, from other sources[98]. Figure 5.2 shows the relative energy flows within a food plant. At the food and beverage processing level, energy is consumed in: cooking, heating, packaging, storing, handling, sterilising, freezing, and refrigerating various farm products, and the total energy used for plant food preparation includes energy consumed by appliances (stoves, refrigerators, freezers, microwaves, ovens, heating and lights); in these processes, energy losses (5%-15%) may generate at each step. While the ‘‘hot’’ processes (e.g., drying, cooking, frying, evaporation, pasteurisation, sterilisation) rely on natural gas, petroleum derivatives, and, to a lesser extent, electricity, the ‘‘cold’’ processes (e.g., freezing, cooling, and refrigeration) are almost completely dependent on electricity (CAEEDAC, 2000 and Maxime and Marcotte, 2006).

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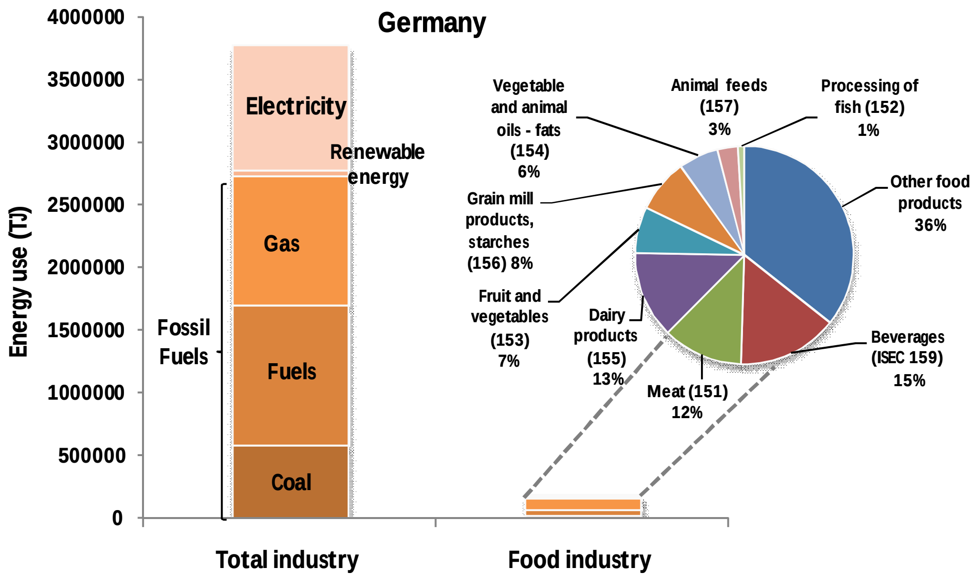
[95] ISEC classifies data according to the kind of economic activity; German and Colombian statistical data are reporting with this classification.

[96] Approximately half of all energy end-use consumption is used to change raw materials into products (process use). Boiler fuel represents nearly one-third of end-use consumption (boiler fuel can be used to produce steam, which can have two end-uses). Moreover, food preservation is dependent on strict temperature controls; safe and convenient packaging is extremely important in food manufacturing and is also energy intensive (Okos, et al., 1998).

[97] The manufacture of other food products includes the manufacture of bakery products, the manufacture of cocoa, chocolate and sugar confectionery, the manufacture of macaroni, noodles, couscous and similar farinaceous products and the manufacture of other food products n.e.c. (e.g., the production of coffee products and the manufacture of extracts and preparations based on tea).

[98] In 2000, 29% of the German food sector’s energy came from electricity, 41% from natural gas, and 26% from fuel oil. In Colombia, 16% of the food sector’s energy came from electricity, 6% from natural gas and 15% from fuel oil.

Figure 5-1 Comparison of energy used by the German and Colombian food industries, 2005. (According to ISEC classification of economic activities at the 2-3 digit levels of aggregation)



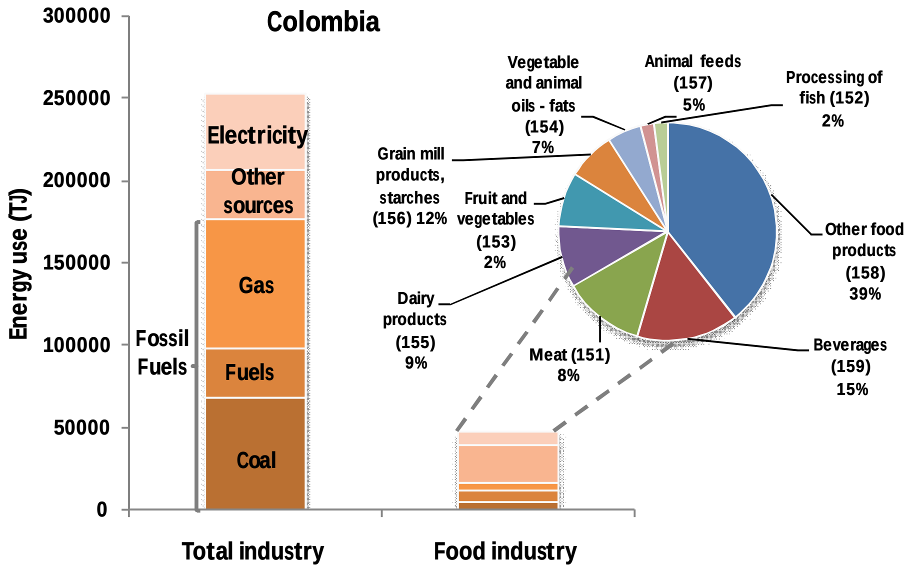
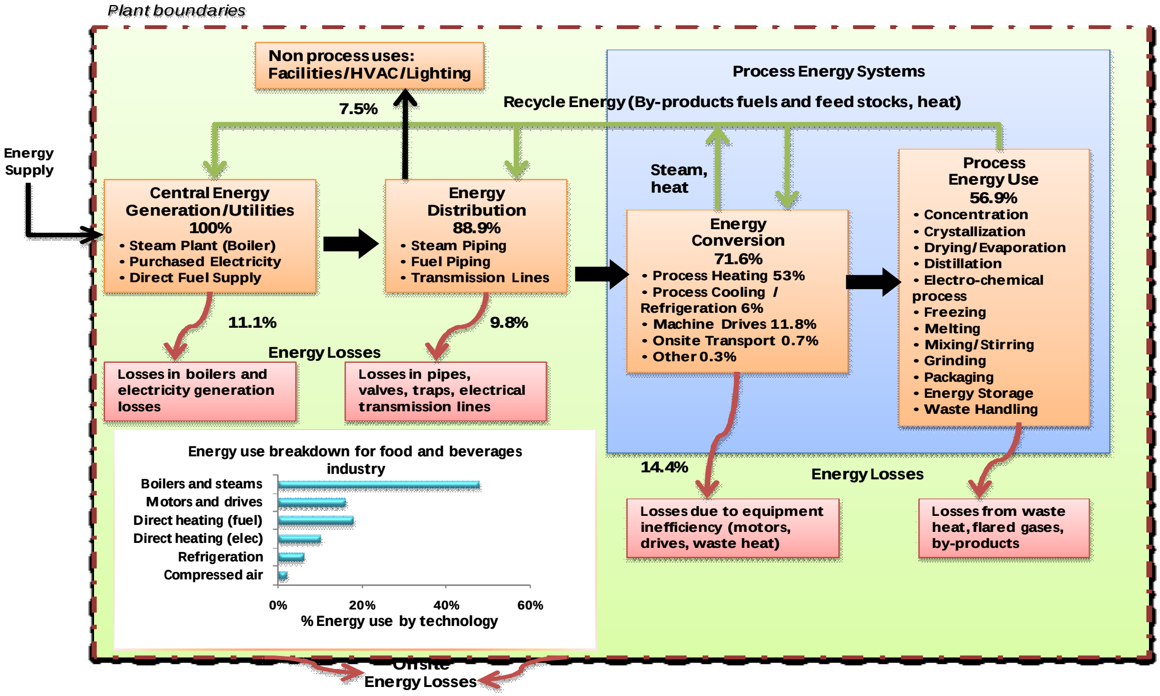


Figure 5-2 Energy flows within the food and beverages industry



Source: U.S. Department of Energy 2004, Maxime et al., 2005 and Okos et al., 1998.

5.3 Data and methodology

The analysis made in this chapter and the analysis of energy efficiency developments in the German and Colombian food industries depended on the methodology used and the kind, availability and reliability of the data required. This section described the data sources used and the methods used to assess energy efficiency in the food industry.

5.3.1 Data

Data of German and Colombian food industries are published by the Statisches Bundesamt Deutschland (German Bureau of Statistics) and the Departamento Nacional de Estadística (Colombian Department of Statistics, DANE). German energy data were taken from the annual energy balances for the food industry published in the Use of the Environment and the Economy Report by Statisches Bundesamt Deutschland (German Bureau of Statistics), and Colombian energy data are published by Departamento Nacional de Estadística (Colombian Department of Statistics, DANE) and Unidad de Planeación Minero Energética (Unit of Mines and Energy Planning, UPME). In this study, unless otherwise specified, energy refers whole energy consumption for each food industrial sector only. Colombian data are published in the Annual Manufacturing Survey and in reports of UPME. They base their analysis on 3-digit levels of disaggregation of the German and Colombian International Standard Economic Classification (ISEC). The advantage of using this highly disaggregated data is that it is closer to the industrial process itself[99].

5.3.2 Energy intensity

Energy intensity indicators measure the quantity of energy required to perform an activity. In this study, the energy intensity (EI) is defined as the energy used per unit of economic production (Equation 1).

$$EI_i = \frac{E_i}{P_i} \qquad (1)$$

EI_i = $Energy\ intensity\ indicator\ (Mj/€)$

E_i = $Final\ energy\ consumption\ of\ the\ food\ sector\ i\ (e.g., Mj)$

P_i = $Production\ of\ food\ sector\ i$ (€)

5.3.3 Decomposition analysis

An index decomposition methodology is applied to analyse the change effect of a sector's structure on energy intensity and energy consumption. There are several decomposition methods; Ang and Zhang (2000) give a survey of different methodologies. This study chooses to use a Multiplicative Log-Mean Divisia Method, which has shown to be "perfect in decomposition but also consistent in aggregation" (Ang and Zhang, 2000).

The energy intensity approach has been applied. In this approach, the total change in aggregate energy intensity (EI_{agg}) is decomposed into a structural effect (F_{str}) associated with the industrial

[99] In order to ensure comparability between countries and over time, the series were as follows: (i) the variables were deflated using the respective wholesale price index (1998=100) (ii) we use exchange rates to account for monetary variables in Euros in the Colombian case. See Appendix (1) for more details on the data.

composition of the sector, and an intensity effect (F_{int}) associated with changes in sector energy intensity[100]. The equations used are shown below (Ang and Zhang, 2000):

- Decomposition method:

$E_t = \sum_i E_{it}$ (1)

$E_t = The\ food\ sector's\ energy\ consumption\ in\ the\ year\ t$

$E_{it} = Subsector's\ energy\ consumption\ in\ the\ year\ t$

$i = The\ index\ of\ sub-sector$

$Y_t = \sum_i Y_{it}$ (2)

$Y_t = Level\ of\ output\ or\ total\ food\ industrial\ production\ in\ year\ t$

$Y_{it} = Unit\ of\ activity\ or\ subsector's\ production\ in\ year\ t$

$EI_{it} = E_{it}/Y_{it}$ (3)

$EI_{it} = Energy\ intensity\ of\ subsectors$

$S_{it} = Y_{it}/Y_t$ (4)

$S_{it} = Structural\ parameter$

- Energy intensity approach:

$EI_{agg} = \sum_i S_{it} * EI_{it}$ (5)

$EI_{agg} = Aggregate\ energy\ intensity$

$S_{i,t} = Production\ share\ of\ sector\ i\ in\ year\ t\ (= Y_{i,t}\ /\ Y_t)$

$EI_{i,t} = Energy\ intensity\ of\ sector\ i\ in\ year\ t\ (= EI_{i,t}\ /\ Y_{i,t})$

$F_{tot} = EI_{aggt}\ /\ EI_{agg0} = F_{str} * F_{int}$ (6)

$F_{tot} = Total\ change\ in\ aggregate\ energy\ intensity$

$F_{str} = Structural\ effects$

$F_{int} = Intensity\ effects$

$F_{str} = exp\left\{\sum_i \frac{L\ (\omega_{i,t}\ \omega_{i,0})}{\sum_i L\ \ (\omega_{i,t}\omega_{i,0})} \ln(\frac{S_{i,t}}{S_{i,0}})\right\}$ (7)

$F_{int} = exp\left\{\sum_i \frac{L\ (\omega_{i,t}\ \omega_{i,0})}{\sum_i L\ \ (\omega_{i,t}\omega_{i,0})} \ln(\frac{EI_{i,t}}{EI_{i,0}})\right\}$ (8)

$\omega_x = Energy\ share\ of\ sector\ i\ in\ year\ t\ (= E_{i,t}\ /E_t)$

Where

$L(x, y) = (y - x)/\ ln\ (y/x)$

[100] This approach is used because allows measurement of efficiency, separating out the influences of structure and energy intensity. Moreover, the changes in energy intensity can be interpreted as "indicator" of change in energy efficiency.

5.4 Energy efficiency development in the German and Colombian food industries

During the period of study, energy consumption in the German food industry increased by an average of 1.3% per year, largely due to the manufacture of other food products and dairy products, whereas the Colombian food industry decreased its energy consumption by an average of 1.9% per the year, mostly due to the beverages and vegetable and animal oils and fats sectors. Energy efficiency performance was assessed using the methods described in the methodology section in order to analyse the relationship between energy consumption and output across sectors of food industry at 3-digit levels of aggregation during the sample period.

