ENERGY SECTOR TRANSFORMATION IN UKRAINE: IMPACT ON ENERGY DEMAND AND EFFICIENCY

by

Solomiia Pikh

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Thesis Supervisor: ______________________________ Professor Oleg Nivievskyi

Approved by ____
Head of the KSE Defense Committee, Professor

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Date ___________________________________

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Abstract

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Ukraine has undergone multiple attempts to reform its energy sector during the last two decades. At the same time, few empirical studies were developed to understand the policy responses of the economic agents. With the unique data gathered for the country's energy sector, this research aims to investigate key relationships related to its demand and efficiency. Using the Fisher Ideal Index decomposition, we show that efficiency variation rather than structural changes in the economy is the main determinant defining Ukrainian energy intensity. The latter has been steadily decreasing for some time already for all energy sectors, except for electricity. Moreover, our panel data models support the idea that both price and institutional factors are important for enhancing energy efficiency and reducing demand. This response is not unified across the energy and economic sectors, though. Accounting for these differences as well as for the abovementioned energy intensity determinants might be particularly useful for potential policy implications. The research, therefore, focuses on the inferences that could contribute to evidence-based policy introduction in the sector.

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GLOSSARY

(T)PES. (Total) Primary Energy Supply. The sum of energy production and net imports excluding international bunkers and accounting for stock changes.

TFC. Total Final Consumption.

Mtoe. Million Tonnes of Oil Equivalent.

Ktoe. Thousand Tonnes of Oil Equivalent.

Bcm. Billion cubic meters of natural gas.

PSO. Public service obligations. Special obligations on market participants for ensuring general public interests in the process of the functioning of the electricity market (Energy Community Compliance Note No 3/20, 2020)

MECI. Ministry of Energy and Coal Industry of Ukraine.

Chapter 1

INTRODUCTION

Any country's development depends critically on energy. Being an integral part of the production, communication, modernization drive, or climate change, governments and policymakers worldwide strive to enhance energy efficiency, responsible consumption and ensure their energy, and thus national security.

While most of the Central and Eastern European countries have succeeded in reforming their energy sector after the dissolution of the Soviet system, Ukraine is still on the path of reforms (OTA 1994). It has undergone multiple transformations in its energy sector since independence and yet continues to look for a sustainable policy mix that would effectively help it to reach energy efficiency levels, at least those of its neighbors (IEA 2020).

The favorable location in terms of the mineral resources abundance (coal, natural gas, oil), alternative energy capacity (hydro, wind, and biomass potential), and proximity to key markets of Europe and Asia make Ukraine one of the largest Europe`s energy markets (IEA 2020). At the same time, the country is an uppermost energy consumer among EU4Energy countries consisting of European Partnership and Central Asian regions, with a PES (Primary Energy Supply) of 93 Mtoe in 2018 corresponding to 90% of the energy consumed in Poland (OECD 2019).

Despite the significant potential for energy efficiency, difficulties in policy implementation precluded energy intensity reduction to the reference EU levels (Dodonov 2016, IEA 2020). Price controls, in particular, price ceilings for the residential sector, that have existed in the country for a long time led to excessive demand, discouragement for supply transformations, and heavy energy dependence. Ukrainian energy-intensity (the ratio of energy used relative to economic output) being 0.25 toe /1000 USD (PPP), which is two times higher than the world's average and ten times higher than the OECD average (Oliver 2014, OECD 2019). Lower tariffs for residential users that encourage overuse and discourage modernization of the sector are partially compensated by the higher industrial tariffs that continue to cross-subsidize households (Sakva 2015). Given that the industry is the largest consumer of energy (19.1 Mtoe in 2018) (Fig. 1) while the residential sector takes second place (16.7 Mtoe), the issue of energy reforms which mostly entail price changes is very sensitive and excessively speculative in the country (IEA 2020).

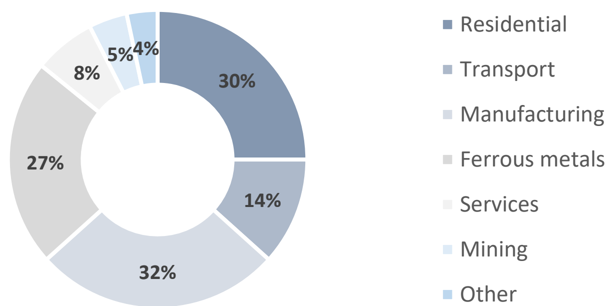

Figure 1.1. TFC by the end-user in Ukraine, 2018
Source: SSSU, IEA (2020)

Despite being gradually moving toward market-based pricing[1] (which mostly works for industrial users as of now), elimination of over-subsidization, and fully-fledged competitive markets of the primary energy resources, so far, there is a limited scope of empirical analysis in Ukraine conducted on the topic. Partially, this is because of the lack of reliable data for a comprehensive analysis which has only recently become available. While the Ukrainian energy sector has significantly transformed

[1] Market-based pricing in electricity sector relates to the wholesale pricing mechanism of a day-ahead market which balances supply and demand; in gas sector – unregulated import-parity pricing for both industrial and residential consumers based on the relationship between competitive suppliers and consumers; for coal – demand-balanced import-parity price accounting for indicative average price of coal on the European market

since independence (see Figure 2 below), it is hard to distinguish whether this transition was attributable to structural changes in the economy, pricing reforms, or increased efficiency measures. Moreover, to what extent those factors influence changes in energy consumption, supply, and industries' costs? That is why it is of particular interest to investigate contributors to that transformation and estimate their relative importance.

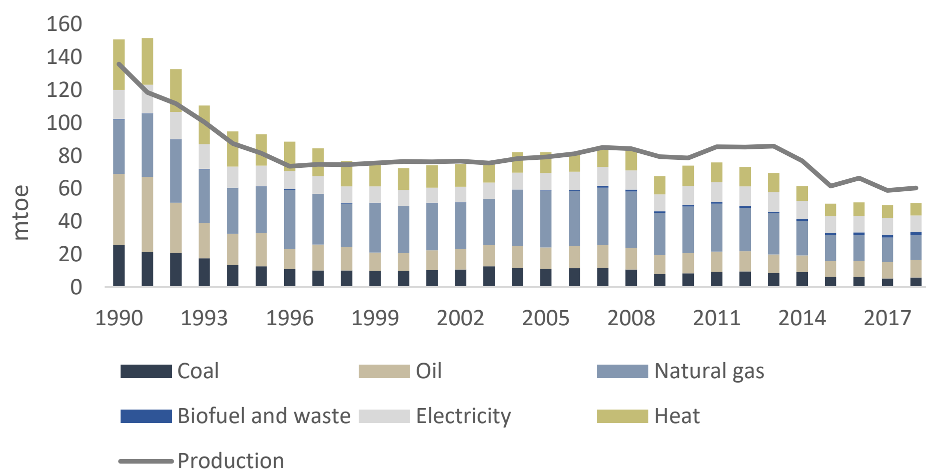

Figure 1.2 Energy production and consumption by source, 2018
Source: SSSU

The starting point for any policy, not alone energy reform, is an understanding of the relationship between demand, production, and prices. The suggestion is that the energy demand will naturally fall with a price increase. However, it is the number of factors that would influence the size and the speed of the effect that are of interest (IER 2010).

Empirical evidence suggests that the effects of the energy sector reforms, especially for the countries with a high share of heavy industry and low alternative consumption possibilities, might not always be predictable (OTA 1994). While it is expected that reforms inducing higher prices would encourage energy-efficiency measures and alternative-resources usage for both industries and suppliers, for a heavily energy-dependent country like Ukraine it might not be the case. This is especially relevant when accounting for a highly monopolistic and regulated market structure. Given the newly introduced time-series by the SSSU on the energy output and consumption by sectors for a period since the 1990s, the research aims to understand how sensitive is the demand and supply for energy in Ukraine to the introduction of certain policy measures as well as to track how the sector was changing over time and what spill-over effects this had onto the Ukrainian economy.

Particularly, we would like to disassemble energy intensity (ratio of energy consumption to GDP) into energy efficiency and energy activity using the Fisher Ideal index to comprehend which factors and through which channel drives the resulting change in energy intensity. Indexes are important in understanding energy consumption transformation, and yet we usually lack the rationale of what drives changes in them over time. In light of this, the paper conducts an analysis on both sector and energy-source levels using macroeconomic, sector-specific, and qualitative data to study respective demand responses.

For most countries, efficiency variation is the main factor defining energy intensity. Yet we expect the activity component to play a significant role in Ukraine due to the industry structural changes during the last decades (Metcalf 2008). Moreover, for energy-intensive sectors, we suggest changes in energy costs to be more attributable to fuel-price effects and less to real output or energy intensity (efficiency, industry structure) effects because of the lack of alternatives.

While most energy studies in Ukraine concentrate on the residential sector, this research focuses on the industry. To the best of our knowledge, no energy-source level analysis was conducted for Ukraine using energy intensity decomposition with limited researche attributable to energy efficiency estimation in Ukraine together with other Central European countries. Furthermore, since Ukraine is still in the process of building a clear action plan on energy transformation, understanding the possible reactions of the market participants in response to the main drivers involved could provide valuable insights on policy implementation and develop a broader understanding of its implications.

The structure of the paper is organized as follows. *Chapter 2* starts with a literature review on the relevant energy studies and reform research. In *Chapter 3* short energy sectors revision is presented. *Chapter 4* develops on the methodology of the study. *Chapter 5* describes the data for the models to which results are to be presented in *Chapter 6* along with considerations on alternative data management and robustness checks. *Chapter 7* summarizes the main findings and discusses policy implications for the Ukrainian energy sector.

Chapter 2

LITERATURE REVIEW

As the energy sector was transforming worldwide, so were the methods used to study it. What has not changed for the last 50 years, though, is the nature of the relationships in the interest of the researchers.