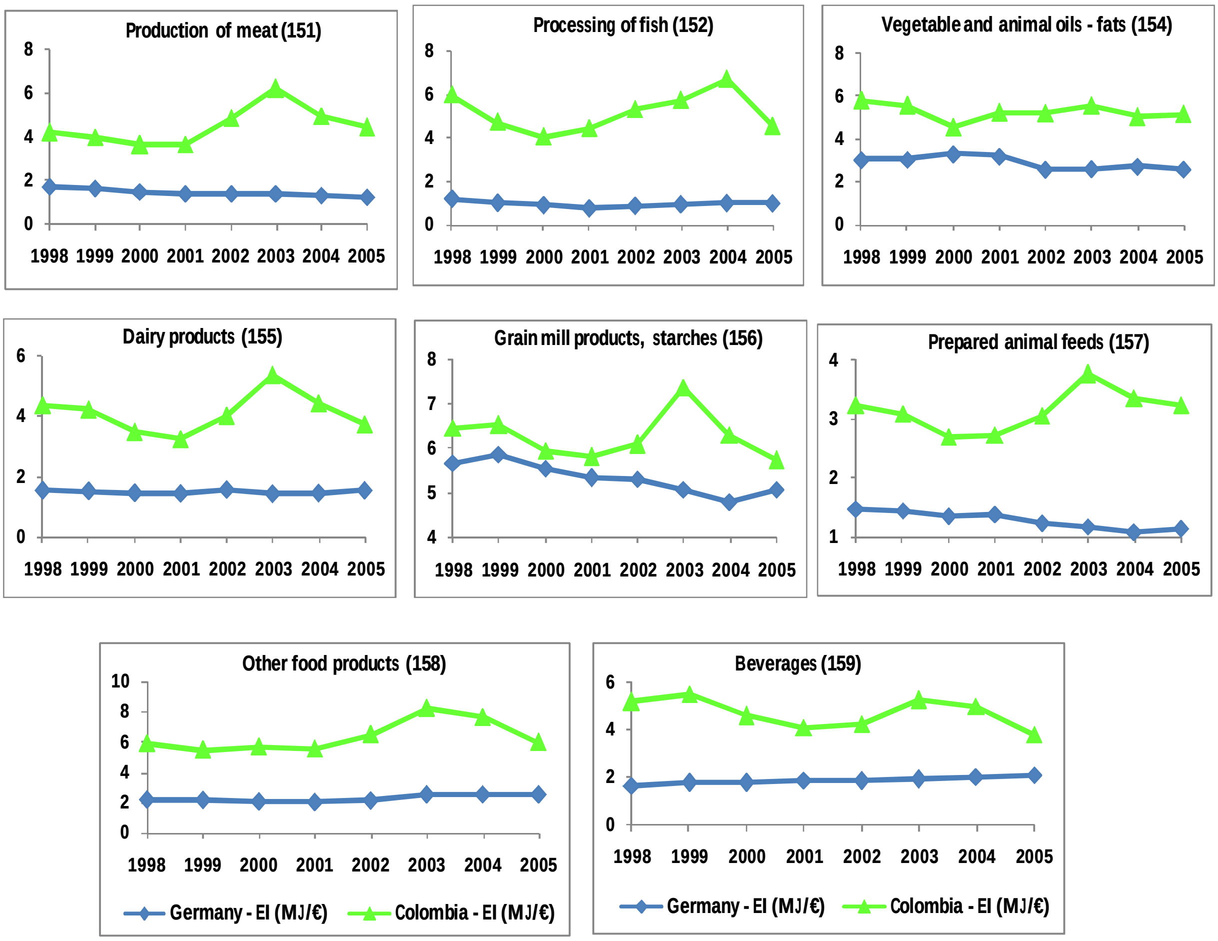
The results of the German energy intensity indicator as gross production showed that the more energy-intense sectors were the manufacture of grain mill products (5.1 Mj/euro in 2005) and the manufacture of vegetable and animal oils (2.6 Mj/euro in 2005). The manufacture of beverages and the manufacture of other foods increased in this measure while the other sectors decreased in this measure by an average of 17%. In the Colombian case, the manufacturers of grain mill products (5.7 Mj/euro in 2005) and the manufacture of other food products (5.9 Mj/euro in 2005) were the most energy-intense sectors. Production, processing and preserving of meat and meat products and the manufacture of other foods increased in this indicator, whereas the other sectors decreased this indicator by an average of 12% (see figure 5.3). Moreover, the values of energy intensity were higher in the Colombian food industry than in the German food industry (on average, Colombia needs 2.2 times more energy than Germany to produce a unit of gross production).

In Colombian food industry, an outstanding increase in the values of energy intensity occurs between 2002 and 2003, indicating a decrease in the energy efficiency in these years in the Colombian food industry. These results could be explained by the use of currency exchange rate method in the assessment of energy intensity where results are subject to a great deal of volatility due to economic fluctuations, which concur with the behavior of the world economy in these years that was characterised mainly by sluggish growth of output, euro revaluation[101] and inflation edging upwards, indicating the direct relationship between improvement of energy efficiency and economic stability. Moreover, these results suggest that the energy efficiency performance in the Colombian food industry is dependent on economic factors (e.g. exchange

[101] In the Colombian case, the exchange rate between Euro and Colombian Peso increased on average 30% between 2001 and 2003 increasing the values of energy intensity on average 40% during these years.

rate behaviour) and that energy intensity performance is more sensitive to economic changes in developing countries than developed countries due to the fact that industrial output is so closely linked to economic growth and prosperity[102], as can be observed in the results.

Figure 5-3 Developments in energy intensity by sectors of German and Colombian food industries



5.4.1 Decomposition analysis

In order to analyse the results of energy intensity in the German and Colombian food sector, the Multiplicative Log-Mean Divisia Method I was used, which was described in the methodology section. The analysis was carried out for every food sector (3-digit level of disaggregation) in both countries between 1998 and 2005. Moreover, the decomposition analysis was made also for electricity and fuel with the aim to evaluate differences in inter-fuel composition and the role

[102] The energy use, the level of economic activity and the structural change in the economy are strongly linked, and they contribute to energy intensity performance in the industrial sector of a country (Stern, 2003 and Cotte, 2007).

of substitution fuels in energy efficiency performance in the German and Colombian food industries. The changes observed in energy consumption and aggregated energy intensity and the relative contributions of the structure and intensity effects are shown in the table 5.1. In this analysis, a value of one meant that the variables (such as structure or intensity) had no impact on aggregate intensity and energy consumption. Values over one indicated a contribution to higher aggregate intensity and energy consumption while values below one indicated a decline. A decrease in aggregate energy intensity meant an increase in energy efficiency during the sample period.

Table 5-1 Decomposition of aggregate energy intensity, electricity intensity and fuel intensity for the German and Colombian food industries into structural (Fstr) and intensity (Fint) effects using production value as measures of economic output

German food industry. Energy								
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
F_{str}	1	0.999	0.992	0.999	1.005	1.004	1.000	0.995
F_{int}	1	0.997	0.999	0.995	0.993	0.997	0.999	0.996
EI_{agg}	1	0.951	0.939	0.951	0.988	1.002	0.991	0.935
Colombian food industry. Energy								
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
F_{str}	1	1.005	1.014	1.017	1.017	1.010	1.001	1.001
F_{int}	1	1.000	0.983	0.975	0.992	1.023	1.009	0.990
EI_{agg}	1	0.942	0.979	0.942	1.072	1.258	1.078	0.913
German food industry. Electricity								
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
F_{str}	1	0.997	0.990	0.993	1.015	1.012	0.992	0.988
F_{int}	1	1.001	1.002	0.999	0.999	1.012	1.013	1.011
EI_{agg}	1	0.948	0.939	0.948	1.100	1.169	1.039	0.996
Colombian food industry. Electricity								
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
F_{str}	1	1.002	0.987	0.989	1.061	1.046	0.976	0.976
F_{int}	1	1.007	1.002	0.996	1.017	1.056	1.045	1.023
EI_{agg}	1	0.896	0.921	0.896	1.647	1.918	1.157	0.990
German food industry. Fuel								
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
F_{str}	1	0.997	0.990	0.993	1.016	1.011	0.992	0.988
F_{int}	1	0.999	0.993	0.990	0.992	0.999	0.998	0.999
EI_{agg}	1	0.887	0.884	0.887	1.049	1.072	0.935	0.915
Colombian food industry. Fuel								
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
F_{str}	1	1.002	0.987	0.989	1.060	1.046	0.975	0.976
F_{int}	1	0.996	0.984	0.978	0.997	1.030	1.011	0.985
EI_{agg}	1	0.785	0.809	0.785	1.447	1.627	0.904	0.751

The decomposition analysis shows that:

- In German food industry, structural and intensity effects had similar results (with values close to 1), which suggest that both effects caused the decrease of the values of the aggregate energy intensity. Therefore, the results for aggregate energy intensity were caused by intensity and structural changes in the food industry. In the first case, the contribution could be due to improvements in technology, and the second case was due to the decrease of production in some sectors as fish (153), other food products (158) and beverages (159).

- In Colombia, intensity effects contributed in the decrease of the values of the aggregate energy intensity, whereas structural effects did not contribute in the decrease of the aggregate energy intensity because the values were over one (values between 0.99 and 1.061), meaning that the results for aggregate energy intensity were mainly caused by changes in the intensity. These results might be attributed to fact that during the sample period, improvements in economies of scale and production standards, where the growth of an industry and the increase in its quantity produced will have a better chance to decrease energy consumption and increase productivity; this concurs with Reardon et al., 2008 in the context of the food industry in developing countries.
- During the sample period, the aggregate energy intensity decreased in both countries. These facts might prove that economic and technical factors have played an important role in the energy efficiency performance because increases in economic growth and technology improvements increase the industrial sector's ability to improve energy efficiency, as is observed in the German and Colombian food industries.
- In both countries, the aggregate electricity intensity increased, whereas the aggregate fuel intensity decreased indicating that the increase in electricity use and the decrease in use of other fuels generated a decrease in the aggregate energy intensity. Therefore, a change in the fuel used from low to high quality (i.e., from oil to natural gas) can influence energy efficiency in the food industry. These results concur with Ramos and Ortege, 2003 where their study showed that the decline in the energy intensity in the industrial sector has been due to the ability to expand the use of higher quality fuels.
- The results show that the increase in electricity use and the decrease in use of fuels in both countries generated a decrease in the aggregate energy intensity. These results could be explained by the inter-fuel substitutions. Hence, during the sample period, the German food industry increased its use of electricity and natural gas, whereas other fuels decreased their total share by the same amount. Likewise, in the Colombian food industry, the situation was similar except for a large increase in the consumption of natural gas. During this period, the majority of the Colombian food industries fed their boilers with natural gas, meaning that a change in the fuel used from low to high quality (i.e., from oil to natural gas) can influence energy efficiency (Hall et al., 1986). Moreover, it is important to note that in both countries,

the substitution of fuels has been intended to increase the use of clean fuels or of those generating less greenhouse gas emissions.

5.5 Empirical analysis and discussion of results

The results showed that energy efficiency in several sectors of the food industry has improved in the period of study in both countries; the values of energy intensity were higher in the Colombian food industry than in the German food industry; structural and intensity effects caused the decrease of the values of the aggregate energy intensity in German food industry; and intensity effects contributed in the decrease of the values of the aggregate energy intensity in Colombian food industry. To determine the causes and differences of these results in the German and Colombian food industries, regression and correlation analysis were conducted.

5.5.1 Regression analysis

The measure of energy efficiency obtained in this chapter as energy intensity is used as dependent variables in the regression model using different factors as independent variables[103] (equation 9). Regression analysis is obtained by Ordinary Least Squares (OLS)[104]. For each energy efficiency measure, an initial regression was run with all explanatory variables. A second model was then run retaining only those variables that were significant at the 10% level or better.

$$\Delta EI_i = \gamma_0 + \gamma_1 * EP + \gamma_2 * KL + \gamma_3 * ELE + \gamma_4 * ENSI + \gamma_5 * IP + u \qquad (9)$$

$\Delta EI_i = The\ changes\ in\ energy\ eintensity\ measured\ as\ energy\ intensity\ (EI)$

$EP = Energy\ prices$

$KL = capital\ input$

$ELE = the\ share\ of\ electricity\ in\ total\ energy\ (fuel)$

$ENSI = the\ share\ of\ the\ manufacturing\ output\ in\ small\ and\ medium\ Enterprise\ (SMEs)$

$IP = Index\ of\ production$

[103]The variables are created from Destatis data (German case) and DANE data (Colombian case).
[104] The regression analysis was also estimated for German and Colombian food industries together. However, the results were not robust, mainly due to the differences in the results of indicators of energy efficiency and independent variables between both countries. Therefore, in comparisons across countries with significant differences in their indicators and variables; regression analysis should be estimated for each country in order to understand the main factors that could determine energy efficiency performance.

Tait (2000) states that energy price is key variable to improve energy efficiency in the food industry. The energy price variable is used to determine the relationship between energy efficiency measure and changes in energy prices. It would expect a higher energy price to be associated with less energy intensity and more energy efficiency.

European Commission (2007) states that the decrease in energy consumption could be influenced of a substitution effect caused by changes in the industrial structure and the capital stock towards higher productivity or also by substitution of energy for labour and/or other input factors. Therefore, it analyses capital input as the capital-labour ratio KL in each sector of German and Colombian food industries and this variable could have either positive or negative coefficient.

In the food industry it is possible to increase energy efficiency through inter fuel substitutions (Persson, 2000). To evaluate inter fuel substitutions the variable ELE is used as the share of electricity in total energy (fuel) consumed in every sector of food industry.

The enterprise size variable *ENSI* measures the share of the manufacturing output in small and medium Enterprise (SMEs), it would expect a higher production in SMEs should be associated with less energy efficiency.

Order important economic variable in the analysis of energy efficiency performance is the production level that has relationship with economies of scale where the growth of an industry and the increase of its production units will have a better chance to decrease its costs and energy consumption and increase its productivity. The index of production (IP) variable is measured as output index for every food sector during the sample period, and it would expect a higher value of this variable is associated positively with improvements in energy efficiency.

Table 5.2 summarises the results obtained. As can be seen from the results, energy prices, capital input and electricity variables have influence on energy efficiency, whereas the influence of size enterprises and index of production variables are insignificant in the German food industry. In the Colombian case, energy prices, capital input and size interprises[105] variables

[105] Higher levels of production in medium and small enterprises to be associated with lower energy efficiency because the management and staff resources of small and medium enterprises (SMEs) are more constrained. In addition, they typically do not have dedicated energy or facilities managers (DEFRA, 2006).

have influence on energy eficiency, whereas electricity and index of production variables are insignificant.

The results of the energy prices variable suggest that in the German and Colombian food industries, this variable has helped improve energy efficiency. Therefore, increases in energy price should generate effective mechanism to improve energy efficiency and this strategy ought to consider in which sector of food industry should generate effective impact to improve energy efficiency (Broder et al., 1981 and Patel et al., 2005).

Table 5-2 Results of OLS regressions for explaining energy efficiency performance in the Geman and Colombian food industries

Parameter	Germany		Colombia	
	(1)	(2)	(1)	(2)
Intercept	2.344*** (4.33)	2.392*** (4.71)	-0.495 (0.73)	.-0.280* (1.60)
Energy prices	-1.211*** (6.20)	-1.220*** (6.40)	-0.212** (3.01)	-0.206** (2.93)
Capital Input	-0.810*** (6.25)	-0.809*** (6.35)	0.174*** (4.88)	0.178*** (5.02)
Electricity	0.888*** (4.70)	0.897*** (4.87)	0.138 (0.61)	
Size enterprises	0.094 (0.35)		0.478*** (11.32)	0.475*** (11.49)
Index of production	-0.132 (0.27)		-0.035 (0.96)	
R^2	0.52	0.49	0.72	0.71
F static	12.52	21.46	29.8	49.8
Obs.	64	64	64	64

Figures in parentheses are t-statistics.
, **, * imply significance at the 10%, 5%, and 1% level, respectively.*

The effect of capital input was positive and significant in the German food industry, indicating the likely close relationship between technical progress and capital in this sector that has also achieved improvements in energy efficiency. On the other hand, in Colombian food industry the effect of capital input was negative meaning that the energy intensive sectors of food industries tends to be more capital intensive and technical changes to save energy have secondary importance and the capital is rather used in order to save labour (Kander et al., 2007).

The electricity (ELE) variable had positive and significant influence in German food industry where the increasing use of cogeneration (CHP)[106] that is considered as mainly strategies to

[106] Combined heat and power (CHP) systems is the combine production of electrical and useful thermal energy from the same energy source.

improve energy efficiency in this sector[107] because this technology decrease the amount of electricity bought but no electricity consumption because the electricity generated with this technology has higher efficiency than when the electricity is produced or utilized from other sources. On the other hand, in Colombian food industry this variable had also positive influence on energy intensity showing likely that the patterns of electricity consumption have no generated improvements in energy efficiency. However, inter fuel substitutions have increased the use of natural gas due to its competitiveness in price and efficiency, the increase environmental regulations and the decrease of CO_2 emissions allowing that the industries do not decrease the electricity consumption because energy source had higher efficiency in production and cost.

The results of the enterprise size variable (the share of gross production in medium and small enterprises) show that in the Colombian case this variable is important to improving energy efficiency performance whereas in the German case, this variable has not played an important role, meaning that in industrialised countries, the levels of technology are similar for both great enterprises and SMEs while in developing countries, there is a higher gap in technology between great enterprises and SMEs in the food industry. This is probably because the majority of measurements have focused on large industries, despite the existence of small to medium enterprises (SMEs). Therefore, in developing countries, SMEs have good potential to improve their energy efficiency performance[108] not only to save money but also to promote their image as energy- and environmentally-responsible companies (EC, 2009).

Likewise, the results of the index of production showed that in German and Colombian food industries this variable achieves improvement in energy efficiency indicating possibly that several sectors of food have increased their production decrease costs and energy consumption due to economies of scale that are quite significant for this industry[109].

[107] Cogeneration offers a substantial potential gain in efficiency with a market share of 6% takes the 4th position in Germany, after natural gas (47%), oil (25%) and electricity 11.5% (Schulz, 2006).
[108] SMEs in the food processing sector of developing countries have opportunities and challenges with respect to the production of non-traditional products and improvements in productivity, quality and technology, which could indirectly increase energy efficiency performance (Wilkinson, 2004).
[109] Several studies have identified the importance of scale economies in food industry e.g., Dalzell (2000) and Wijnands et al., (2007) in the context of European food industry, Gervais et al., (2006) in Canadian food processing, and Reardon et al., (2008) in food industry of developing countries.

5.5.2 Correlation analysis

In order to understand from another approach the factors that determine energy efficiency in the food industry, correlation analysis is applied between energy intensity, investments and concentration process[110]. These variables were selected because have a direct relationship with best technologies and the potential energy saving in the food industry[111].

Table 5.3 shows the results of correlation analysis. In the German food industry, the investments variable had significant correlation with the improvements in energy efficiency performance, whereas the concentration process was not significant correlation with the improvements in energy efficiency performance. In the Colombian food industry, both variables had significant correlation with energy efficiency performance.

The results of investments variables concur with German research institutes and centres specialising in the food industry[112] that report for the period of study that the food industry made technological changes particularly linked with the compressed air system, cogeneration, pumping systems, the refining of raw materials, pasteurisation and sterilisation techniques, the use of renewable energy, extrusion procedures, automation and check processes, which are in line with the results found for both indicator assessment and empirical analysis[113]. In the Colombian case, the investments made were focused on technical changes such as the conversion of boilers to natural gas, some projects of cogeneration and the use of renewable energy, condensed recovery and the acquisition of new factories and equipment.[114] Moreover, the aim of these investments was particularly to align strategic or market competencies between national companies and multinational companies established in Colombia during the sample period.

[110] This variable determines the influence of the elimination of the smaller or the least-efficient plants on energy efficiency.
[111] Tait (2000) and Kander and Schön, 2007 showed that the potential investments and best technologies are highly complementary with improvement in energy efficiency in the manufacturing industry.
[112]According to Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz, www.initiative-energieeffizienz.de, FEI: Forschungskreis der Ernährungsindustrie Projektdatebank: www.fei-bonn.de/projekte/projektdatenbank.html and Max Rubner - Institut: www.mri.bund.de
[113] These technologies have mainly been applied to the dairy industry, the production of meat, the manufacture of grain mill products, among others. This list aligns with that of sectors that have successfully improved in the indicators of energy efficiency.
[114] These technological changes have mostly been made in the sectors with the highest improvements in energy efficiency, e.g., the manufacture of beverages, oils and dairy products.

Table 5-3 Correlation between energy intensity (EI_i) and investment and the concentration process

Measure of energy efficiency	Investments	Concentration process
	Germany	
EI_i	-0.309**	-0.187
	Colombia	
EI_i	-0.601**	-0.651**

**, ** imply significance at the 5%, and 1% level, respectively.*

The results of the concentration process variable and its relationship with energy efficiency concurs with the Herfindahl-Hirschman Index (HHI)[115] for the period sample where the HHI for German food industry is 1856 indicated that this sector is highly concentrated, whereas the HHI for Colombian food industry is 1356 indicated moderate concentration. Furthermore, several studies have shown that in developed countries the food industry has increased the concentration process in the last two decades (e.g., Poole et al., 2002, Bernauer and Caduff, 2004, Jansik, 2004 and Wijnands et al., 2007). In contrast, in developing countries the concentration process has grown from the end of the 1990s, largely as a result of foreign direct investment through cross-border mergers and acquisitions in the food industry in the last few years (Belik and Dos Santos, 2002, Gopinath, 2000, McCorriston and Sheldon, 2003 and Witteloostuijn, 2007). Therefore, the results should indicate that the elimination of smaller, least efficient plants (concentration process) had played an important role in the reduction of energy intensity in the Colombian food industry. However, most Colombian food industrial sectors the concentration process offer limited results for the future.

Finally, the results showed that in the food industry the improvements on energy efficiency performance are mainly generated by technological change, which involves more efficient production methods and the implementation of best energy management practices and is also influenced by the substitution effect caused by changes in the industrial structure and the capital stock towards higher productivity or also by the substitution of energy for labour and/or other input factors. Moreover, the general results indicate that increased efforts should be made by industry and policy markers if we want to reach the level of energy savings and energy efficiency that would significantly contribute to the reduction of greenhouse gas emissions.

[115] The Herfindahl-Hirschman Index (HHI) was calculated for the sample period by squaring the gross production share (expressed in percentage terms) of each food sector in every country, and then adding the squared values together (U.S. Department of Justice).

5.6 Conclusions

This chapter analysed the development of energy efficiency in the German and Colombian food industries in the time period 1998-2005 using energy intensity and decomposition analysis. The results showed that Germany increased its energy consumption by an average of 1.3% by the final year, largely due to the manufacture of other food products and dairy products, while the Colombian food industry decreased its energy consumption by an average of 1.9% by the final year, mostly due to the sectors of beverages and oils. However, the values of energy intensity were higher in the Colombian food industry than in the German food industry.

The results of decomposition analysis showed that structural and intensity effects caused the decrease of the values of the aggregate energy intensity in German food industry; intensity effects contributed in the decrease of the values of the aggregate energy intensity in Colombian food industry; and in both countries, the increase in electricity use and the decrease in use of other fuels generated a decrease in the aggregate energy intensity. These results should indicate that economic, technical factors and fuel substitution have played an important role in the energy efficiency performance because increases in economic growth and technology improvements increase the industrial sector's ability to improve energy efficiency, as is observed in the German and Colombian food industries.

In order to determine the effects of different factors in energy efficiency performance across sectors and countries a regression analysis was performed in terms of several key characteristics of food industry. This analysis reveals that the variables such as energy price and index of production have positive influence in energy efficiency in German food industry; and size enterprises have played an important role in energy efficiency performance in Colombian food industry.

It concludes that, for the German food industry, energy prices and capital input variables have a positive influence on energy efficiency. For the Colombian case, it concludes the following: energy prices have a positive influence on energy efficiency and higher levels of production in medium and small enterprises to be associated with lower energy efficiency indicating a negative influence of size of company on energy efficiency.

In the Colombian case, the results of the size of company variable showed that this variable is important to improving energy efficiency performance, whereas in the German case, this variable has not played an important role, meaning that in industrialised countries, the levels of technology are similar for both great enterprises and SMEs while in developing countries, there is a higher gap in technology between great enterprises and SMEs in the food industry. This is probably because the majority of measurements have focused on large industries, despite the existence of small to medium enterprises (SMEs).

The effect of capital input was positive and significant in the German food industry, indicating the likely close relationship between technical progress and capital in this sector that has also achieved improvements in energy efficiency. On the other hand, in the Colombian food industry, the effect of capital input was not significant, indicating that the capital is rather used in order to save labour costs and not the costs of energy in production.

The results of correlation analysis for the concentration process variable indicated that this variable had played an important role in the reduction of energy intensity in the Colombian food industry, and the investment variable had a significant correlation with the improvements in energy efficiency performance in both countries.

Finally, the results showed that in the food industry the improvements on energy efficiency performance are mainly generated by technological change, which involves more efficient production methods and the implementation of best energy management practices and is also influenced by the substitution effect caused by changes in the industrial structure and the capital stock towards higher productivity or also by the substitution of energy for labour and/or other input factors. Moreover, the general results indicate that increased efforts should be made by industry and policy markers if we want to reach the level of energy savings and energy efficiency that would significantly contribute to the reduction of greenhouse gas emissions.

In developing countries, it is important to develop strategies to improve the technology in the food industry especially in SMEs with the aim of increasing productivity and optimising energy consumption because significant opportunities exist to enhance the use of existing efficient technologies through an appropriate combination of policy instruments that encourage and the barriers that inhibit improving energy efficiency in the food industry.