Significant movement in econometric approaches to energy studies was prominent in the last two or three decades. Before the 1970s, as Pindyck (1979) has stressed, understanding of the long-run response of energy demand to the changes in income and prices was rather limited. This, in turn, precluded efficient energy policy design. A relationship between energy demand and economic growth became the center of attention for the researchers. Hartman (1979) critique of the early models was based on the fact that they were a single equation, single fuel aggregate demand models with usually an energy price as the only explanatory variable. Neither institutional nor modernization effects were accounted for, let alone the impact difference in the short and long run.

The main developments in energy studies in the early 90s were panel data methods and the so-called translog revolution demand models (Griffin 1993, Timilsina and Govinda 2009). Despite being quite flexible and straightforward, translog function required data on the capital stock, which was a serious deficiency with data limitations in the energy sector. Panel data analysis, in contrast, became one of the main tools in related studies due to the possibility of accounting for both interregional and time variations.

At the end of the 90s – beginning of the 00s studying energy demand elasticities was accelerated both in developed and developing countries. Since 1985, when Codoni et al. used income elasticity of demand for Korea energy sector evaluation, policies adopting GDP-elasticities and energy intensities in the long-run demand forecasts were applied by policymakers in India, China, and Mexico (Chandra 2006, Timilsina and Govinda 2009). These studies concentrated not only on residential demand as in previous decades but on the industry response and transport sector studies, in particular (Berndt and Samaniego 1984, Bose 1998, Tiwari 1999).

Further research on energy demand differentiates between commercial and non-commercial energy and presents a detailed sector disaggregation for more precise results (Timilsina and Govinda 2009). Huntington and Barrios (2017) have made a selective review on energy demand studies since the 2000s stressing that both income and price elasticities for most fuels are below one, ranging from 0.24 to 1.75 (income) and from -0.03 to -1.3 (own-price) for all considered studies universally; the response also depends on the country, sector, and time. Authors point out the rapid increase in fuel source substitutability and further technical progress that add dynamism in energy-efficiency improvements but are also hard to be accounted for empirically.

While developing and transition countries worldwide have been engaged in continuous rounds of reforming attempts in the energy sector, the last 15 years of energy research provided a lot of studies on energy efficiency and intensity apart from demand models. Additionally, the incorporation of qualitative data into empirical analysis became more widely used. Cornille and Fankhauser (2004) suggest that energy prices and firms restructuring measures are the key determinants of a more efficient energy sector. They split Central-Eastern European countries into three groups based on reforms implemented and present a difference in energy intensity responses. Countries that have experienced privatization and market-pricing reforms, like Hungary or Poland, have shown a sharp drop in industrial energy intensity. However, in most CIS countries where such reforms did not succeed, and technical change did not follow, energy intensity has increased during the last decade. The third group of transition countries with a large share of heavy industry, like Poland or Romania, experienced a decrease in total energy intensity but no response in industrial energy intensity. Thus, we have to account for the technical and structural changes in our model to make reasonable conclusions.

Cantore and Fellow (UNIDO 2011) in their study on the energy intensity of 28 Eastern European and Central Asian countries during 1998-2008, concluded that the main reason for the decline in energy intensity in those countries is more efficient energy use rather than structural changes in the economy. Similar Ukrainian-Lithuanian joint analysis for 11 post-communist countries, while emphasizing the importance of technological modernization and accession to the European Union found that firms restructuring and governance improvements were not significant in energy efficiency and per capita energy consumption equations (Sineviciene and Sotnyk 2017). Of those who study energy in Ukraine, Chepeliev (2014) conducted comprehensive research estimating the positive effects of cross-subsidies elimination on investment and rising manufacturing capacity. At the same time, Dodonov (2016) applied LMDI decomposition methodology to estimate energy intensity and compare it over time. The study emphasizes the importance of recent energy efficiency increase for the energy savings potential of Ukraine.

While the results sometimes contradict each other, some do not support the general economic theory of the price-demand relationship due to the country-specific environment. In Pakistan, for example, an increase in per capita income was found to be the main factor contributing to energy intensity rise, while price changes – ineffective policy instrument for intensity influence (Ullaha 2019).

A new era of energy research has started from the introduction of energy intensity index decomposition into energy efficiency and structural changes index (called activity index). Studies by Metcalf (2008), Cantore (2011), Trinomics (2017) isolated the impact of fuel use efficiency on energy intensity. Metcalf (2008), by analyzing 30 years of US state-level data, also concludes that higher income per capita and market prices for energy cause a decrease in energy intensity primarilyrough the efficiency channel (meaning that the rise in efficiency was more important for energy intensity reduction than structural changes). This effect is not robust for all transition countries, though, and that is why it is of interest to each country's specific setting estimation. Studies on energy continue to improve along with the transformation of the energy sector across the world. From studying the effects on industry production costs (DG ENER 2017), three-dimensional analysis of energy demand (Burke 2018), attempts to account for nonlinearity, asymmetry, and heterogeneity in a cross-sectional setting (Brantley 2017) to completely novel approaches in the model construction.

Given the relevance of the researches described and the new approaches developed to study energy sector demand and efficiency, this research aims to apply the existing knowledge for the Ukrainian setting while accounting for country-specific features on a more disaggregated level. For the industry-response study, we will use an approach similar to the one suggested by DG ENER (2017) with some modifications to account for data availability. Demand estimation models, while relying on most of the abovementioned studies in control variables selection, will apply a methodology reviewed in Huntington and Barrios (2017). Finally, we consider studies of Metcalf (2008) and Cantore (2011) as a benchmark for our energy intensity decomposition. We will, however, use energy-sector disaggregation. Results are expected to provide practical insights for a more effective policy discussion given the limited scope of prior sector research.

Chapter 3

ENERGY SECTOR DEVELOPMENT AND POLICY REVIEW

During the last decade, Ukraine has moved forward significantly in terms of transforming its energy sector, given the series of implemented energy reforms in the electricity, gas, and oil sector (IEA 2020, OECD 2019). Yet it was only after the Revolution of dignity, in 2014 when serious steps were taken due to the severing ties with Russia. Diversifying supply and reducing consumption became the main sector goals (Atlantic Council 2020). To understand the effects of the recent reforms, it is important to review each sectors' development along with the policies implemented so far.

3.1 Electricity

After the USSR's dissolution, Ukraine lost 38% of the electricity generation power between 1990 and 1999 (IEA 2020). First attempts to create a wholesale market with separate agents for electricity generation, transmission, and distribution started as early as 1996 (OECD 2019). It was operated by the state enterprise Energorynok - a unique wholesale trader and payments settlement mechanism from 2000 up to 2019 (IEA 2020). All generating companies had to sell electricity to Energorynok, which then sold it to energy supply companies (oblenergoes) at an average price. Reverse payment flows from consumers were also made through the Energorynok. The scheme was complicated and prone to corruption (Zanuda 2020). Remaining state-owned enterprises, weak competition, and heavily regulated prices put a constant burden on public finance, discouraging energy-efficiency measures or modernization.

In 1998th the first phase of the privatization of oblenergos (created in 1995 in each oblast as distribution and retail enterprises) started (SPFU 2020, IEA 2020). While necessary in the long-term, changed ownership during the sector restructuring and with no future development strategy further complicated reforms implementation. Moreover, the state-owned company, Energy Company of Ukraine, had been developed from the re-unbundled assets at the beginning of the 2000s (OECD 2019, IEA 2020). Only in 2011, when Ukraine entered the European Energy Community, market participants had begun to operate along with the state ones. As for 2019, most Ukrainian energy supply companies are privatized, while production is split equally between the state-owned companies and the private ones (23% of which belong to the largest vertically integrated company DTEK) (OECD 2019).

In 2013 the Law on Liberalization of the Electricity Wholesale Market and Competition Encouragement was adopted following the EU regulations, mainly the EU Third Energy Package (Verkhovna Rada, 2013). However, the war in 2014th had slowed down market-oriented reforms. At the same time, the Association Agreement signed during this period raised the possibility of integration into the European Network of Transmission System Operators (OECD 2019). The Law on Electricity Market followed in 2017 and started to fully function in July 2019 (Verkhovna Rada 2017). According to the law, a single buyer model was replaced with a set of competitive markets (long-run bilateral contracts market, intra-day, day-ahead, balancing, and ancillary services markets). Apart from the market-based pricing, it also establishes unbundling of oblenergos into the Distribution System Operators (DSOs), separating electricity supply and distribution processes (NEURC 2019, IEA 2020).

Ukrenergo, the Ukrainian state-owned electricity company, continues to perform the function of the Transmission System Operator (TSO), managing more than 21 300 km transmission lines and networks (including cross-border ones). Its new role with the reform implementation also expanded to the technical support of the Energorynok and settlement administration (OECD 2019, IEA 2020). The transformation of the Ukrainian electricity market scheme and the new market-based pricing structure are presented in Appendix A.

Before the 2013 reform, electricity prices were fully regulated by the government through the National Energy and Utilities Regulatory Commission (NEURC) following the 'costs+' methodology (Epravda 2019). Households have been long buying electricity at the below-costs prices, while tariffs for industrial consumers were significantly higher due to the cross-subsidizations. After the reform, NEURC became responsible only for setting tariffs for the Ukrenergo's electricity dispatching and transmission. Industrial prices have increased 20-30% immediately after the 2017 market implementation. At the same time, residential tariffs were still protected by PSOs (up to July 2020) and price caps, suggested by the government, as a transition period measure. With residential prices remaining below market level and due to the subsequent market interventions by the government, Energoatom has developed significant debt to 'green' energy producers. Until all market players, including the state, start following the rules of the developed mechanism, it is inopportune to declare the reform completion (USAID 2020).