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Appendix

Appendix 1 Summary of the main variables used for German and Colombian food industries

Variable	Main sources
Germany	
Monetary gross output of production in the food industry	Destatis (GENESIS-Table: 42251-0002)
Labour – the total number of persons employed	
Energy price – Relationship between expenditure on energy and energy consumption	Destatis and author's calculations
Capital – stock by taking the value of fixed assets at prices of 1998 (Annual mean value)	Destatis (Table: 3.2.16)
Investments- the share of investments in gross production (%)	Destatis (GENESIS Table:42231)
Energy consumption (TJ)	Destatis Chapter 5- Table: 5.2.2.1-5.3.11
Energy sources (electricity, natural gas, petroleum products, and other in TJ)	
Concentration process - Manufacturing output per company	Destatis (GENESIS Table: 42251)
Size of companies - the share of gross production in medium and small enterprises for each industrial sector by year taking into account the categories established by German statistics office based on the number of workers and output levels for every industrial sector.	Destatis - Fachserie 4 Reihe 4.3 and author's calculations
Colombia	
Monetary gross output of production in the food industry	DANE (Table: 3.1)
Labour – the total number of persons employed	
Capital – stock by taking the value of fixed assets at prices of 1998 (Annual mean value)	
Energy price – Relationship between expenditure on energy and energy consumption	DANE, UPME and author's calculations
Investments- the share of investments in gross production (%)	DANE (Table: 5.5)
Energy consumption (TJ)	UPME (Energy balance)
Energy sources (electricity, natural gas, petroleum products, and other in TJ)	
Concentration process - Manufacturing output per company	DANE (Table: 3.1)
Size of companies - the share of gross production in medium and small enterprises for each industrial sector by year taking into account the categories established by Colombian statistics office based on the number of workers and output levels for every industrial sector	DANE (Table: 3.3) and author's calculations

PART III.

THE RELATIONSHIP BETWEEN POLITICAL, ECONOMIC AND PRODUCTION TECHNOLOGY FACTORS AND ENERGY EFFICIENCY PERFORMANCE

As a state we are so uniquely positioned in so many ways.
Our geography, our placement in the country,
and our history positions us to be the state
that propels energy efficiency as an industry.
Jennifer Granholm

Engineering consultants shoulder the responsibility
to promote energy-efficient and eco-friendly technologies
to meet the challenge of energy over-consumption
and environmental deterioration"
Zeng Peyan

Chapter 6.

Policies, measures and management strategies influencing energy efficiency in the German and Colombian manufacturing industries*

Abstract

Improved Energy-Efficiency (EE) helps not only in enhancing competitiveness through cost reduction but also in minimising environmental degradation. A good understanding of factors influencing EE, however, is essential for EE improvement. This chapter attempts to determine these factors in the German and Colombian manufacturing industries. Based on the primary data from German and Colombian industrial associations and representative industries, the factors that could influence energy efficiency performance are studied. These factors are classified *a priori* under three categories: Economic Factors (EF), Production Tecnology Factors (TF), and Political Factors (PF). Based on the primary data, the results in both countries should indicate that energy management for the industrial sector is important within business strategy and that the quantification and assessment of energy consumption and energy efficiency are input indicators to improve and optimise processes within a sustainability development. Moreover, the results show that in German industry, an adequate combination of economical, technical and political factors is important to achieve better energy efficiency performance, whereas in the Colombian case, improvements in energy efficiency are closely related with economic and production technology factors. The results suggest that policy strategies in the industrial sector have to comprise legal and fiscal instruments and voluntary agreements to generate supporting framework conditions to improve energy efficiency. Moreover, it is important to strengthen international cooperation for scaling up of sustainable energy solutions in developing countries.

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6.1 Introduction

Energy is a basic factor for industrial production, and the level of electricity consumption is used to measure the progress and economic development of nations. Globally, growing population, industrialisation and rising living standards have substantially increased dependence on energy. As a result, the development of conventional energy resources, the search for new or renewable energy sources, energy conservation (using less energy), and energy efficiency (same service or output, less energy) have become unavoidable topics within politics.

Generally, an ideal policy cycle sees a given policy formulated, implemented, monitored and evaluated to verify its effectiveness and fulfilment of the proposed objectives, and in accordance with the results of this evaluation, the policy is then kept, reformulated or abolished. In this cycle—and above all, in industrial energy politics—it is important that the policy makers recognise the influence of economic, technical and political factors and have an understanding of the mechanisms that determine energy efficiency performance such that the instruments and strategy they formulate become successful.

Strategies and instruments developers drafting an energy policy need to understand the behaviour of the industrial sector with respect to energy consumption in order to (i) motivate, (ii) target energy actions that will be adopted, and (iii) develop energy saving and energy efficiency actions and technologies that will be of interest (Kant, 1995 and Thollander et al., 2007). The quantity and quality of energy conservation support or energy efficiency programs will depend on perceived interest and as well as the need for energy conservation changes.

There are limited studies and information currently available on the perception of approach to energy efficiency in companies. Therefore, this study seeks to analyse the factors and strategies that address energy efficiency in the industrial sector. This information may be useful for energy policy and program development as well as pollution prevention and energy efficiency strategies. The research questions that guide this chapter are:

- What is the role of energy consumption and energy efficiency in business strategies in the industrial sector?
- What are the variables of political factors that may have more influence on energy efficiency performance?

- What are the strategies and instruments that may generate better results to improve energy efficiency in the industrial sector?

These questions were investigated in this study by means of a questionnaire and a series of interviews and analysis of literature. The questionnaire was sent out by mail to main industrial associations and representative industries in Germany and Colombia, and it contained a list of different factors, variables and measures influencing energy efficiency performance that the respondents were asked to rank.

This chapter is structured as follows. In section 6.2, examines energy efficiency policy in both countries. Section 6.3 shows the methodology used in this study. Results and discussion appear in section 6.4 while the section 6.5 shows different strategies and recommendations for an effective energy efficiency policy in the Colombian industrial sector. The main conclusions of the study are presented in section 6.6.

6.2 General characteristics of energy efficiency policy in Germany and Colombia

6.2.1 The German energy efficiency policy

The German energy policy is based in the commitment to the “3 Es”: energy security, economic efficiency and environmental sustainability. In this context, Germany emphasises environment and climate change objectives, and energy efficiency assumes increased importance in the country’s overall energy policy. Moreover, in the last decade, the key German energy policies have been based on the expansion of the use of renewable energy and the establishment of new energy efficiency targets and an energy research program (IEA, 2007).

From the mid-1990s, the dominant instruments employed to improve energy efficiency in the German industrial sector were voluntary agreements. Since its introduction in 2004, however, the emissions trading system has become the most important policy measure in the industrial sector, and it has also provided a key incentive to raise energy efficiency (Eichhammer, et al., 2006).

Regarding cross-cutting measures to improve energy efficiency in Germany, the main policy is the Ecological Tax Reform, i.e., the introduction of a so-called Eco Tax on oil, gas and electricity[116]. Additionally, the Renewable Energy Sources Act provides digressive compensation rates for new installations for all renewable energies[117].

The German energy efficiency policies for the industrial sector have worked mainly with the following strategies:

- Voluntary agreements: the improvements in the efficiency of on-site electricity generation, particularly combined heat and power (CHP).
- Eco-tax: Germany's red-green coalition government introduced a set of ecotaxes on 1 April 1999 designed to make energy and resource consumption more expensive while lowering the cost of labour. Taxes on petrol and diesel, electricity, heating oil and natural gas had been increased in five stages, and the bulk of the tax revenue generated used to reduce pension insurance contributions.
- Emission trading system means to achieve ecological and economic success. It means assuring the ecological integrity of the instrument, competition neutrality and low transaction costs. In other words, the emission trading system makes use of market-based mechanisms to encourage the reduction of greenhouse gas emissions in a cost-effective and economically-efficient manner, while maintaining the environmental integrity of the system.
- Specific Regulations such as: the Energy Performance of Buildings that seek to promote the energy performance of buildings taking into account outdoor climatic and local conditions as well as indoor climate requirements and cost-effectiveness, and the Minimum Energy Performance Standards for appliances or equipments and mandatory labels that are used to increase the energy efficiency of individual technologies.
- German CHP Law supports of cost efficient technology to reduce CO_2 emissions. This law contains the definition of CHP electricity and heat; support mechanism for high efficiency CHP, and mechanise to supervise reporting of CHP electricity production in CHP plants.
- Renewable Energy Sources Act creates a feed-in tariff system which requires utilities to purchase a predetermined amount of renewable energy at a fixed price. The policy provides economic security for investors and manufacturers and is responsible for the bulk of Germany’s dynamic scale-up of renewable electricity capacity and equipment production.

[116] The tax was introduced in two stages: a first tax increase from 1 April 1999 and a further four-step increase in taxation from 2000 to 2003. There are tax reductions for some consumers, chiefly within the manufacturing industry, agriculture and the railways. The revenue from this tax is used for a reduction of the non-wage labour costs and the promotion of renewable energies (Eichhammer, et al. 2006).

[117] The rates are adapted to the efficiency potential of the different branches. This will provide a strong incentive to reduce costs and increase efficiency (Eichhammer, et al. 2006).

- Grants and loans: the *Kreditanstalt für Wiederaufbau (KfW) Umweltprogramm* (Environment Program) that provides capital for investment in environmental protection activities and the low-interest loans to SMEs that can be used to supplement the European Recovery Programme's Environment and Energy Saving Program.
- Technology specific rebates are programs used to promote energy management and new energy-efficient technologies.
- Public information and advice: the sub-project under the Initiative *Energieeffizienz* (Energy Efficiency Initiative) campaign, DENA, the German Energy Agency.

6.2.2 The Colombian energy efficiency policy

In 1991, with the introduction of the new Constitution, Colombia adopted the principles of sustainable development as a guide to economic development and assigned to municipalities the duty to regulate especially the industry and energy intensive activities. The deregulation of the Colombian electricity system[118] began in the same period, as did the restructuration of the public environmental management system[119]. These elements have characterised the development of energy policies in this country, where the emphasis has been on the formulation of projects and regulations concerning energy efficiency in the industrial sector. Moreover, additional instruments for environmental management involve agreements with industry or other relevant organisations. In 1997, the National Environmental Council approved the National Policy of Clean Production. The key objectives of this consensus-based energy policy were to increase the environmental efficiency and quality of energy resources and to develop environmental guides (*guias ambientales*) detailing options for improving energy efficiency performance in specific sectors. Other strategies used to increase energy efficiency in the industrial sector included the establishment of the energy excellence program (*Merito URE*), the conversion of urban factories from coal or diesel to natural gas and the development of strategies planning for energy efficiency and renewable energy. Currently, the government is developing two legislation projects to improve energy efficiency: Cogeneration Law and the

[118] The Colombian electricity industry is characterized by a large hydroelectricity component, close to 70%, and is considered to be one of the most open markets in the developing world, and the market evolution with this model has been satisfactory in terms of investment, competition, efficiency and reduction in electricity losses (Larsen et al., 2004).

[119] The Colombian environmental administration characterizes to be decentralized, democratic, participatory, fiscally solvent, and socially legitimate with measures as a system of pollution taxes, require environmental impact assessments for large construction projects, and institutionalize legal remedies against polluters (Blackman et al., 2006).

design of the Colombian program of normalisation, accreditation, certification, and labelling of final use of energy equipment.

Hence, Colombian energy policies are based almost entirely on direct regulation. Apart from some small exemptions to VAT taxes for environmental investments, the principal use of economic incentives in energy policies involves the pricing of fuels and agreements with specific industrial sectors that have high potentials to improve energy efficiency or to carry out changes in technology and renewable energy.

6.3 Methodology

A mail survey of the main industrial associations and representative firms in Germany and Colombia was conducted in the first semester of 2009. The preliminary database with on average of four companies and associations in each country was used as the sample frame. A total of 100 respondents received the questionnaire, resulting in seven replies from Germany and 30 from Colombia.

The survey was designed to identify factors and variables that determine energy efficiency in the industrial sector. It included three sections, each with a unique objective. The first section was designed to establish general information about energy consumption, structure of energy source and energy efficiency.

The second section was designed to assess and rank the importance of different factors and variables in the achievement of improved energy efficiency performance. Questions were asked on issues relating to economic, technical and political factors with their respective variables.

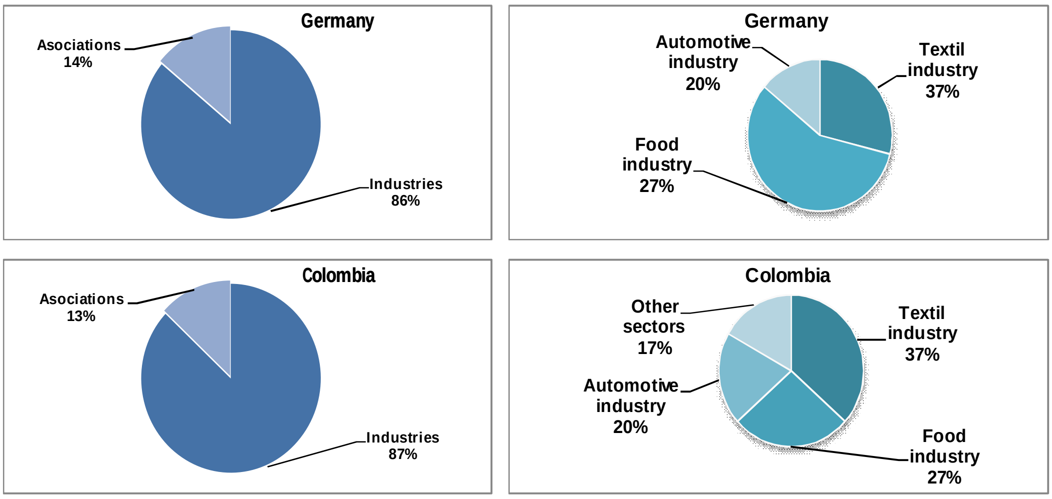
The third section was designed to assess external factors and instruments that would cause or encourage improvements in energy efficiency performance, and what kinds of internal measures or actions would tend to increase energy efficiency performance in the industry.

All surveys included a cover letter and a business reply self-addressed envelope. The cover letter explained the purpose of the survey, the risks and benefits of participation, and background information on energy efficiency. The cover letter also included contact information and a submission deadline.

6.4 Results and discussion

The questionnaire was answered in both countries by different associations and industries. In the German case, one association and six companies answered the questionnaire, with most replies coming from the food sector, and in the Colombian case, the questionnaire was answered by four associations and 26 companies, mainly of the textile sector (see figure 6.1).

Figure 6-1 Breakdown of questionnaire responses from the German and Colombian associations and firms



6.4.1 Features of energy consumption, energy efficiency and energy source in German and Colombian industries

The results of questionnaires show that in the German and Colombian cases more than 50% of companies or associations consulted have made studies on energy efficiency and that within of these companies and associations, the majority has analysed and assessed energy efficiency performance and its advantages and disadvantages and included the topic of energy efficiency within their business plans and strategies.

The results also show that the majority of firms and associations know their energy consumption. However, in both countries, the assessment of energy intensity in the companies and associations is a fairly new topic. Moreover, from 2000 to 2008, the assessment of energy consumption and energy intensity has become more prevalent, indicating, possibly, that within the German and Colombian industrial sectors, the energy topic is becoming more important in the production system and management. This trend would coincide with the increase in certifications of environmental management systems by the countries' in the German case 65% and in the Colombian case 30% by year during this period (ISO, 2007). Hence, energy management is a key program to improve sustainability and environmental performance.

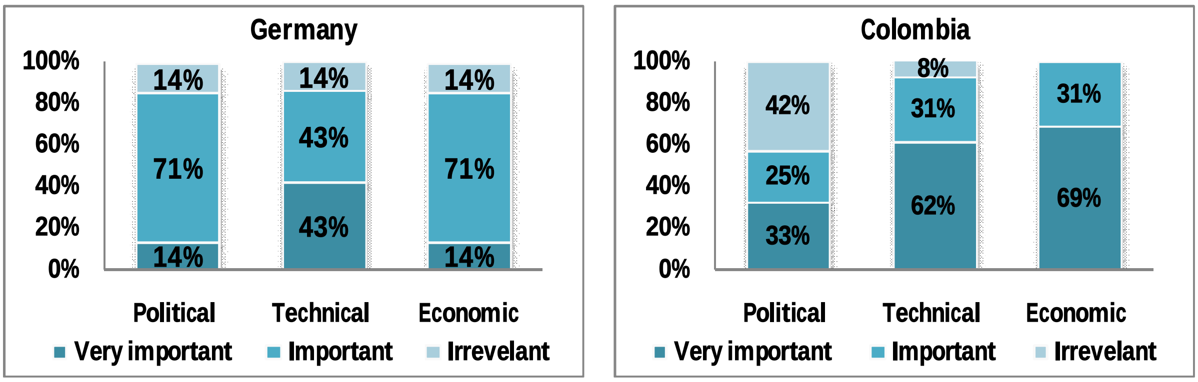
In both countries, the main energy sources for the firms consulted are electricity and natural gas. Energy costs for the firms were between 0.5% and 3% in the German case and between 0.5% and 5% in the Colombian case.

The results in both countries indicate that energy management in the industrial sector is important for business strategy and that the quantification and assessment of energy consumption and energy efficiency are input indicators to improve upon in optimisation processes working towards sustainability.

6.4.2 Factors influencing energy efficiency

In the German case, 43% of firms and associations consider production technology factors very important, and 71% feel that economic and political factors are important in the improvement of energy efficiency performance. In the Colombian case, economic (69%) and production technology factors (62%) are very important factors in achieving improvement of energy efficiency, whereas the political factor is irrelevant (42%) for firms and associations (see figure 6.2).

Figure 6-2 Factors influencing energy efficiency in German and Colombian industries



These results indicate that in the German case, the firms and associations consider that economic, technical as well as political factors influence energy efficiency, whereas in the Colombian industrial sector improvements in energy efficiency are only closely related with economic and production technology factors, mainly because energy efficiency policies are limited and are focalised mainly in support and recommendations of the better technologies.

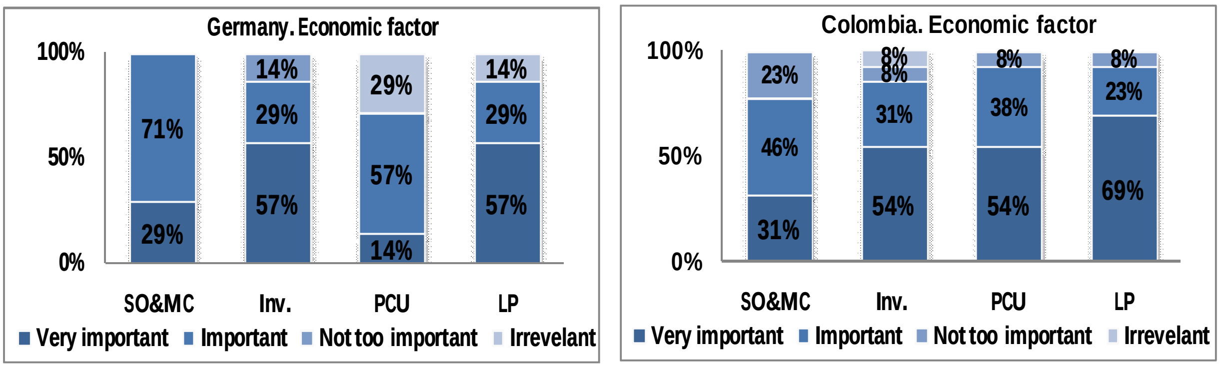
- **Variables in economic factors influencing energy efficiency**

Energy consumption in the industrial sector is influenced by the behaviour of several economic variables—e.g., high energy prices or constrained energy supply motivate industrial facilities to try to secure the amount of energy required for operations at the lowest possible price (McKane et al., 2008); structural changes in the industrial sector cause shifts in final energy use and energy intensities; and the plant capacity utilisation provides an indication of how efficiently plants and equipment are utilised and consequently, could measure the efficiency of energy use.

In the German case, the variables of the economic factor that have the most influence on energy efficiency are improvement in structural operations and maintenance costs and investments in new technologies, equipment or specific activities of energy management investments. Improvements in plant capacity utilisation and levels of production have less importance. On the other hand, in the Colombian case, all variables of the economic factor are important, but the most relevant are improvement in plant capacity utilisation and improvement in levels of production (see figure 6.3).

These results indicate that industrial sectors of developed countries consider that energy efficiency improvements have higher dependence of investments and production methods, whereas industrial sectors of developing countries relate energy efficiency improvements with capacity and levels of production. This means that in developed countries, improving energy efficiency is important as an investment strategy, whereas in developing countries, energy efficiency is a secondary result from production strategy. This finding concurs with Tholander et al., (2007) who identified the non-priority of energy efficiency investments and lack of access to capital—especially in small and medium enterprises—as main barriers to increased energy efficiency in the industrial sectors of developing countries in contrast with the situation in developed countries. Moreover, industrial sector in developing countries likely prefers traditional investments like expansion of industrial plants or power generation. Furthermore, energy efficiency projects without large capital investments are often perceived as riskier and / or are too small to attract multilateral financial institution lending (UNIDO, 2007). These results concur with empirical analysis showed in previous chapters with respect to investments and improvement in plan capacity utilization in textile industry.

Figure 6-3 Variables in the economic factors influencing energy efficiency in German and Colombian industries



SO&MC: Improvement in the structure of operation and maintenance costs. Inv.: Investments in new technologies, equipments or specific activities of energy management. PCU: Improvement in plant capacity utilisation. LP: Improvement in levels of production.

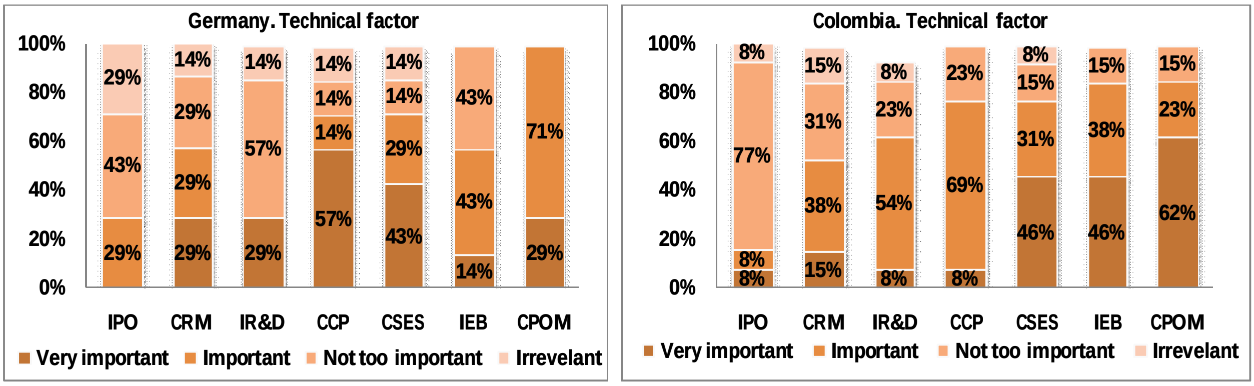
- **Variables in production technology factor influencing energy efficiency**

The need for improvement of energy efficiency is just one of the drivers for technology development in industry. Moreover, the potential technical energy savings are available based on proven technologies, best practices and use of new energy sources (IEA, 2007).

The industrial sectors of both countries consider the most important technical variable in improving energy efficiency to be changes in process, operations and machinery. However, for German industries, changes in the structure of energy sources and consumption patterns are also important, while in the Colombian case, in the emphasis is on improved employment behaviour (see figure 6.4). These results concur with empirical analysis where energy sources emerging as an important variable that influences energy efficiency and in the case of automotive industry and food industry changes of raw materials have been a key variable to improve energy efficiency.

These results show that the industrial sectors of both countries feel that the best way to improve energy efficiency is by changes in process, operations and machinery (Germany 71% and Colombia 62%) generally these processes in the organizations begin with an internal analysis of the production process and machinery to determine opportunities to decrease energy consumption and increase energy efficiency. Moreover, in the Colombian case, it's also important the analysis of employment behaviour because behaviour change erodes the energy savings due to the technical energy efficiency improvements, especially in developing countries (IEA, 2005).

Figure 6-4 Variables in the production technology factor influencing energy efficiency in German and Colombian industries



IPO: Increase processes outsourcing. CRM: Changes of raw materials. IR&D: Increase in the resources of R&D. CCP: Changes of consumption patterns. CSES: Changes in the structure of energy sources. IEB: Improvements in employment behaviour. CPOM: Changes in the process, operations and machinery.

Hence, the results confirm that Germany has achieved important developments in energy efficient-technology and significant improvement in energy efficiency performance in the industrial sector. According to the Federal Ministry of Economics and Technology, Germany in recent years has achieved a decrease in its energy consumption even though the gross domestic product has more than doubled and German researchers and companies have submitted many global patent applications in the development of energy efficient industrial cross application technologies.

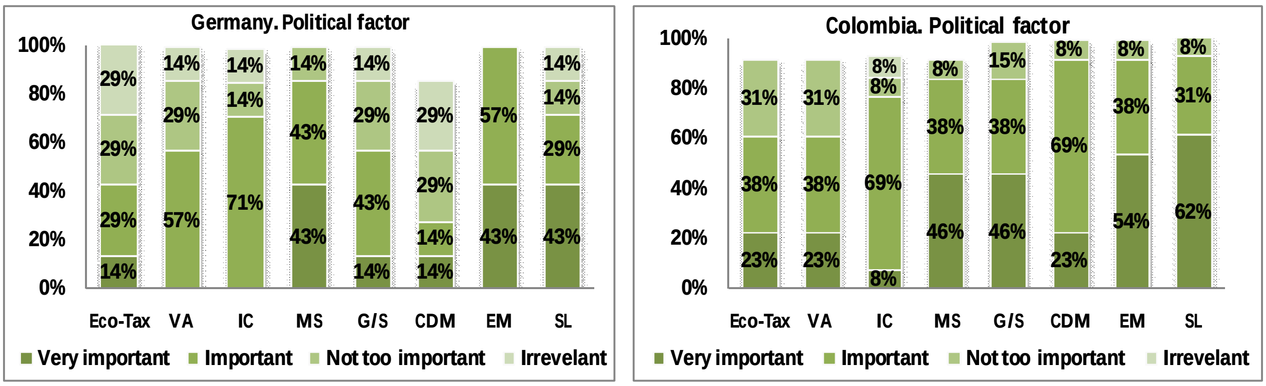
- **Variables in political factors influencing energy efficiency**

Market forces and other factors determine energy efficiency in the industrial sector. However, these factors can be influenced by an effective energy policy that encourages cost effective energy efficiency through the application of different types of policy instruments that include information, regulation and economic instruments.

Figure 6.5 shows the results of variables in the political factors affecting energy efficiency in German and Colombian industries. In the German case, the most important variables of the political factor are to encourage the application of energy management in the organizations, mandatory standards (such as the efficiency of electric motors and the efficiency of industrial boilers), and soft loans—especially for cogeneration (CHP). These results concur with Eichhammer, et al. (2006), who showed that only some measures are seen as a high-impact (the first voluntary agreement with German industry from 1995 and the second financial measures (CHP Act, *KfW Umweltprogramm*)), whereas the impact of the Ecological Tax Reform has been estimated as medium, and other measures have been assessed as low-impact.