3.2 Natural gas

The Ukrainian gas sector has also been significantly transformed during the last decade, especially after 2014 when the moves towards establishment of the free gas market became proactive. Before, highly subsidized prices for residential consumers and import-parity prices for industrial users provided a possibility for illegal arbitrage[2] from one side and huge fiscal deficits from the other: 3.3$ billion were spent on gas subsidies in 2014, less than military spending in the same year, with

[2] The scheme was to buy gas at low state-regulated prices and re-sell it at disproportionately high market price (monopoly protected) or use this cheap gas in production of export products (Oslund 2015).

the budget deficit reaching 4.6% (Saha and Sagatom 2018). After the introduction of the unified prices to all consumers (industrial and residential), natural gas subsidies have fallen from more than 6% of GDP in 2014 to more than 1% already in 2017 (Dodonov 2018). At the same time, Naftogaz – the largest state-owned energy company in Ukraine (vertically integrated and engaged in the full cycle of gas production and distribution until the unbundling in January 2020), finally became profitable (IEA 2020). Yet, no policy was introduced to prevent the government from turning back to the market price regulation and subsidies reintroduction in the future, leading to continuing discrepancies in prices and government interventions in the market. While natural gas per capita consumption has almost halved during the last decade, Ukraine still consumes more than neighboring Poland (by 20%), Romania (by 15 %), or the World average (by 26%) (Our World in Data 2019).

Ukraine pledged to conduct property unbundling (between transmission/distribution and generation/production) along with the introduction of a fair and open retail market after becoming a member of the European Energy Community in 2011(Dixi Group 2019). Energy market reforms based on the European regulatory framework – Third Energy Package - were declared in the Ukrainian Energy Strategy 2035. The model of the new gas market, along with the price formation mechanism is presented in Appendix A.

While in 2020 the Ministry of Energy and Coal industry approved the completion of the package implementation, the market environment has not yet been established, with Naftogaz companies holding a preferential position in the market. The monopolistic access to the Ukrainian gas resources, the status of the supplier of last resort and control over all stages of transportation and distribution prevents the competition development in the form of independent suppliers and distributors network. It also discourages own gas production increase, which after the

Ukrainian-Russian war development and the gas blockade in 2014 became a question of the country's energy security. Subsidies monetization and transfer targeting implemented in 2019 helped to reduce budgetary spending, yet the share of energy recipients is still high – 3.1 million of households with an additional 1.8 million receiving payment benefits (Ministry of Social Policy 2021).

While many steps towards the fair and competitive market are to be finalized both legally and factually, the Ukrainian gas reform is still considered as one of the most successful energy reforms in the country and serves as an example to many post-Soviet states (OECD 2019).

3.3 Oil

Among hydrocarbon sector development, oil usually received much less attention. The soviet heritage left Ukraine with depleted oil fields making a country dependent on foreign natural resources, mainly from Russia and Belarus. Only in 1991own oil production fell by 5 million tonnes compared to almost 10 million produced at the end of 1980s (Smolansky 1995). The decline in extraction continued during the following two decades with a minor increase in recent years. At the same time, oil and oil refined products import constituted 85% of total consumption as of 2018 (Ukrstat). This led to active energy substitution reflected in lowered consumption levels. Four-fifths of the total consumption, though, is still attributable to transport and industry where alternatives are few (OECD 2019).

To a great extent, discouragement to develop domestic oil extraction capacities given the high extracting potential (200 ml tones - approximately 20 years supply) resulted from the prolonged inconsistent government policies (UIF 2019). For a long time, rents from the oil and gas extraction were high, making the practice unprofitable while licenses were awarded without any transparent mechanism. In 2018 according to Ukraine's Anti-Corruption Action Center, 25% of permits were granted to politically exposed persons, some of which have not been in the energy industry before (Anti-Corruption Action Center 2018). Because of the complexity and non-transparency of the procedure as well as minimum property right protection many potential investors have left Ukraine in recent years including the large US Marathon, Vanco, and Chevron (Prince 2019). Asthe gas industry, the largest share of oil produced and pipelined in the country belongs to the Naftogaz company and its subsidiaries. Ukrnafta, de jure state-owned company which is the main oil manufacturer, is de facto controlled by the private structures of one stakeholder. UkrTransNafta, also a subsidiary of the Naftogaz, manages the oil pipeline network. Private players are usually the same vertically integrated owners as in the other energy sectors fueling the monopoly power.

Oil refining, on the other hand, is deteriorating. Given the low level of raw oil consumption relative to the high level of final products the country consumes, estimated annual losses reach 1.6% of GDP according to MECI. From seven existing oil refining factories, only two are working, while oil refining capacities are loaded by as much as 20% comparing to more than 70% average in Europe (MECI 2019). At the same time, level of fixed assets depreciation reaches more than 80% (less than 60% on average across Europe), with the cost of refining being twice the European level. Some factories stopped working because of unprofitability due to outdated capacities.

Modernization and improved regulation remain critical to the hydrocarbons' development. In 2017 Ukraine's oil and gas sectors scored 49 out of 100 in the Resource Governance Index mainly due to the weak revenue management, value realization, and poor enabling environment categories (NRGI 2017). The Institute for the Index estimation, however, also emphasizes the number of successful reforms in the sector during the last couple of years. In 2016, after the license granting procedure amendments were made along with more transparent auctions, the way for the competitive oil business development was opened again. In 2018 the Law on Disclosure of Information in the Extractive Sector was adopted, postulating the disclosure requirements related to the beneficial ownership and reporting of rent payments (Verkhovna Rada 2018). Moreover, the number of permits necessary for oil field development fell by 20 (Prince 2019). In 2016 the rent was also lowered and decentralized with 5% paid by the extracting companies to local budgets, though it increased again only two years after the stimulus introduction (KPMG, 2018). Still, no clear taxing strategy for hydrocarbons' extractive companies has been developed so far – the fact that prevents many foreign investors from entering the market.

As the central part of the Third Energy Package commitments, each European country has to sustain a certain level of crude oil and/or oil products reserves. According to the directive 2009/119/EU of 14th September 2009, the stock should cover at least 90 days of imports or 61 days of consumption (Dixi Group 2017). The mechanisms developed by the Energy Community allow reducing risks in case of supply restrictions, especially for transport and chemical industries dependent on the resource. For Ukraine, the question of building up its reserves is also a political issue. While in 2019, following the Russian ban on oil sales to Ukraine, the country developed some imports from the US, diversification remains an issue of energy security in the future (Atlantic Council 2020). Despite the first steps taken, the country has been struggling to develop an efficient mechanism and divide the responsibility regarding reserves accumulation already for a few years now.

3.4 Coal

Ukraine is naturally richly endowed with coal resources, yet its production and consumption have also been steadily falling over time. While in the 90s coal production constituted more than 60% of the total energy produced and one-third of TPES, it plunged to over 23% in 2019 (OECD, Ukrstat 2019).

From nearly 300 Ukrainian coal mines, most are located in the East, mainly in the Donbas region. After the Russian annexation of Crimea, the conflict in the region severely affected domestic coal production, with illegal mining becoming a widespread phenomenon. According to MECI estimations, coal production fell by 49% in 2018 comparing to 2014 when the destabilization began (MECI, OECD 2019). Ukraine continued mining up to the 2017 rail blockade and halted cargo traffic with the region afterward. With a view of potential shortage threats, the government was trying to diversify foreign suppliers and substitute rich eastern anthracite with other coal types. During this time, in 2016, a controversial Rotterdam+ formula was introduced to determine the wholesale price of coal. It tied prices to the Netherlands' Rotterdam Port also adding the cost of resource transit to Ukraine. Since transportation costs were in reality far smaller, the scheme is perceived to have benefited the vested interests of the heat and power plants' owners. The National Anti-Corruption Bureau has estimated costs from the formula to reach approximately $710 million (Hromadske 2020). The scheme officially stopped working in 2019 after the introduction of a new market model.

The coal market is shared between both state-owned (11%) and private players, with the latter introduced mostly by two companies' groups: and Metinvest (Zorkin et al. 2020). They also operate multiple coal processing plants in the country. Still, many state-owned companies require significant budget subsidization, which in 2019 reached UAH 3.7 billion (given the revenue of 11.4 billion in 2018) (NEURC 2019, Ministry of Economy 2018). Their market share has dropped to less than 10% in recent years because of the high production costs (Dixi Group 2020).

To modernize the unprofitable coal sector and reduce state subsidization, the Big Privatization program in the energy sector has continued since 2006. Nevertheless, most of the companies and facilities are still state-owned or in the ownership of DTEK – the largest vertically integrated energy company in the country (the share of the company in coal extraction has reached 79% in 2019) (SPFU, Zorkin et al. 2020).

In 2017 the first concept of coal sector transformation was introduced. By 2020 the government planned to liquidate unprofitable mines, create an aggregate national coal company and increase extraction volumes. None of the initiatives were implemented, while the costs for the program were mostly spent on the debt restructuring for the state subsidiaries (Dixi Group 2020). In 2020 MECI introduced a new concept of reforming the coal industry by 2027. While reporting 29 out of 33 state mines being unprofitable with two-thirds of the equipment obsolete, the updated program aims to finally close those factories for which modernization is not feasible. The concept also pledges to gradually decrease coal extraction (by 25% till 2027) while stimulating renewables development and restructuring local economies dependent on resource extraction (MCTDU 2020). New workplaces and vocational programs were introduced to smooth the transition period for sectoral workers.

While the second stage of the Energy transformation roadmap (Energy Strategy of Ukraine to 2035) de jure starts in 2021, the country has yet to finalize its 2018-20 first stage targets of liberalized and competitive energy markets creation.

Chapter 4

METHODOLOGY

The research aims to answer some key questions related to any energy sector which can become a basis for an efficient evidence-based policy discussion. For this reason, we want to study the dynamics and the fundamental relationships using several approaches that would allow us to establish basic interconnections on the one side and build a more comprehensive picture of the sector on the other.

First, we want to test the hypothesis of the increased contribution of energy prices to the changes in industrial energy costs relative to other factors and its subsequent spillover effects on the total production costs. Since total costs change is reflected in the final consumer prices of commodities, understanding the main drivers of the costs variation builds a bridge between the energy policy and both producers and consumers. We will carry out a simplified Log Mean Divisia Index (LMDI) decomposition of energy and total production costs for several periods and industrial sectors to trace the dynamics and main determinants of the change.