However, according to studies of Ecofis et al., (2206) voluntary agreements to save energy are adequate in these circumstances when dealing with a small number of actors with which you need to negotiate or a strongly organized sector and / or when there is much relatively cheap energy saving potential. The characteristics that could determine the success of this instrument are the following: the target group motivated to participate, there are penalties in case of non-compliance, there is a good monitoring system, and adequate supporting instruments such as audits, energy monitoring systems, financial incentives and demonstrations projects.

Figure 6-5 Variable in the political factors influencing energy efficiency in German and Colombian industries



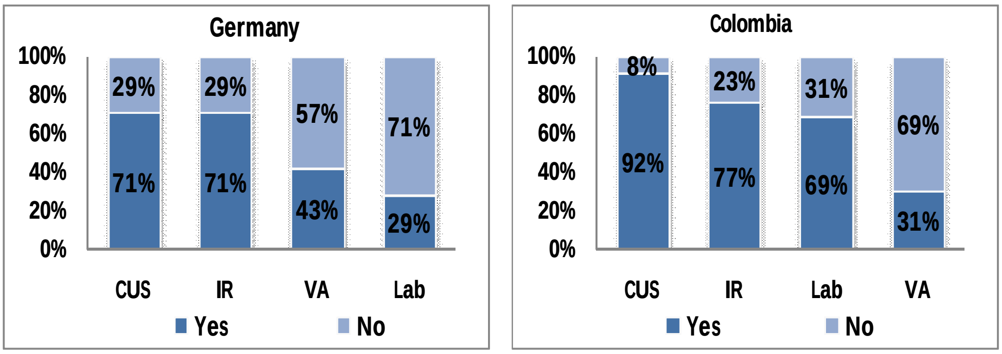
Eco-tax: Eco-tax.VA: Voluntary audits. IC: Information campaigns. MS: Mandatory standards (the efficiency of electric motors and the efficiency of industrial boilers). G/S: Grants / subsidies. CDM: Emission trading / Clean Development Mechanism. EM: To encourage the application of energy management SL: Soft Loans for Energy Efficiency, Renewable energy and CHP.

In the Colombian firms, the most important variables are soft loans (for Energy Efficiency, Renewable energy and cogeneration (CHP)), to encourage energy management and the emissions trading / Clean Development Mechanism—indicating that in developing countries, a barrier to improved energy efficiency is the limited amount of resources available to change technology and to achieve improved energy efficiency, a conclusion which concurs with the studies of Kant, 1995; Tanaka, 2008 and Gillingham et al., 2009.

6.4.3 Instruments influence interest to improve energy efficiency performance

Figure 6.6 shows that instruments and measures would cause or encourage the German and Colombian industrial sectors to improve energy efficiency performance. In both countries, the main instruments are changes in upstream sector (energy prices) and institutional regulations, whereas labelling to have a lower impact.

Figure 6-6 Percentage of respondents who felt that specific measures and instruments could improve energy efficiency performance



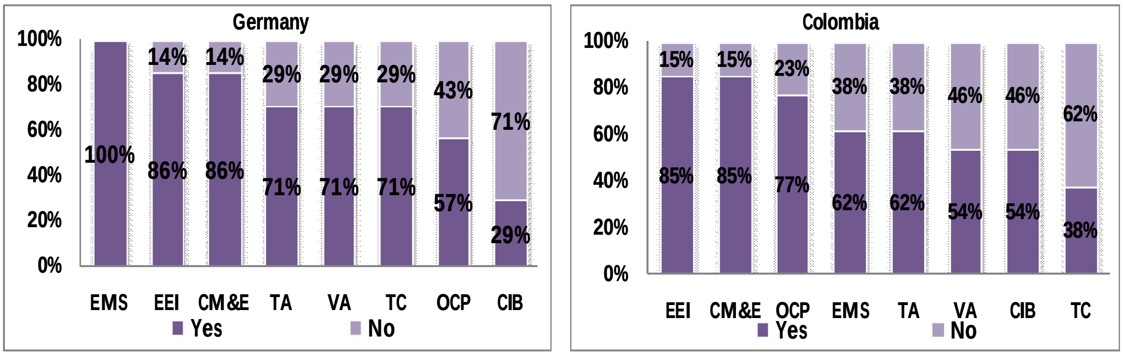
CUS: Changes in upstream sector (energy prices). IR: Institutional regulations (Regulatory standards, - Fiscal policy, State aid for R&D). VA: Voluntary agreements. Lab: Labelling (e.g. industrial motors, EMAS, ISO 14001).

The results are clear in the German case, where a series of energy-conservation instruments have been implemented to include: the replacement of traditional gas- or oil-fired boilers with condensing gas-fired boilers, the gradual replacement of traditional fuels with more expensive bio-fuel, and the consecutive emergence of integrated gasification combined cycle (CGC) and combined heat and power (CHP) systems. As a result, the energy intensity of Germany has decreased 20% from 1990 to 2003, with an annual decrease rate of 1.75%. Moreover, during the last decade, the energy policy of Germany has been strongly influenced by environmental issues, and the German government has consecutively introduced various acts related to renewable energy and energy efficiency. During 1999, to stimulate energy conservation, energy efficiency, and the application of renewable energy technologies, the German government introduced the Eco-tax, which subsequently became the Renewable Energy Act, which targets a short-term goal of doubling renewable power generation by 2010, together with an intermediate-term goal of increasing renewable power generation capacity to 20% of total power generation capacity by 2020 (Blesl et al., 2007).

6.4.4 Internal measures and actions the industrial sector would consider to increase energy efficiency performance

Figure 6.7 shows the kinds of internal measures and actions the industrial sector would consider to increase energy efficiency performance. In the German case, the most important internal measures in order of importance are energy management systems, energy efficiency investments, and changes in machinery and equipment. In the Colombian case, the most important internal measures in order of importance are energy efficiency investments, changes in machinery and equipment, and optimisation of production capacity and production level.

Figure 6-7 Kinds of internal measures and actions the industrial sector would consider to increase energy efficiency performance



EMS: Energy management systems. EEI: Energy efficiency investment (e.g. changes in machinery, equipments and technology). CM&E: Changes in machinery and equipment. TA: Training activities. VA: Voluntary audit. TC: Major product/process related technological changes, whether or not introduced as part of public/private national and the R&D programmes. OCP: Optimization of production capacity and production level. CIB: Conversion of industrial business (in terms of both products and processes).

These results show that in both countries, the industrial sector has an interest in increasing their investments to improve energy efficiency through changes in machinery and equipment—demonstrating that the industrial sector considers improvements in energy efficiency to be closely related with technological change. This result coincides with opportunities to improve industrial energy efficiency through new technologies such as the use of high-efficiency motor-driven systems, the optimisation of compressed air systems and the potential that exists based on currently available improvements. In fact, the possibility of implementing new and emerging technologies with potential savings of as much as 35 percent in energy costs is creating entirely new lines of business (IAC, 2007).

Finally, the results of this study suggest that policy strategies in the industrial sector have to utilise legal and fiscal instruments to generate supporting framework conditions as well as targeted programs in the fields of R&D, technological change, market transformation, information, education, dissemination of best practice, etc. Moreover, policy will always have to live with unavoidably sub-optimal solutions, while growing knowledge and changing frameworks will constantly impose the need to search for better solutions and new opportunities. In this context, energy policy strategies represent not only (static) problems of policy choice but—above all—dynamic search and learning processes aimed at designing effective policy measures.

6.5 Recommendations for the formulation of energy-efficiency policies in the Colombian industrial sector

According to our results and the literature, it is important that there be a formulation of an adequate package of policies and measures that are addressed to guarantee effective and efficient impact to improve energy-efficiency performance and reducing greenhouse emissions in the Colombian industrial sector. The following strategies and instruments in policy settings are recommended in order to achieve improvements in energy efficiency in a cost-effective manner:

a. Policy support. Policy support should aim at making energy efficiency easy ("Make it easy!"), realisable ("Make it possible!"), and beneficial ("Make it rewarding!") for stakeholders, thereby contributing to the development of the market for energy-efficient technologies and services. Due to the implementation of the support programmes, it also becomes clear that energy efficiency is politically intended and crucial ("Make it a policy!"). A pre-planned, target-group-specific, differentiated mix of policy instruments and measures is necessary, with integrated measures that are directly addressed to stakeholders. In such a way, the specific situations, incentives, barriers and obstacles of different stakeholders should be addressed by specific policy mixes (Thomas and Irrek, 2007).

b. Integral approach. The most effective way to improve industrial energy efficiency is through an integrated approach, where a number of policies and programmes are combined to create a strong overall industrial energy-efficiency policy that addresses a variety of needs in Colombian manufacturing sectors. There should thus be an adoption of a policy of energy-efficiency sector targets and related programmes in which individual industrial sectors committed to specific improvements in energy intensity over a given time period in exchange for governmental support in the form of financial incentives, information programmes, demonstration programmes, and training programmes, significant energy savings could be realised.

c. Energy efficiency strategies. National energy efficiency strategies in Colombia could accelerate the implementation of energy efficiency in the industrial sector. National energy-efficiency strategies should be useful because during their development, implementation and evaluation, they can help to achieve the following: make the vision for energy efficiency explicit; focus attention on the important issues; identify gaps in current work programmes; identify necessary tasks and resources and allocate implementation and monitoring responsibility.

d. Energy data. The Colombian government through the statistical office and energy agency (UPME) must improve the availability of high-quality energy efficiency data because without accurate energy time series data, it is difficult to target and develop appropriate energy efficiency policies in the industrial sector. Moreover, for developing sectoral energy efficiency benchmarks and best practices, action plans should: assess energy consumption by end-use in industrial sector; identify the economy's energy-saving potentials and establish objectives and adequate methods for evaluating the success of the plan.

e. Mandatory standards. For the Colombian industrial sector, the most important technical variable to improve energy efficiency is change in processes, operations, machinery and equipment. For this reason, the Colombian government should consider adopting mandatory minimum energy performance standards for machinery and equipment (e.g., the efficiency of industrial motors and the efficiency of industrial boilers) in line with international best practices. Moreover, it should examine barriers to the optimisation of energy efficiency through technology systems and design and implement comprehensive policy portfolios aimed at overcoming such barriers.

f. Energy management. Among Colombian firms, one of the most important political variables is the encouragement of the application of energy management[120]. The Colombian government should thus consider providing effective assistance in the development of energy management (EM) capability through the development and maintenance of EM tools, training, certification and quality assurance. Moreover, it should encourage or require major industrial energy users

[120] There are significant cost-effective energy savings to be realised in industry through the more widespread adoption of best practices in energy management (EM). EM addresses the way in which an industrial plant or facility is managed to identify and exploit cost-effective energy savings opportunities (IEA, 2008).

to implement comprehensive energy management procedures and practices that could include, according to IEA, 2008:

- The development and adoption of a formal energy management policy. The process and implementation of this policy should be reported and overseen at the company board level and reported in company reports. Within this policy, companies would need to demonstrate that effective organisational structures have been put in place to ensure the following: that decisions regarding the procurement of energy-using equipment are taken with the full knowledge of the equipment's expected life-cycle costs and that procurement managers have an effective incentive to minimise the life-cycle costs of their acquisitions.
- The appointment of full-time qualified energy managers at both the enterprise- and plant-specific levels as appropriate.
- The establishment of a scheme to measure, monitor, evaluate and report industrial energy consumption and efficiency at the individual company sector and national levels. As a part of this effort, appropriate energy performance benchmarks should be developed, monitored and reported at levels deemed suitable for each sector.

g. Small and Medium-sized Enterprises (SMEs). The size of company variable was significant for Colombian industry. The Colombian government should thus consider developing and implementing a package of policies and measures to promote energy efficiency among SMEs. This package should include: a system for ensuring that energy audits, carried out by qualified engineers, are widely promoted and easily accessible for all SMEs; the provision of high-quality and relevant information on energy-efficiency best practices; the provision of energy performance benchmarking information that ideally would be structured to allow international and national economy comparisons; and appropriate incentives to adopt capital acquisition and procurement procedures with the lowest life-cycle costs.

h. Investments. For the Colombian industrial sector, the results indicate that energy efficiency investments are a key variable to improve energy efficiency. However, among the many impediments to the adoption of cost-effective energy efficiency investments is the “finance barrier” (Tholander et al., 2007 and IEA, 2008). The Colombian government should facilitate the industrial sector’s and stakeholders’ involvement in energy efficiency investments by: I) adopting and publicising to the industrial sector a common energy-efficiency savings verification and measurement protocol in order to reduce existing uncertainties in quantifying the benefits of energy efficiency investments and stimulate increased private sector involvement; II) reviewing their current subsidies and fiscal incentive programmes to create more favourable grounds for private energy-efficiency investments; III) collaborating with the private financial sector to establish public-private tools to facilitate energy-efficiency financing; IV) promoting risk-mitigation instruments such as securitisation or public-private partnerships; V) putting in place institutional frameworks to ensure regular co-operation and exchanges on energy efficiency issues between the public sector and financial institutions and VI) design an energy tax programme to provide an incentive to industry to improve energy management at firms' facilities through both behavioural changes and investments in energy-efficient equipment.

i. Taxes and tariff structure. This study demonstrated that energy costs and taxes are important for improving energy efficiency. The Colombian government should design a package of taxes and a tariff structure that include the following: I) the reduction of subsidies or using energy to balance the effect of subsidies, providing the energy consumer with a more realistic indication of the actual costs associated with certain forms of energy; II) the use of taxes to more accurately reflect the environmental costs, or "externalities", associated with energy consumption; III) the imposition of taxes and fees associated with energy use resulting from energy consumption on users with the goal of creating incentives to reduce wasteful energy consumption practices or creating public programmes and funds for encouraging energy efficiency and IV) having the price system ensure that all individual agents are confronted with the full costs that their decisions impose on others; this means addressing externalities and market failures through a greater use of taxes, charges and tradable permits and correcting policy failures through reforms of support programmes that are environmentally harmful and economically inefficient and have undesirable social effects.

j. Control, monitoring and evaluation. Developing effective energy-efficiency policies requires a good understanding of how energy is used as well as the various factors that drive or restrain demand. Such an understanding requires accurate data on energy end-use and the associated activities. The Colombian government should thus ensure that instruments of energy efficiency policies are adequately monitored, enforced and evaluated so as to ensure maximum compliance and that their energy-efficiency policies are supported by adequate end-use information by substantially increasing their effort to collect energy end-use data across all sectors and relating to all energy types.

k. Technology transfer and cooperation. In the Colombian industrial sector, this analysis demonstrated that the technology level is still moderate and that this technical factor is a key strategy to improve energy efficiency. The Colombian government should thus promote technology transfer through an appropriate enabling framework in order to enhance international cooperation for the scaling up of sustainable energy solutions. The transfer of technology requires a careful balancing act that includes both fair treatment for innovators and energy policies that stimulate global diffusion of energy technology to address energy efficiency.

6.6 Conclusions

In this chapter, an analysis of factors influencing energy efficiency performance in the German and Colombian manufacturing industries has been presented. Based on the primary data from German and Colombian industrial associations and representative firms in each country, the economic, technical and political factors were studied with respect to impact on energy efficiency. The results in both countries indicate that energy management for the industrial sector is important within business strategy and that the quantification and assessment of energy consumption and energy efficiency are input indicators to be used in improvement and optimisation processes within sustainability development.

The results also show that in German industry, economic, technical and political factors influence energy efficiency, whereas in the Colombian case, improvements in energy efficiency are closely related with economical and production technology factors.

In the German case, the results showed the following: (I) the variables in the economic factor with the most influence on energy efficiency are the structural operations and maintenance costs and investments, whereas plant capacity utilisation and levels of production have lower importance. (II) The most important technical variables to improve energy efficiency are changes in the processes, operations and machinery, changes in the structure of energy sources, and changes of consumption patterns. (III) The most important variables in the political factor are to encourage the application of energy management, mandatory standards (such as the efficiency of electric motors and the efficiency of industrial boilers), and soft loans especially for cogeneration (CHP). (IV) The most important internal measures to improve energy efficiency are energy management systems, energy efficiency investment, and changes in machinery and equipment.

In the Colombian case, the results showed the following: (I) All variables for the economic factor are important, but the most relevant are plant capacity utilisation and levels of production. (II) The most important technical variables to improve energy efficiency are changes in the processes, operations and machinery, and improvements in employment behaviour. (III) The most important variables of the political factor are soft loans (for Energy Efficiency, Renewable energy and cogeneration (CHP)), to encourage the application of energy management and emissions trading / Clean Development Mechanism. (IV) The most important internal measures for increasing energy efficiency are energy efficiency investments, changes in machinery and equipment and optimisation of production capacity and production level.

Moreover, the results suggest that policy strategies in the Colombian industrial sector have to combine the following strategies: integral approach, energy data, mandatory standards, energy management, the promotion of energy efficiency in small and medium-sized enterprises, investments, a tax program, an adequate tariff structure, control and evaluation, technology transfer and cooperation.

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Chapter 7.
Conclusions and Recommendations

7.1 Conclusions

In this thesis, we have analysed the development of energy efficiency at different aggregation levels in German and Colombian manufacturing industries from 1998 to 2005. Table 7.1 summarises the results of the analysis and confirms the hypotheses formulated in this study concerning the influence of various factors on energy efficiency performance.

1. What are the differences in energy efficiency development at different aggregation levels and using different assessment approaches?
2. What are the factors and variables that have played a significant role in energy efficiency improvement in the industrial sector?
3. In the industrial sector, has the shift in the structure of energy sources from lower end use efficiency fuels (e.g., coal and petroleum products) to higher end use efficiency fuels (e.g., gas and electricity) improved energy efficiency as well as reduced green house gas emissions?

This thesis tried to resolve research questions by the application of several methodologies. The first and second research questions were answered for each level of aggregation in the industrial manufacturing sector (macro, meso and micro levels). The third research question is solved as one of the selected variables in each level of aggregation. The results showed variation in energy efficiency performance at different aggregation levels in both countries. The main findings and answers for research questions are the following:

a. At the macro level (decomposition analysis), the industrial sector has increased its energy consumption, by 2.3% in Germany and 5.5% in Colombia and also decreased their aggregate energy intensity (12% and 6% respectively). In Germany structural and intensity effects contributed to the results of the aggregate energy intensity. In the first case, was due to the decrease of production in energy intensive sectors, and the second case the contribution could be due to improvements in technology or production standards. On the other hand, in Colombia, intensity effects dominated over structural effects. This might be attributed to fact that during the sample period, a concentration process generated improvement in production standards and process optimisation (mainly in the chemical, food, basic metal, and glass industries).

Table 7-1 Summary of results at different aggregation levels in German and Colombian manufacturing industries

At the macro-level (*Decomposition analysis*)

Variable	Germany	Colombia
Structural effects	(+) B	(+) C
Intensity effects	(+) B	(+) B
Changes in production	(+) B	(-) A
Improvements in EISs	(+) A	(+) A
Capital-energy intensity	(-) B	(-) B
Labour-energy intensity	(+/-)C	(-) B
Substitution fuels	(+) C	(+) B
Energy prices	(+) A	(+) B

At the meso-level (*DEA models*)

Variable	Germany		Colombia	
	EISs	NEISs	EISs	NEISs
Technical efficiency	(+) A	(+) C	(+) A	(+) C
Cost efficiency	(+) A	(+)	(+) B	(+)
Substitution fuels	(+) C	(+) C	(+) A	(+) C
Value added	(+)	(+) A	(+) B	(+) A
Labour productivity	(+) A	(+) A	(+) A	(+) A
Enterprise size*	(+) B	(+)	(+) B	(+)
Capital input	(-)	(-)	(-)	(-)
Change in energy costs	(+) A	(+) C	(+) C	(+) C
Investments	(+) B	(+)	(+)	(+)

At the macro and meso levels (*Demand model*)

Variable	Colombia		
	Whole industry	EISs	NEISs
Energy price	(+) A	(+) A	(+) A
Electricity price	(+) C	(-) C	(+) C
Machinery and equipment investment	(+) B	(+)	(+) B
R&D investment	(+)	(+)	(+)
Foreign investment	(+) B	(+) B	(+) B

At the micro level *(Regression and correlation analysis)*

Variable	Food industry	
	Germany	Colombia
Structural effects	(+) A	(+)
Intensity effects	(+) A	(+) B
Energy prices	(+) A	(+) B
Capital input	(-) A	(+) A
Electricity	(-) A	(-)
Enterprise size*	(+)	(+)C
Index of production	(+)	(+)
Investments	(+) B	(+) B
Concentration process	(+)	(+) B

The sing in parentheses indicates the type of correlation, (+) direct and (-) inverse on energy efficiency. A, B and C imply influence about energy efficiency performance at the high, middle and low levels, respectively.
**The share of gross production in medium and large enterprises for each industrial sector.*

From energy consumption approach, the results might prove that economic and production technology factors have played an important role in the energy efficiency performance because

increases in economic growth and technology improvements increase the industrial sector's ability to improve energy efficiency, as is observed in the German and Colombian cases.
The values of energy intensity were higher in the Colombian industrial sector than in the German industrial sector (on average, Colombia needs 2.4 times more energy than Germany to produce a unit of gross production, measured as exchange rates). These differences can be explained by the relationships between energy and capital intensity and energy and labour intensity. In the first case, the results of the two countries revealed that Germany is more capital intensive and less energy intensive than Colombia, and this fact might mean that the capital of the industrial sector of a country is related to better technology and could indirectly involve less energy consumption, and energy and capital have a complementary interaction in the industrial sector. In the second case, the changes in energy intensity should not directly depend on the changes in labour intensity indicating that higher growth rates of energy intensity do not necessarily mean higher or lower rates of labour intensity, and therefore, the changes in energy intensity should not directly depend on the changes in labour intensity.

As for energy efficiency performance, one might deduce that during the sample period, energy prices influenced energy efficiency performance because decreases in aggregate energy intensity occurred in the years in which energy prices increased. However, the difference in energy prices between Germany and Colombia is meaningful and might explain the better energy efficiency performance of Germany than Colombia.

The results of decomposition analysis, both in Germany and Colombia, might demonstrate that the energy efficiency developments of the industrial sector of a country are driven by the energy performance of EISs. However, NEISs have an important role in improving the energy efficiency measured as an aggregate of energy intensity in the industrial sector due to their production levels, economic contribution and relatively high growth rate, as shown in the results of both countries.

The analysis of the shift in the structure of energy sources showed that the increase in electricity use and the decrease in use of other fuels in both countries generated a decrease in the aggregate energy intensity, measured as production value, of other fuels, and the total aggregate energy intensity had a minor role. Moreover, it is important to note that in both countries, the substitution of fuels has been intended to increase the use of clean fuels or of those generating less greenhouse gas emissions.

b. At the meso level (DEA models). During the sample period in Germany, energy intensity remained almost constant in EISs and NEISs, whereas in Colombia it increased between 1998 and 2003 and declined thereafter in both sectors. A possible explanation for this change may be that in these years the world economy was characterised mainly by sluggish growth of output, Euro revaluation and inflation edging upwards, indicating the direct relationship between improvement of energy efficiency and economic stability. Moreover, the increases had a higher impact in Colombia, suggesting that the energy efficiency performance in the industrial sector is dependent on economic factors and that energy intensity performance is more sensitive to economic changes in developing countries than developed countries due to the fact that industrial output is so closely linked to economic growth and prosperity.

The gap between German and Colombian NEISs is lower than for EISs, indicating that the productivity process and production standards are probably similar for NEISs due to energy use being confined mainly to processes of physical conversion and motor drive in those sectors, and where the gap in technology is lower in comparison to other productive processes of EISs.

The first DEA model reflected how several sectors experienced technical progress, particularly in the sectors with the highest energy intensity in both countries. Further, in Colombian EISs, these improvements were meaningful. Hence, these results showed the potential of EISs to improve technical efficiency, especially in developing countries.

The second DEA model showed that in both countries, the great majority of EISs improved on this measure during the sample period, demonstrating that energy input is an important variable within the production structure and a key element in technology development. On the other hand, several NEISs declined on this measure during the sample period, indicating that energy savings for this sector are of secondary importance due to the fact that energy is a minor cost item in relation to labour, and the fact that capital is instead used in order to save on labour costs.

From technical efficiency DEA models, in the German case, the two measures of energy efficiency were similar in both sectors, indicating that energy efficiency improvement is necessary to achieve technical efficiency. On the other hand, in the Colombian case, we saw that the energy efficiency results in both sectors were lower than in the German case, meaning that developing countries with an emerging and expanding industrial infrastructure have great potential to improve their energy efficiency by applying energy-efficient best practices, technologies, and innovations.

From an economic perspective (the third DEA model), in German and Colombian EISs and NEISs, the results showed that when input prices were taken into consideration, the annual average energy efficiency across sectors was higher than the measured cost efficiency, suggesting that, for cost minimising over a set of inputs, industries should be conserving more of other inputs rather than energy in both countries, energy efficiency based on cost minimisation was higher in NEISs, demonstrating that energy prices in this sector are not the key variable for improving energy efficiency probably because the industrial sector should use more energy than is actually being used, by substituting energy for other inputs.

In the German case, the three measures of energy efficiency from DEA models were similar, indicating that energy efficiency improvement is necessarily an appropriate combination of technical efficiency and cost minimisation. On the other hand, in the Colombian case, we saw that the highest energy efficiency measured was from the cost minimisation model, suggesting that the relative price of energy in Colombian industry does not reflect the real cost of using energy. As such, energy is the relatively cheaper input. Therefore, it is worthwhile to note that, in Germany, especially over the last years, energy prices have brought about energy efficiency improvement, whereas, in the Colombian case, energy prices have not generated the proper incentives to improve energy efficiency.

For German and Colombian EISs and NEISs, from fourth DEA model, the total factor of productivity improved, indicating that the output increased; alternately, CO_2 emissions decreased during the sample period due to a positive contribution of technical progress, mainly by application of energy-efficient technologies or adoption of new technologies. In the German case, the results were higher in EISs than in NEISs, indicating that technical changes in NEISs possibly did not have energy efficiency improvement as their main aim. On the other hand, in the Colombian case, the results were just the opposite, meaning probably that NEISs had higher levels of technology than did EISs. However, comparing the results from both countries shows that German industry displayed higher values in indices than did Colombian industry, which demonstrates that, in the Colombian case, the technology level is still moderate, and technological adoption will be much easier to achieve in the industrial sector.

To explain the observed variation in energy efficiency across EISs and NEISs from DEA models in both countries over sample period, regression analysis was used. The three alternative measures of energy efficiency assessed with DEA analysis were defined as dependent variables. The main conclusions are the following:

Enterprise size variable. In Germany and Colombia had a positive influence on energy efficiency for EISs, implying that higher output in medium and large enterprises lead to higher energy efficiency, which could explain the fact that small and medium enterprises' (SMEs) management and staff resources are more constrained, and they typically do not have dedicated energy or facilities managers. In the case of NEISs, this variable was not significant in both countries, meaning that the size of companies does not greatly influence energy efficiency performance in this sector, probably because production processes and technology levels have similar features in both large enterprises and SMEs due to the specific requirements of products, such as machinery, computers and electronics, and transportation equipment.