Second, we check the asymmetry of demand responses to changes in prices and institutional factors in four main energy sectors by conducting four separate sets of panel data regressions using sector-specific data. While single equation energy demand models proved to have low robustness for different setting compositions, they are still useful for decision-making processes due to their relative simplicity. Moreover, given the data limitations in the Ukrainian energy sector, such models provide general insights into potential relationships in the sector and allow to include institutional factors to study demand responses.

Finally, the main part of the research is concentrated on the energy intensity decomposition analysis using Fisher Ideal Index. While the center of any energy policy is to reduce energy intensity (the ratio of energy consumption to GDP), the goal is to learn whether efficiency variation is the main factor defining energy intensity in Ukraine or does the structural shifts in the economy determine how energy sector was changing over time. For this estimation, we first construct separate indexes of energy intensity, activity, and efficiency. Then, we look at the key drivers of energy intensity and channels through which they affect the sector.

4.1 Industrial costs decomposition analysis

To evaluate the extent to which a given change in energy costs is attributable to certain factors and to isolate those impacts, we define costs as a product of industrial output, energy intensity (level of consumption per unit of gross output), and price mix of energy consumed by a sector (DG ENER 2017). Using logarithmic transformation, the expression can then be turned into an additive equation with the necessary effects separated. Since the analysis is conducted for disaggregated sectors on country-level data, LMDI simplifies to the logarithmic additive decomposition:

$$Energy\ costs = Output\left(constant^{3}\right) \cdot \frac{Energy}{Output(const)} \cdot Price\ of\ energy \quad (4.1)$$

$$LN(Energy\ costs) = LN\left(Output(const)\right) + LN\left(\frac{Energy}{Output(const)}\right) + \\ +LN(Price\ of\ energy) \quad (4.2)$$

For smaller effects, the growth rate expressed in percentages is identical to the logarithmic estimate, while for the higher values over-or underestimation occurs.

[3] Refers to the physical output proxy.

Hence for Ukraine, we express the effects in the logarithmic form while interpreting them as a percentage change approximate estimate.

Consistent with the equation, energy costs determinants are isolated in the following effects: (i) Real output effect; (ii) Real energy intensity effect (energy per unit of the industrial sector output) which represents changes in energy intensity either due to efficiency changes, structural shifts or behavioral factors; (iii) Energy price effect. The real output effect reflects changes in energy costs attributable to the changes in the production volume. Variation in real output captures potential changes in the economic environment, including demand, economic cycles, competitiveness, or exchange rate changes. Gross output deflated using sector-specific deflators stands for physical output proxy as suggested by DG ENER. Deflated estimates help control for the sector-level price variation leaving only the effect of the real production volume change. Besides incorporating activity and efficiency changes in an industry, energy intensity effect may also account for behavioral components or weather patterns such as an effect of temperature on energy consumption (DG ENER 2017). Finally, the energy price effect represents changes in weighted-average energy prices for each industrial sector. We weigh the prices for energy resources consumed in a sector by a fuel share in consumption and add them up to get the final energy price. Since we do not have the necessary data for prices other than for the four main energy resources - namely, coal, electricity, natural gas, and oil, we stick to the DG ENER assumption of them growing in line with a weighted-average of the existing ones.

Additionally, we present total production costs decomposition to reflect the extent to which energy costs variation contributed to the total costs change and, hence, influenced final consumer price:

$$\Delta(Total\ production\ \ costs) \\ = \Delta(Energy\ costs) \cdot costs\ weight\ in\ Total\ Costs \\ + \Delta(Other\ costs\ of\ production) \cdot \\ \cdot weight\ of\ other\ costs\ in\ TC \tag{4.3}$$

4.2 General demand elasticity analysis

Huntington and Barrios in their review on international energy demand elasticities study in 2017, found that of 258 pieces of research reviewed, the highest share (66 studies) were estimated as Multivariate Logarithmic Equations. Autoregressive Distributed Lag and Log Dynamic OLS are the second and third most popular choices with 52 and 20 studies made, respectively. Most of them also include price and income as the key independent variables while rarely considering technological progress or institutional factors. Average results for all countries in the review reflect inelastic demand responses to the changes in both prices and income with an exception for natural gas. Authors claim, though, that responses vary greatly among countries.

In order to study industry demand elasticities for the Ukrainian energy sector, we split the dataset into four - for each big energy source (electricity, natural gas, oil, and coal) and estimate elasticities separately for each. For each dataset, we also disaggregated the economy into five major industrial sectors: mining without fuel-related mining activities and processing, construction, transport, commerce and public services, and agriculture (including forestry sector). This provides us with a higher variation in the data and the ability to control for the sector-specific factors (Timislina and Govidna 2009). Consequently, more precise estimations are expected.

Given the individual industry-specific effect and time factor, we build the fixed effect panel data models for each energy source where the specification of the main equation could be presented as follows:

$$\begin{aligned} Energy\ sector(s)demand_{it} \\ = Sector\ VA_{it} + [Producer\ Subsidies]_{it} \\ + High\ Tech.Export\ share_t + KI/L_{it} + Events_t + \varepsilon_{it} \end{aligned} \quad (4.4)$$

Demand and real price are expressed in the logarithmic terms given different scales and for the straightforward interpretation as price elasticities. The subscript *i* is an industrial sector-specific index, and *t* stands for time (year) factor.

For small (in terms of global energy consumption market) developing countries, price could be considered exogenous. Thus, we do not have to correct for any potential endogeneity in a model as is the case for large developed countries like the US or EU.

Producer Subsidies variable is only present for the electricity sector demand model and is related to the PSO scheme that existed in Ukraine up until recently. The variable reflects compensation (subsidies) that the electricity suppliers received for having to sell electricity to residents at the below-market prices. Since there was a so-called cross-subsidies mechanism, where industrial users would have to pay more when prices for residents were lower, we expect a positive sign on the coefficient, meaning that the more the suppliers are compensated for potential 'losses', the less would the industry pay instead.

While many studies (Burke 2018, Anupama et al., 2016) use GDP per capita as income variable in simple energy demand models, we decided to use *Sector VA* (Value Added) instead. It allows us to capture the effect of income change in a particular sector rather than in the economy as a whole while also capturing the size of the particular industry. In an alternative specification, we also use *Industry Share* variable to control for the share of heavy industry in the economy considered to be particularly energy intensive (Sineviciene and Sotnnyk 2017).

Early demand models are criticized for the absence of additional variables that would account for technological change. Following the approach used by

Sineviciene and Sotnnyk (2017), we include *High technological export* share as a percentage of total export for technology improvement proxy. It captures modernization in the economy overall. *Energy loss* which reflects the losses of energy in network transmission, or during the transformation is also used for the sectors for which data is available as an alternative measure for modernization. *Capital investments to labor ratio (KI/L)* is also added to the base model to account for technological change within industries following the approach of Metcalf (2008) yet the relationship in its regard might be ambiguous. On one side, as suggested by Metcalf, a higher ratio indicates more energy-intensive production. At the same time, for Ukrainian industries, it may also mean more energy-efficient equipment and investments, which would potentially lead to lower energy consumption or, at least, lower losses.

Finally, the *Events* variable is a dummy that gets the value of 1 in the years, which either affects the calculation or represents shocks (war in Donbas region) and 0 otherwise. We expect it to be negatively related to the energy demand due to the restraints the war put on the supply of energy resources from Eastern Ukraine and terminated contracts with Russia.

We also test alternative specifications using more institutional variables like *Governance* based on the World Development Indicators data, *Corruption Perception Index, Privatization dummy,* and proxy for monopolization (*Naftogaz share* in production) for some sectors, yet they usually provide very low variation for Ukraine.

Moreover, we use a simplified energy demand model which does not directly incorporate structural effects (like GDP or Value Added) into the consumption estimate as well as any dynamic component. While Bohi and Zimmerman (1984) found that such reduced models produce comparable results and provide valuable policy-related insights, their main objective is still to identify general statistically significant relationships between the key variables and to investigate the asymmetry of their strength between the energy sectors.

Tismilina and Govidna (2009) claim that even those models that include the structural components and estimate energy intensity instead of energy consumption directly often found price insignificant in developing countries, where the demand is mainly driven by income. This might be a potential problem in the evaluation of policy measures, most of which are price-based. Many researchers also emphasized the limits of using energy-to-GDP, a conventional energy efficiency measure, for the demand-related effects estimations (Schipper et al. 1992, Ang and Lee 1994, IEA 2004, Can et al. 2012). Studies claim that energy intensity is not a sole factor affecting energy consumption, and it should be estimated in the interconnection with activity and structural effects. Since then, energy decomposition techniques were developed to isolate the effects affecting energy use and, hence, to better estimate energy intensity change and its key drivers (Can et al. 2012). These became a new generation of models in estimating energy usage.

4.3 Energy intensity decomposition

We will use the Metcalf (2008) adaptation of the Fisher Ideal Index decomposition of energy intensity. This method uses Fisher's (1921) ideal index approach first applied to the energy sector by Liu and Ang (2003). The geometric mean of the Laspeyres and Paasche indexes allows to perfectly decompose energy intensity into efficiency and activity components using sector-level data.

Energy intensity (EI_t) expressed as a function of energy efficiency and economic activity could be represented as follows:

$$EI_t = \frac{E_t}{Y_t} = \sum_{i}^{n} (\frac{E_{it}}{Y_{it}}) \left(\frac{Y_{it}}{Y_t}\right) = \sum e_{it} \cdot s_{it} \tag{4.5}$$

where E_t and Y_t – aggregate consumption of energy and GDP in the economy in a given year; E_{it} and Y_{it} – energy consumption and economic activity measure

(Value Added) for a sector *i* in a year *t*. Energy consumption of the separate sectors should add up to the total energy consumption in the economy, while the sum of economic activity measures should not necessarily sum to the economy-wide GDP (sector VA already works as the weight of the sector in a total sectors' VA).

Here e_{it} represents an energy efficiency measure in a specific industrial sector, while s_{it} reflects the share of the sector in the national GDP.

To construct the indexes for the whole economy, we first have to calculate the above-mentioned measures for each sector with the following aggregation into the Laspeyres and Paasche efficiency and activity indexes. With e_{i0} and s_{i0} denoting energy efficiency and activity measures for a base year (1996 in our dataset) the Laspeyres and Paasche indices could be written as:

$$L_t^{activity} = \frac{\sum_i e_{i0} \cdot s_{it}}{\sum_i e_{i0} \cdot s_{i0}} \tag{4.6}$$

$$L_t^{efficiency} = \frac{\sum_i e_{it} \cdot s_{i0}}{\sum_i e_{i0} \cdot s_{i0}} \tag{4.7}$$

$$P_t^{activity} = \frac{\sum_i e_{it} \cdot s_{it}}{\sum_i e_{it} \cdot s_{i0}} \tag{4.8}$$

$$P_t^{efficiency} = \frac{\sum_i e_{it} \cdot s_{it}}{\sum_i e_{i0} \cdot s_{it}} \tag{4.9}$$

Thus, the Laspeyres indices base period is included with fixed weights while Paasche indexes are currently weighted. Each index estimates the change in energy activity or efficiency by the respective weighting procedure. The Fisher Ideal Indexes then follows:

$$F_t^{activity} = \sqrt{L_t^{activity} \cdot P_t^{activity}} \tag{4.10}$$

$$F_t^{efficiency} = \sqrt{L_t^{efficiency} \cdot P_t^{efficiency}} \tag{4.11}$$

e_0 being aggregate energy intensity in a base year, energy intensity index for the whole economy could be perfectly decomposed into indexes of efficiency and economic activity without residual (for the proof of the perfect decomposition, please see Fisher 1921):

$$\frac{e_t}{e_0} \equiv I_t = F_t^{eff} \cdot F_t^{act} \tag{4.12}$$

After constructing the decomposed indexes for the four energy sectors, we are interested in what drivers and through which channels affect energy intensity. For this purpose, we build panel data regressions for each index and compare the strength and the direction of the relationship. We continue using fixed-effect models as they allow us to control for time and individual-sector time constant unobservables (energy sector here). Yet we also check random effect and pooling models to check the system fit. Formally, the model could be presented as

$$\begin{aligned} Index_{it} = log(Real\ Price_{it}) + Population\ growth\ rate_t \\ + log\ (Real\ per\ capita\ Income)_t + KI/L_t + (KI/L)_t^2 \\ + Events_t \end{aligned} \tag{4.13}$$

where i is now a subscript of the energy sector and t – of the time (year). $Index_{it}$ would be either Activity, Efficiency of Intensity Index as in the decomposition analysis. Following Metcalf (2008), decomposition also suggests a way to explain energy savings defined as the difference between current energy consumption and the one that would have occurred had the energy intensity stayed on the 1996 level ($\hat{E}_t$).

$$\Delta E_t = E_t - \hat{E}_t \tag{4.14}$$

$$\Delta E_t = \Delta E_t \left(\frac{ln\,(F_t^{act})}{ln(I_t)}\right) + \Delta E_t \left(\frac{ln\,(F_t^{eff})}{ln(I_t)}\right) \equiv \Delta E_t^{act} + \Delta E_t^{eff} \tag{4.15}$$

From the equation, we then could attribute energy savings to the improvements in energy efficiency and structural changes separately.

Potential problems in the estimations process arise mainly from the data availability and aggregation methodology. Thus, several assumptions are to be made about some variables that are then to be tested with a series of robustness checks.

Chapter 5

DATA

Data for the Ukrainian energy sector remains the main obstacle for the quality analysis performance. Since there is no aggregated data source for the necessary energy-related information, various sources were used with great emphasis on the data provided by the Ukrstat and IEA. To perform the analysis, data for a 24-year period was collected: from 1996 up to 2019. Since the beginning of 2010^{th} Ukrstat with the IEA assistance was working on developing Ukrainian energy balance statistics (IEA 2020). Newly introduced energy balance data were used for consumption and energy loss statistics. All data from energy balances is unified and expressed in thousand tonnes of oil equivalent, making the consumption (losses) between sectors easily comparable.

5.1 General data description

As it was already mentioned in the previous chapters, data is disaggregated on two levels: by energy source – electricity, coal, natural gas, and oil, and sector-wise – mining and processing (without fuel mining), construction, transport, commerce, and public services, agriculture, and forestry so that in aggregation with the residential statistics they would sum up to the total consumption in the economy. While we mostly concentrate on the industrial sector in our research as it is not so much regulated and therefore more responsive, we still have to use residential energy consumption data to conduct the energy intensity decomposition.

For economic sector costs decomposition, we use data from the Ukrainian Input-Output tables in consumer prices and Ukrainian Intersectoral balance for the data before 2003. Tables represent flows from various sectors to the electricity and gas sectors as well as to the section of oil and coke products.

These flows, though not perfectly, reflect the energy costs of particular sectors. IO tables also provide data on total costs, calculated as the difference between the output in basic prices and gross profit, total intermediate consumption, and labor costs. All the variables mentioned were deflated using sector-specific deflators to account for the price variations in each of them separately. The resulting data is expressed in 2016 constant UAH. Several periods were chosen to show the drivers' importance based on the quality of the available data. Those are 2000-2012, 2012-2015, 2015-2019, and total change as of 2000-2019. Since we do not want to include the fuel sector itself[4], we have to subtract fuel-related mining shares from the respective estimates in the mining and processing data. These include gas, coal, and oil extraction as well as electricity production in the tables mentioned.

5.2 Price-related data description

Prices data on the selected sectors were combined from various open data sources, including NEURC reports since 1996, which could be uniquely found on the Verkhovna Rada legal webpage as a part of the Cabinet approval documents. These reports are the only source of reliable price data available for the years prior to 2010th. The OECD and the IEA repeatedly stressed this scarcity of open data on energy prices as a factor that precludes comprehensive analysis and effective policy evaluation in the Ukrainian energy sector (OECD 2019). Due to the limitations, several assumptions were made regarding prices. Given the 92% correlation between the industrial natural gas price without VAT and the Russian gas price for Ukraine (in UAH) for the 1998-2016 time period, we approximated missed data

[4] As was mentioned in a previous chapter we want to look at the effects related to the economics sectors without energy sector own consumption. The reason is that drivers studied in the analysis will affect the sector differently than other industrial sectors (in many instances it is the fuel sector that determines these drivers and not vice versa).

for 1996-1997 with the respective import prices using the NBU yearly average exchange rate. Residential prices were taken from Slovo i Dilo analytics group and are presented for the same day annually, while other prices are expressed as years averages. Since the Ukrainian industrial price for electricity is separated by energy classes[5], we used two alternative weight measures to calculate the final price – 20/80 and 50/50 weight for the first and second class, respectively. A detailed description of the price variables along with the units is presented in Appendix B. Below, we also present the correlation between the prices during these 24 years.

Table 5.1 Correlation between real industrial energy prices

	Pelec	Pgas	Poil	Pcoal
Pelec	1			
Pgas	0.944	1		
Poil	0.752	0.754	1	
Pcoal	0.936	0.872	0.699	1

As we can see, the highest correlation exists between electricity and gas prices. This might stem from the fact that electricity and gas tariffs in Ukraine usually increase in concert as opposed to coal and oil prices which move more independently and are the least related. The reason lies in combined cycle plants (electricity and gas) and similar demand movements during weather changes and lower production of the alternatives. Similarly, high coal and electricity price correlation stems from the fact that coal is used in production of thermal power electricity (Endesa 2021).

5.3 Generalizations for the model

For the demand elasticities estimations, we also used data from Ukrstat energy balances and IO tables, yet in this case, we had to make additional approximations

[5] Fist class prices the consumption for above 27.5 kWt voltage (as for 2021) while the second – below 27.5 kWt with the second usually being ~ 20% higher.

regarding missing data for the estimations without the fuel sector. The value-added for the industrial sector (mining and processing) consists of mining and processing, including energy-sector mining and electricity production. Since we might be more interested in the indexes related to the industrial sector 'clear' of the energy sector itself, we have to decrease our VA. As the data on the fuel mining components VA is unavailable, we assume that the VA change would be proportional to the change of the respective mining shares (coal, gas, and oil) in the sales volumes of industrial products. It turns out that the resulting shares mirror the shares of the fuel sector in the VA with a high precision given those years available for comparison (Ernst and Young 2019). For the period for which data on sales volumes is unavailable (1996 -2000), we approximate the share with that of 2001, given the relatively negligent changes in the subsequent years.

Also, from 1996 to 1999, the level of industry aggregation was different from the following years and might have included electricity production (no metadata is available for the exact comparison, yet it is very probable from the data structure presented). Thus, the share of electricity in VA as an average share for five consecutive years (from 2000 to 2004) was subtracted from the original values in the given period. We then test this share (23%) for robustness while conducting the same regression analysis for the original values, values with 23% share subtracted and values with 21% and 19% shares subtracted.

For the labor share costs variable, we also had to make an approximation for the industry without fuel sector category as the value of fuel sector spending on labor was not available for the period from 2004 to 2014. Given the fact that the labor share for the industry without fuel sector was relatively stable for all the years, (the data is available and has ranged from 80 to 95% of the total heavy industry spending on labor) we took an average of the existing values (87%) to fill the missing gaps. We then check our approximations for robustness in regression estimations using alternative shares (90 and 85%).

Generally, the abovementioned approximations relate only to the minor share of our data, specifically to one industrial sector, and should not affect our results, yet additional robustness checks are required for the estimations, which include approximated data. For the demand estimation, we also include macro variables and institutional factors using data from SPFU, WDI, NEURC, etc. For a more detailed data description, please, see Appendix B.