Energy cost and labour productivity variables. For both German and Colombian EISs and NEISs, the energy costs and labour productivity variables had significant influences on energy efficiency. Energy costs had a positive influence on energy efficiency, meaning that a higher energy cost was associated with higher energy efficiency. On the other hand, labour productivity had a positive coefficient, implying that sectors with higher quality of labour experience had higher energy efficiency. This suggests that growth in energy- and labour-productivity are complementary rather than substitutable; and industrial sectors that invest in new capital goods in order to expand or replace existing production facilities (or to increase labour productivity) simultaneously achieve energy efficiency improvements.

The investments variable had a positive coefficient in both the German and Colombian industrial sectors. However, the results show that, in German EISs, these investments had direct relationships with energy efficiency improvements, whereas in NEISs the investments probably did not have energy efficiency improvements as a main aim. Hence, energy savings in the NEISs are a side effect of investments in labour savings and technological changes in general. On the other hand, in Colombian industry, the investment had a secondary effect of energy efficiency improvement because the industrial sector in developing countries likely prefers traditional investments like expansion of industrial plants or power generation.

German and Colombian EISs. In German EISs, the labour productivity, size of company, and energy costs variables were the variables most important to the energy efficiency performance, whereas in Colombia the inter-fuel substitution variable (ELE) was the most significant variable for EISs, indicating that inter-fuel substitution could be a variable that determines a country's development level. This is because a large degree of technical change and substitution fuels an increase in the use of higher quality energy and reduced use of lower quality energy, meaning that technical change has been 'embodied' in the fuels and their associated energy converters.

In the EISs of developed countries, the main factor behind improvement in energy efficiency is the economic factor, whereas in developing countries the technical factor is the key strategy to improve energy efficiency. This is due to the technological differences between developed and developing countries.

German and Colombian NEISs. In the case of NEISs, value added, labour productivity and energy costs variables were the most significant variables predicting energy efficiency in both countries. The effect of capital input (KL) was not significant in the German or Colombian industrial sectors, and the difference in the signs of the coefficients between countries suggests that this variable could be substitutable or complementary in the production framework.

For NEISs in both countries, the economic variables like investments or energy costs have not influenced energy efficiency performance, probably because energy consumption is lower than other inputs in terms of production costs. Therefore, NEISs do not see energy efficiency as a strategy to improve general productive efficiency.

We have shown that during the sample period, the industrial sectors of both countries maintained (in the German case) or increased (the Colombian case) their energy consumption and achieved a lower energy demand per unit of output, especially in energy intensive sectors and great enterprises.

c. At the macro and meso levels (Demand model). The effects of investments on energy efficiency performance were investigated using data from Colombian manufacturing industries; these industries were analysed as a whole and as EISs and NEISs between 1998 and 2005. To determine the effects of investments on energy efficiency, a factor demand model was estimated. Taking advantage of both time-series and cross-sectional dimensions of the panel, the model was estimated using a panel model with fixed effects for industry as a whole and EISs and with random effects for NEISs.

During the sample period, the investments in Colombian manufacturing industries increased more than 50%; these investments were particularly focused in machinery, equipment and buildings. In addition, FI showed consistent growth for the sample period; these investments encouraged the diversification of the economy, job creation and new opportunities for technological transfers. Moreover, energy intensity decreased in Colombian manufacturing industries.

The results indicate that for Colombia's manufacturing industry as a whole and for NEISs, the main variables that determine energy efficiency performance are energy prices, machinery and equipment investments and foreign investments, whereas electricity prices show lower significance levels. R&D is not statistically significant. In contrast, for EISs, only energy prices and foreign investments are statistically significant; electricity prices show a negative effect on energy efficiency is not statically significant. Therefore, energy prices and investments have a close relationship not only with improvements in energy efficiency but also with additional benefits such as increased productivity and competitiveness.

Energy prices show positive effects on energy efficiency in Colombian manufacturing industries. This fact can be explained by increases in energy prices at an average rate of 6.5% per year during the sample period, which led to a decrease in energy intensity by an average rate 1.95% per year. These results demonstrate that energy prices are the most important determinants of energy consumption and efficiency; as has been documented by other analyses, energy prices have been successfully used to promote energy savings in the last year in the industrial sector, and high energy prices motivate industrial facilities to secure the amount of energy required for operations at the lowest possible price.

The foreign investment and machinery and equipment investment contributed to decrease the aggregated energy intensity in the Colombian industrial sector. These results should demonstrate that technological change is closely related with improvements in energy efficiency in manufacturing industries, and that in developing countries, it is necessary to encourage adequate technological transfers in order to increase energy efficiency and decrease CO_2

emissions. Current market developments show that there is a huge demand for technology transfers to developing nations to achieve energy efficiency and emissions reduction in their industrial sectors. However, it is important to realise that successful technologies must also meet a host of other performance criteria, including cost competitiveness, safety and regulatory requirements; these technologies must also achieve consumer acceptance.

These findings have important implications for policy makers focusing their attention on the industrial sectors of developing countries. The results suggest that such policy makers should encourage governments to adopt strategies that adequately combine energy prices and technological change and to strengthen FI with policies aimed at improving technological developments, productivity and energy efficiency in manufacturing industries. In the future, these results should be further scrutinized by using data on other sectors and other countries.

d. At the micro level, with the aim to analyse energy efficiency in an industrial sector with high energy consumption and low energy intensity was selected food industry. The results showed the following:

The results showed that Germany increased its energy consumption by an average of 1.3% by the final year, largely due to the manufacture of other food products and dairy products, while the Colombian food industry decreased its energy consumption by an average of 1.9% by the final year, mostly due to the sectors of beverages and oils. However, the values of energy intensity were higher in the Colombian food industry than in the German food industry (on average, Colombia needs 2.2 times more energy than Germany to produce a unit of gross production).

The results of decomposition analysis showed that structural and intensity effects caused the decrease of the values of the aggregate energy intensity in German food industry; intensity effects contributed in the decrease of the values of the aggregate energy intensity in Colombian food industry; and in both countries, the increase in electricity use and the decrease in use of other fuels generated a decrease in the aggregate energy intensity. These results should indicate that economic, production technology and fuel substitution have played an important role in the energy efficiency performance because increases in economic growth and technology improvements increase the industrial sector’s ability to improve energy efficiency, as is observed in the German and Colombian food industries.

In order to determine the effects of different factors in energy efficiency performance across sectors and countries a regression analysis was performed in terms of several key characteristics of food industry. This analysis reveals that the variables such as energy price and index of production have positive influence in energy efficiency in German food industry; and size enterprises have played an important role in energy efficiency performance in Colombian food industry.

German and Colombian food industries. It concludes that, for the German food industry, energy prices and capital input variables have a positive influence on energy efficiency. For the Colombian case, it concludes the following: energy prices have a positive influence on energy efficiency and higher levels of production in medium and small enterprises to be associated with lower energy efficiency indicating a negative influence of size of company on energy efficiency.

Size of company variable. In the Colombian case, the results of the size of company variable showed that this variable is important to improving energy efficiency performance, whereas in the German case, this variable has not played an important role, meaning that in industrialised countries, the levels of technology are similar for both great enterprises and SMEs while in developing countries, there is a higher gap in technology between great enterprises and SMEs in the food industry. This is probably because the majority of measurements have focused on large industries, despite the existence of small to medium enterprises (SMEs).

Capital. The effect of capital input was positive and significant in the German food industry, indicating the likely close relationship between technical progress and capital in this sector that has also achieved improvements in energy efficiency. On the other hand, in the Colombian food industry, the effect of capital input was not significant, indicating that the capital is rather used in order to save labour costs and not the costs of energy in production.

Concentration process and investment variables. The results of correlation analysis for the concentration process variable (the elimination of smaller, least efficient plants) indicated that this variable had played an important role in the reduction of energy intensity in the Colombian food industry, and the investment variable had a significant correlation with the improvements in energy efficiency performance in both countries.

Finally, the results showed that in the food industry the improvements on energy efficiency performance are mainly generated by technological change, which involves more efficient production methods and the implementation of best energy management practices and is also influenced by the substitution effect caused by changes in the industrial structure and the capital stock towards higher productivity or also by the substitution of energy for labour and/or other input factors. Moreover, the general results indicate that increased efforts should be made by industry and policy markers if we want to reach the level of energy savings and energy efficiency that would significantly contribute to the reduction of greenhouse gas emissions.

Based on the primary data, the results in both countries should indicate that energy management for the industrial sector is important within business strategy and that the quantification and assessment of energy consumption and energy efficiency are input indicators to improve and optimise processes within a sustainability development. Moreover, the results show that in German industry, an adequate combination of economical, technical and political factors is important to achieve better results on energy efficiency, whereas in the Colombian case, improvements in energy efficiency are closely related with economic and production technology factors.

The following conclusions have been reached from a methodology used:

- The value of production as an indicator of energy intensity provides a better description of energy intensity than value added in industrial sectors according to the results of the coefficients of variation. Moreover, the industrial sectors of developing countries may be more vulnerable to economic change than the industrial sectors of developed countries.
- The use of purchasing power parities (PPP) requires careful interpretation with respect to the magnitude of indicators, and the use of this method depends on the aim and context of the study. However, the use of PPP is adequate for analysing projections, scenarios and trends across regions, because this method provides accurate estimates of the growth factors required for countries in a given region in order to attain specified output and price structures.
- The results of the Data Envelopment Analysis (DEA) models show a significant correlation with the traditional energy efficiency measure, indicating that the energy efficiency measured through DEA may be complementary to energy intensity in the analyses of other key elements of energy efficiency performance in the industrial sector.

- The appropriate measure of DEA models depends on which policy objective is at stake. The first two models (which approximate technical efficiency) are useful when the objective of the analysis is to conserve and/or reduce energy in the context of energy-related environmental degradation. The third model (which approximates cost efficiency) is appropriate for the economic objectives of cost minimisation and the maintenance of low output prices. The fourth model (which approximates energy mix effects) is designed for the study of energy efficiency performance patterns in terms of energy consumption (i.e., by source) and CO_2 emissions.
- The "top down" analysis of statistical data shows some restrictions with respect to data availability, the analysis of qualitative variables and the determination of causal relationships between energy efficiency and the main factors that determine energy efficiency performance.

7.2 Recommendations

All research findings presented here are particularly useful for the formulation and development of industrial energy policies and are aimed at improving energy efficiency and reducing carbon dioxide emissions. Such policies should include different strategies to address the key elements of policy instruments that encourage energy efficiency as well as take into account the barriers that inhibit improvements in energy efficiency in industrial sectors at different aggregation levels in developed and developing countries alike.

Any industrial energy policy must include legal and fiscal instruments as well as voluntary agreements to generate the conditions necessary to improve energy efficiency. Moreover, it is important to strengthen international cooperation in order to scale sustainable energy solutions and generate possibilities for technology transfers aimed at improving energy efficiency in developing countries. However, it is also important increase the research impact of these instruments, especially in developing countries.

Improvements in industrial energy efficiency performance depend on both economic and production technology factors; therefore, energy policies should integrate economic and technical instruments in order to achieve the greatest increases in energy efficiency and decreases in CO_2 emissions. By the same logic, such policies should recognise that non-energy intensive sectors require special attention in order to encourage energy efficiency.

The results also reveal that in developed countries such as Germany, improvements in energy efficiency are achieved mainly through changes in economic variables (e.g., energy prices and concentration process), whereas in developing countries such as Colombia, energy efficiency performance is achieved through changes in production technology variables that are highly dependent on improvements in productivity, R&D investments and the application of new technologies. Therefore, these results show the importance of technology, economies of scale and energy efficiency-oriented policies and management strategies to improve energy efficiency in the industrial sector of developing countries. Nevertheless, encouraging technology transfers from developed to developing countries requires more research with respect to barriers and obstacles and with respect to the application of new technologies to the industrial sectors of developing countries.

In developed countries, the design and application of strategies that combine economic factors, production technology and political factors have been important in achieving better results in energy efficiency. However, it is important that this strategy not only is focused in energy-intensive sectors but also has an impact in non-energy intensive sectors as well as small and medium enterprises.

In developing countries, it is important to generate strategies to improve technology in industrial sectors with the aim of increasing productivity and optimising energy consumption, as significant opportunities exist to enhance the use of current efficient technologies. Likewise, at the micro level, effective measures should include financial incentives, information programs, technology diffusion, training programs related to labour standards and energy management systems aimed at energy efficiency.

Policies always run the risk of producing unavoidably sub-optimal solutions, while expanding knowledge and changing frameworks constantly impose the need to search for better solutions and new opportunities. In this context, energy policy strategies do not represent static problems of policy choice but rather dynamic search and learning processes aimed at designing effective policy measures.

The results highlight the need for policy makers and scientists to increase their attention towards energy efficiency, especially in developing countries, non-energy intensive sectors and small- and medium-sized enterprises, and to encourage these industries to adopt energy-efficient technologies and management practices.

The results suggest that policy strategies in Colombian industrial sectors should combine the following strategies, namely, an integral approach, energy data, mandatory standards, energy management, the promotion of energy efficiency in small- and medium-sized enterprises, investments, tax programs, adequate tariff structures, appropriate controls and evaluations, technology transfers and cooperation.