5.4 Descriptive statistics

All nominal variables were deflated with 2016 taken as a reference year: macro variables using the GDP deflator, others – either by using the CPI or sector-specific deflators. Descriptive statistics for some of the main variables is presented below (Table 5.2). The table provides information about some sectoral differences. Negative TPES is only observed for the electricity sector, which from the TPES definition (see Glossary) might mean negative net import for this sector alone. Mean consumption shares reveal that natural gas dominated industrial energy demand on average during the whole selected timespan, with electricity having the lowest average share. This equally relates to the price differentials. At the same time, average energy losses for the natural gas sector are twice lower than those for electricity. Since energy losses relate to energy efficiency and intensity directly, their minimization is a priority in enhancing smarter energy use. In Ukraine, gas sector infrastructure modernization receives stable financing according to the plan developed by TSO (UA Transport System Operator) (GTSO 2020). Electricity generation and transmission facilities, however, with 50-70% wear and tear level experience constant financing deficit due to the high cost of financing (19%) and tariff structure that neither stimulates modernization by private oblenergoes nor provides financing for sector-wide modernization (MECI 2019, ADSO 2016).

Table 5.2 Descriptive statistics of the key variables for demand estimation by the energy sector

Statistic	Obs	Mean	St. Dev.	Min	Max
			Electricity		
Final consumption	120	1565.48	1836.47	62.25	5820
TPES	120	-451.75	261.29	-987	-13.24
Energy loss	120	2057.34	473.97	1413.08	2928.55
Real Price	120	1252.93	382.23	793.52	1936.36
			Natural gas		
Final consumption	104	2700.69	3694.25	8.47	14534.59
TPES	120	49708.47	15854.18	23382.72	74492.80
Energy loss	120	1031.51	487.10	455.00	1812.00
Real Price	120	3645.11	2403.83	973.43	7467.17
			Oil and oil products		
Final consumption	102	2481.89	3113.57	43.00	9688.61
TPES	120	13708.12	2149.59	9906.00	18025.10
Real Price	120	1110.32	429.28	388.30	2362.07
			Coal		
Final consumption	87	2179.24	3616.16	1	14460.32
TPES	120	36570.86	5043.03	25718.22	42718
Real Price	120	2055.72	900.34	651.687	3898.50

Note: for the sectors where the number of observations for final consumption does not match with a real price, full timespan statistics is presented for between-sectors comparison only. Consumption, TPES (*Total Primary Energy Supply*), and Energy loss are measured in ktoe, Price – in UAH per thousand energy units.

Finally, for the energy intensity decomposition, apart from the above-mentioned data, we also added residential sector alternative estimates to construct the necessary indexes. Table 5.3 summarizes measures used for indexes' construction on a sectoral level. Basic prices VA is used for a more precise activity representation in the industrial sector. For the residential sector, final consumption expenditures are included following an approach similar to that of Metcalf (2008).

Table 5.3 Measures used to build energy indexes

	Sectoral Economic Activity	Sectoral Energy Efficiency
Sector	*Measure*	*Measure*
Industrial	Value-added for each industrial sector (2016c mln UAH, basic prices)	Toe/mln UAH (2016c)
Commercial	Value-added aggregated for all commerce & public services sectors (2016c mln UAH, basic prices)	Toe/mln UAH (2016c)
Residential	Final consumption expenditures aggregated (2016c mln UAH)	Toe/mln UAH (2016c)
Total	GDP (2016c mln UAH)	Toe/mln UAH (2016c)

Descriptive statistics for the main model variables (Table 5.4) also provide more data insights. The activity index, which measures the structural change in the economy is above 1, on average, compared to the Energy Efficiency and Intensity indices. This applies to some other Eastern European countries as well, mostly for those specialized in some energy-intensive activities, namely Estonia, Georgia, or Bulgaria, while it is slightly below one at least for other countries (Zhang 2013). For Ukraine, it might mean that structural changes in the economy were not really in the direction of lower total energy consumption as is widely perceived. Capital Investments to Labor ratio was constructed with the capital investments in the fixed capital data provided by Ukrstat. Labor represents costs spent on labor in each sector. While it is not identical to the conventional Capital to Labor ratio, it is a reliable proxy to capture the dynamics of the capital investments relative to other significant firm costs. The table illustrates that the difference in the ratio with and without the fuel sector is minor which might indicate comparably low capital investments in the sector, naturally affecting energy efficiency overall.

Maximum energy losses are twice the mean value reported. Data indicate that these extremes are common for the beginning of the researched period since energy losses in transmission or transformation, though still high, have been declining for the last two decades.

Table 5.4 Descriptive statistics for the main model variables

Statistic	Obs	Mean	St. Dev.	Min	Max
Activity index	96	1.12	0.19	0.51	1.63
Efficiency index	96	0.60	0.25	0.16	1.19
Intensity index	96	0.65	0.27	0.22	1.31
priceMix1	96	1786.98	1366.43	406.53	7629.35
priceMix2	96	1802.30	1359.25	406.53	7629.35
Population growth	96	-0.08	0.01	-0.06	-0.02
Per capita GDP	96	52186.3	11589.50	32394.68	66375.80
Cap. inv. to Labor ratio (KI/L)	96	0.35	0.08	0.23	0.53
KI/L ratio with fuel sector	96	0.37	0.07	0.27	0.54
Energy Loss	96	5924.77	2680.61	3149.99	9973.07
Energy depletion of GNI	92	0.98	0.362	0.271	1.621
Corruption perception index	88	2.541	0.362	1.5	3.2
High technological export share	92	5.357	1.42	3.3	8.5
Governance index	84	-2.875	0.429	-3.905	-1.963

Note: prices are measured in UAH per thousand units of energy; GDP per capita – in mln UAH (const 2016)

By contrast, the energy depletion of GNI, which represents the ratio of the stock of energy resources to the remaining lifetime of the reserves capped at 25 years (WDI estimate) was severely hit by the war in Eastern Ukraine and, therefore, has a wider range. It has decreased by 45 p.p. recently, given the vast resources concentrated in the Donbas region. Corruption perception and governance indexes, which are generally perceived as proxies for the rule of law and reform facilitation by the government, have a quite low variation for the whole timespan (24 years) and are not available for all years, yet the margin of change might be significant and, thus, they will be applied to some of the models.

Chapter 6

ESTIMATION RESULTS

Based on the methodology and data described in the previous chapters, the results are presented along with the necessary robustness checks given on the approximations made, model specifications, and potential problems.

6.1 Costs decomposition analysis

Energy and total costs decomposition analysis are presented on an example of a construction sector (Figures 6.1, 6.2). The vertical axis reflects the percentage change for a given period. Appendix C provides a decomposition and the dynamics of the costs shares for all five selected industrial sectors.

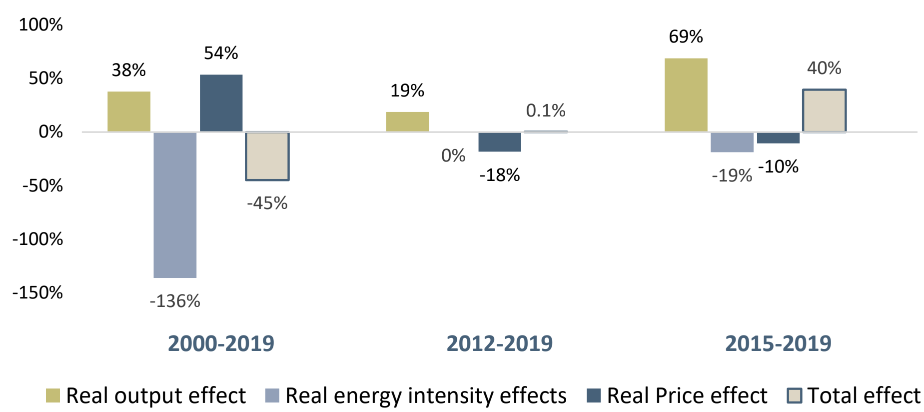

Figure 6.1 Energy costs decomposition for the construction sector.
Source: author's analysis based on the USSS data

As it could be observed, the 45% drop in construction sector energy costs for the last two decades was primarily attributable to the change in energy intensity (energy consumption per unit of output) and price. The same holds for all other sectors

(Appendix C.2). Energy intensity usually declines for one of two reasons: either due to the improved energy efficiency or because of the structural shift to less energy-intensive activities. We will look at which channel is dominant as well as which factors contribute most to this change further in the energy intensity decomposition section. While looking at the last ten years, which are considered the core transformation period in Ukrainian energy history, price led to energy costs increasing only in mining, commerce, and public services sectors, while for construction, agriculture, or transport it comes with a negative sign. Moreover, during the same period, total energy costs ascended only for agriculture, commerce (for almost 40%), and construction (during the last couple of years), meaning that recent reforms have not led to significant energy cost rise in most of the industrial sectors. Except for mining and heavy industry, the share of which in Ukraine was getting lower for some time already, real output effect was a major contributor to the costs increase apart from the energy intensity effect. The original hypothesis was that for energy-intensive sectors (mining, transport, manufacturing) changes in energy costs would be mostly attributable to the fuel-price effect and less to the energy intensity effect as for the lack of alternative opportunities in energy usage. While price is indeed an important factor for transport, construction, and agriculture as for the last decade, our results indicate that it is generally not the only significant determinant.

On the other hand, the energy costs dynamics with respect to the total production costs changes (Figure 6.2, Appendix C.3) demonstrates that the effect of energy costs contribution relative to the other costs change is minor for all selected sectors. Results are aligned with those obtained for the EU countries in a similar study (DG ENER 2017). This fact contradicts the mainstream idea of the large negative effect of the energy costs increase in Ukraine on the industrial sectors and, as a result, on consumer prices.

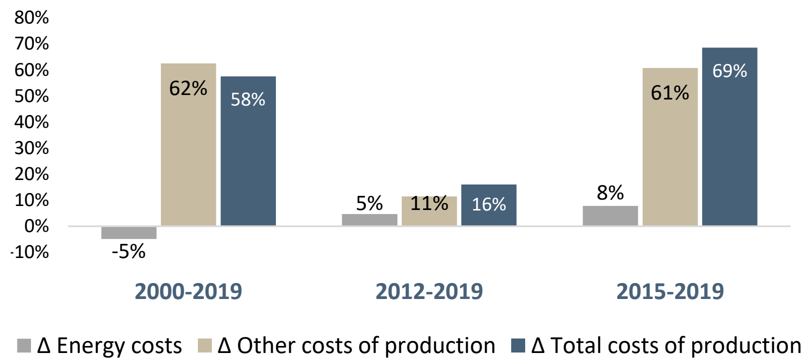

Figure 6.2 Total production costs decomposition for the construction sector. Source: author's analysis based on the USSS data

Despite contrasting media coverage, energy prices for industrial users, though higher than for the residential sector, are still far below the European level. The contradiction lies in the fact that we usually tend to discuss a wholesale price for energy resources (which in Ukraine is often even higher than the European), while it is the final price that determines firms' costs and should be the subject for international comparison. Thus, the electricity price of Ukrainian business as of June 2020 was lower than in 70% of countries out of more than a hundred (GlobalPetrolPrices 2021). According to the Razumkov research center, in 2019, final tariffs were 33% lower than the EU average (Razumkov 2020). While the EU final price is constructed with many additional payment components, not alone taxes, in Ukraine, wholesale price constitutes almost all the final industrial tariff.

6.2 General demand elasticity analysis

We first look at the total energy demand disaggregated by both the energy source and industrial sector (Table 6.1). Price elasticities estimation for across all energy sources are in line with the literature and vary between -0.3 to -0.4, meaning that an increase in energy price by 1 % will, ceteris paribus, be associated with the decrease in energy consumption by much less than the price increase. Energy price elasticities below unity are common for the energy-intensive, less developed countries with not many alternatives to the conventional energy sources (Tismilina and Govidan 2009). For all demand models, we use Arellano (1987) robust standard errors which account for both heteroskedasticity detected by the Breusch-Pagan test and serial correlation common for the models with longer time series (confirmed by Breusch-Godfrey/Wooldridge test for serial correlation in panel models, see Appendix D) (Millo 2017, Croissant and Millo 2018). Income elasticities on the VA closely match those obtained by Chang et al. (2019) for OECD countries' energy-intensive industries.

Table 6.1 Total energy demand

Variable	Log Energy consumption	
Log (Real price)	-0.417***	-0.273*
	(0.112)	(0.145)
Events dummy	-0.065**	-0.050*
	(0.027)	(0.028)
Log (Sector VA)	0.329***	0.380**
	(0.126)	(0.149)
Energy Depletion of GNI	0.254**	0.304***
	(0.100)	(0.106)
High technological export	-0.046**	-0.005
	(0.019)	(0.021)
Governance	-0.231***	-0.211***
	(0.086)	(0.800)
Industry share		4.873
		(2.971)
Time fixed effect	Yes	Yes
Industry fixed effect	Yes	Yes
Observations	413	413
R squared	0.26	0.27

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Standard errors in parentheses are Arellano SE (both heteroskedasticity and serial correlation consistent).

The governance index, representing a weighted average estimate of the indexes of government effectiveness, control of corruption, regulatory quality, and the rule of law is of interest. For the overall energy demand, governance improvement is associated with lower energy consumption. The same holds for the technological improvements represented by the High technological export proxy. Energy depletion (stock of energy resources to the remaining reserve lifetime) also has an expected positive sign on energy demand, while the inclusion of the industry share variable (second column regression), while statistically insignificant, decreases the coefficient on the price by more than 30%. The issue of little consistency of the elasticity estimates in such types of regressions is often mentioned by the literature (Tismilina and Govidna 2009, Chang 2019).

Table 6.2 Energy demand responses by energy source

Variable	Log Energy consumption			
	Electricity	*Natural gas*	*Oil*	*Coal*
Log (Real price)	-0.273*	-0.391***	-0.113	-1.49***
	(0.157)	(0.120)	(0.118)	(0.572)
Events dummy	-0.045**	0.029	0.082	-0.021
	(0.023)	(0.091)	(0.105)	(0.059)
Log (Sector VA)	0.133	0.140	0.117	0.831*
	(0.108)	(0.088)	(0.141)	(0.448)
High technological export	-0.027*	-0.051*	-0.061*	-0.062
	(0.016)	(0.029)	(0.030)	(0.061)
Log (Subsidies to producers)	0.143*			
	(0.086)			
KI/L	-0.047	-0.253***	-0.344***	-0.042
	(0.051)	(0.051)	(0.124)	(0.189)
Time fixed effect	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes
Observations	120	104	102	87
R squared	0.32	0.46	0.15	0.33

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Standard errors in parentheses are Arellano SE (both heteroskedasticity and serial correlation consistent).

Besides some variation, though, the estimates stay in line with the original model results despite specification changes (see Robustness check section). Table 6.2 demonstrates how responses differ for each energy sector. On a sector-specific level, the only statistically significant coefficients are price, high technological export, the ratio of capital investments to the labor costs, and producer subsidies for the electricity sector.

Most relationships are of expected signs, and elasticities could be related to those estimated for other Eastern European countries (Huntington and Barrios 2017). The highest price elasticity is reported for the coal sector (-1.49) which might be explained by relatively lower product shares in industrial consumption and higher substitutability in power generation. The lowest (-0.113) – for the oil sector yet is not statistically significant in almost all the model specifications. Natural gas naturally has higher price elasticity (in absolute terms) than electricity (-0.39 versus -0.27), yet it is much lower than the average found by Huntington and Barrios for the 258 selected studies across the globe (-1.36). Authors stress, however, that natural gas demand elasticities are to a great extent influenced by infrastructure and the pipeline system in a country. Ukraine being a gas transit country with a well-developed gas infrastructure has been historically inclined to higher gas consumption and lower price elasticity.

Additionally, variables related to energy efficiency increase, namely capital investments, and modernization proxy, are statistically significant and positively influence lower energy consumption in a country. On average for four sectors, a 10% increase in the High Technological Export share is associated with a 0.5% decrease in energy consumption. Capital investments to labor share ratio effect depend on the sector with a visible and most significant effect for natural gas and oil sectors – main recipients of investments among the four sectors (Ukrstat). Subsidies to producers in the electricity sector, which represent a change in the PSO scheme, as expected, are associated with a rise in industrial energy consumption. Since these subsidies are granted to producers to offset residential purchases by understated prices, the industry must, therefore, pay a lower cost as cross-subsidy. Ukrenergo in 2019 has estimated the additional load on the industry from PSO inflated prices to reach approximately $37 bill per year (Tkachuk 2019).

6.3 Energy intensity decomposition

We decomposed energy intensity into efficiency and activity indexes for four main energy sectors as described in Chapter 4. Figure 6.3 visually depicts a decomposition by demonstrating indices' dynamics.

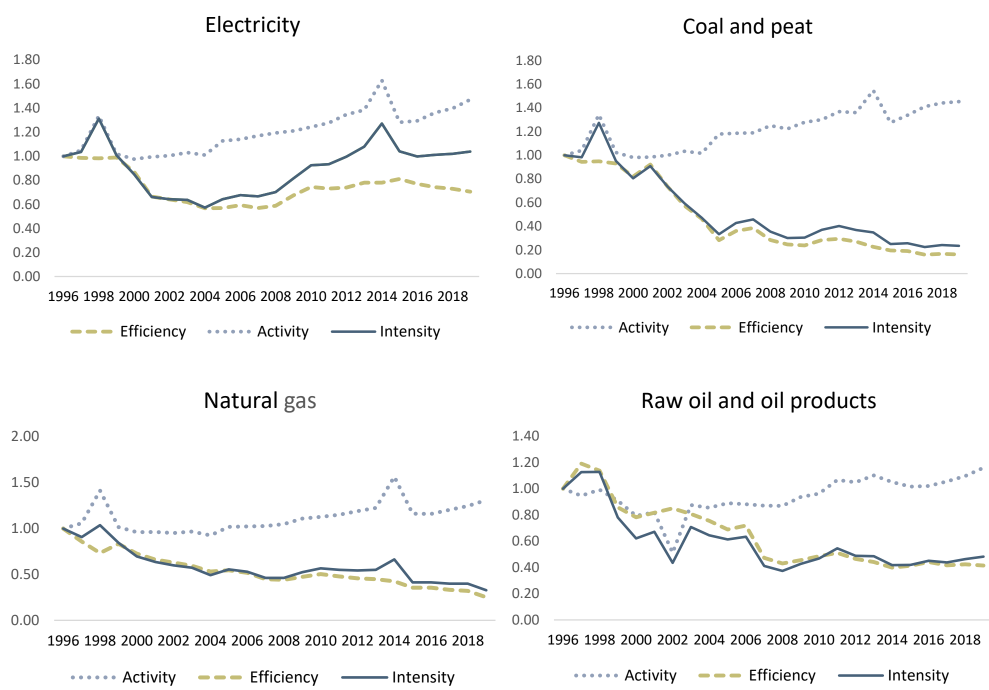

Figure 6.3 Energy decomposition for four main energy sectors.
Source: author's analysis

The graphs illustrate that while energy intensity was steadily declining for gas, oil and coal industries since the 90s, it was actually increasing in electricity sector since 2004. This might be partially explained by the fact that electricity is usually used as a substitution for other energy sources due to its lower price. The previous chapter also stressed the highest level of energy loss in a sector alongside a constant financing deficit which precludes modernization.

The most significant difference between activity and efficiency indexes – in the coal sector. This dynamic has started even before the war in Eastern Ukraine and stems from the fact that coal is mostly used in power generation. During the last two decades, though, the share of electricity generated from coal declined from 50-60% in the 90s to slightly over 30% in recent years and was effectively substituted by nuclear power production (MECI, NEURC 2020). Furthermore, in all four graphs, the dynamics of energy intensity closely follow the dynamics of the energy efficiency line rather than the activity one. We are to support our primary assumption of the dominant efficiency channel with a regression analysis further.

The decomposition also allows energy savings interpretation relative to energy use that would have occurred had the energy intensity stayed at its 1996 level (see Eq. 4.14). In 2019 energy Intensity index was 0.33 of the 1996 level, Efficiency and Activity indexes – 0.25 and 1.25, respectively. Had the structure of the economy remained the same as in 1996, energy intensity would have been 0.25 of its 1996 level. At the same time, had energy efficiency stayed at its 1996 level, energy intensity now would have increased to 1.25 of its 1996 level. This again stresses the importance of energy efficiency in the energy intensity decrease in Ukraine for the last two decades.

Table 6.3 further develops on which drivers and through which channels influence this change in intensity. In this type of regressions, we use aggregated industry and residential data. Heterogeneity in the panel is now introduced by the time and energy sector fixed effect rather than the industry-level effect used in the demand models. Since we only have four energy sectors and a twenty-four-year time series, several issues are to be accounted for. First, Appendix D contains results for the Intensity index OLS, Fixed and Random effect models along with the related tests for serial correlation, stochastic trends, and cross-sectional dependence common for macro panels with long time series (Millo 2018). Tests are conducted for the Random effect model as suggested by the Hausman test.

Table 6.3 Random effect regression results by indexes

Variable	Activity	Efficiency	Intensity
Intercept	-3.65***	7.234***	4.775*
	(0.714)	(1.896)	(2.684)
Log (priceMix1)	0.089*	-0.155***	-0.143***
	(0.046)	(0.051)	(0.044)
Population growth rate	-0.212	0.399	-0.147
	(0.864)	(0.904)	(0.292)
Log (Real per capita income)	0.506***	-0.459**	-0.158
	(0.080)	(0.205)	(0.283)
KI/L	-6.204***	-2.551***	-7.018***
	(0.623)	(0.785)	(1.107)
$(KI/L)^2$	6.318***	2.876***	7.610***
	(0.823)	(0.537)	(0.738)
Events dummy	-0.044*	-0.022***	-0.055***
	(0.025)	(0.007)	(0.015)
Time effect	Yes	Yes	Yes
Energy sector effect	Yes	Yes	Yes
Observations	96	96	96
R squared	0.61	0.76	0.59

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Standard errors in parentheses are Arellano robust SE.

Coefficients of random and fixed effect models are very close, yet while the Random effect model is suggested as a better fit, the interpretation has to account for both within and between sector effects. Coefficients represent an average effect on the index when independent variable changes across time and between energy sectors by 1 unit. At the same time, the most important for a given regression is the relative magnitude and directions of the effects. On contrary to the original assumption of the possible significant role of the activity index in determining energy intensity of Ukraine, it is the efficiency channel that is dominant. Index dynamics graphs have already depicted that structural changes in the economy did not generally contribute to the decrease in energy intensity in Ukraine, at least during the last two decades. While the share of industry in GDP (includes heavy industry, manufacturing, and construction) had fallen during the first years of independence, it has only changed by 3 pp. as for the last decade (World Bank 2019). The growth of other industries, on the other hand, is accompanied by the rise in traditional energy source consumption.

Similar to Metcalf (2008) and Zhang (2013), while the effect of price on the structural index is positive or ambiguous, a price increase clearly decreases energy intensity through the efficiency channel. Moreover, the effect is very statistically significant and the highest in absolute terms: a 1% increase in price between energy sectors is, on average, associated with a 0.15% decrease in energy efficiency index and 0.14% decrease in energy intensity. Real per capita income elasticity is also of expected sign for efficiency and intensity indexes (for the latter it is insignificant though) while for activity index the coefficient is positive. Moreover, the effect is larger in absolute terms than that of the price change. There is a highly statistically significant quadratic response of the indexes to the capital investments variable. With a ratio increase up to the 46% level (1.5 standard deviations above the mean in our dataset), the energy intensity declines while starting to rise afterward. Finally, the Events dummy has a larger positive impact on energy consumption (meaning decrease) through the activity index, probably because of the war affecting the heavy industry in Eastern Ukraine.

6.4 Robustness checks

To test our core models for robustness we conduct similar regressions to those made in the previous paragraph while changing model type, specification, and heteroskedasticity/serial correlation correcting technique. Appendix E presents the main tables for the robustness check (features only the results for which change was apparent).

First, we include other variables in demand elasticity models. We use lag Price, Energy Loss instead of High Technological Export, include Corruption perception index and proxy for monopolism in gas and oil sector (Naftogaz's share in production). For both the total and energy sector-specific models, price lag turned out to be insignificant. Additionally, the inclusion of the new variables for the total demand model generally did not change core variables' significance while slightly affecting the magnitude of the price elasticity (Table E.1). For sector-specific models, though, change of the model specification sometimes led to more significant changes in the price effect magnitudes and significance. For example, Naftogaz's share in gas production included in a model (a proxy for monopolization) decreased gas price-elasticity more than twice – from 0.391 to 0.140 in absolute terms (Table E.2). This effect often appears in the literature studying energy demand (Tismilina and Govinda 2009, Chang 2019) as such models might be sensitive to the inclusion of new variables. Nevertheless, base inferences made from the original models regarding the sign and relative magnitude of the effects remain robust.

Assumptions on electricity and labor cost shares for the fuel sector are robust for all alternatives (see Chapter 5) up to the fourth decimal place. The same holds for the electricity price weighted by classes. Results apply to both demand and decomposition models. For the latter, we conclude that our main specifications have valid statistical inferences as they are independent of the model specifications. Tables E.3-E.4 present alternative fixed-effect models for all three indices while using Arellano (1987) and HAC standard errors (Zeileis 2004). These are two alternative measures applied to the panel data models to account for both heteroskedasticity and serial correlation where the timespan is large. HAC Covariance Matrix estimator made the Events dummy statistically insignificant and slightly decreased the significance of the *Capital Investments to Labor ratio* and *GDP per capita* variable. Otherwise than this, the results stayed in line with the original model. We, thus, conclude the robustness of decomposition analysis inferences.

Chapter 7

CONCLUSIONS AND POLICY IMPLICATIONS

7.1 Conclusions

In this research, we managed to test several hypotheses related to energy consumption and efficiency in Ukraine using different techniques.

First, our industrial cost decomposition analysis did not support a hypothesis of increased fuel price contribution to changes in industrial energy costs relative to other factors. The last decade shows that price led to energy costs rise only in mining, commerce, and public services sectors, with the opposite effect for construction, agriculture, and transport. In contrast to our original hypothesis, for energy-intensive sectors (mining, transport, manufacturing) changes in energy costs are mostly attributable to the energy intensity effect rather than directly to the fuel-price effects. At the same time, the real output effect plays a significant role. Moreover, energy costs contribution to the total production costs change relative to the other costs was found to be minor for all selected sectors. Thus, we cannot conclude any potentially significant spillover effects on consumer prices.

Second, we found evidence of the asymmetric energy sector's demand response to fuel price changes. The coal sector shows the only elastic own-price response with the lowest elasticity attributable to the oil sector. Elasticities for electricity and gas sectors range from -0.4 to -0.2 depending on the model specification. On a sector-specific level, variables related to energy efficiency (capital investments, modernization proxy) were statistically significant positive factors for lowering energy consumption, besides price. At the same time, producers' subsidies in the electricity sector are associated with a rise in industrial energy consumption. Moreover, we supported the idea of the importance of institutional factors in determining total energy demand. Governance and corruption indices improvement are, therefore, associated with lower energy consumption.

Finally, energy-intensity decomposition analysis refuted the hypothesis that structural shifts in the economy mostly determine energy intensity changes in Ukraine. The decomposition illustrates that most of the intensity reduction during the last twenty-five years occurred because of energy-efficiency improvements rather than the shifts from more energy-intensive activities to less intensive. Energy intensity has decreased for all energy sectors except for electricity for which it has been steadily rising for the last decade. Splitting energy intensity into efficiency and activity indices allowed us to determine which factors and through which channels influence the intensity most. Key roles are, therefore, attributable to the price, real per capita income, and capital investments. Price reforms, higher capital investments, and overall income rise reduce energy intensity in the country. This is achieved mostly through efficiency improvements, whereas the structural index is less responsive or shows ambiguous effects.

7.2 Policy implications

The empirical results of this study provide important policy implications for the further Ukrainian energy sector reforms.

First, the strategy for the higher energy-sector productivity should target energy efficiency improvements rather than rely on the structural changes in the economy. Market pricing for all participants, both industrial and residential, and energy-efficiency modernization programs should be prioritized in any sectoral policy. The effective continuation of the price-reform will, to a great extent, affect the ability of the country to save energy in the next decade at least. In this respect, the extent of the subsidy's mechanism should be considered with caution given the proven significant negative impact on energy demand.

Efficiency-enhancing efforts should be concentrated on the economic sectors with high energy usage and value-added growth which are expected to be more susceptible to energy costs management improvements. Considering this, it is important to account for different economic sectors' responses to fuel-price changes while allowing for the necessary adjustment period. On the other hand, Regulatory Asset Based Tariffs (RAB) for energy providers could raise incentives for capital investments and modernization of existing infrastructure on the supply side.

Given the significance of institutional factors for energy demand management, for any specific sector reform to be effective, it must be accompanied by the respective management-related ones. These include control of corruption, regulatory quality, and the rule of law (e.g. Antimonopoly laws) to name a few. Moreover, the lack of consistent energy data collection, which is now an obstacle for evidence-based, research-oriented policy implementation, should not be underestimated. Specific attention should be attributable to the electricity sector – the only one for which energy intensity has been increasing recently. Energy losses in electricity are twice the gas sector level while depreciation somewhere reaching 60-70% (NEURC 2019). This directly influences sector efficiency and energy intensity. Moreover, electricity is a primary substitute for other energy sources due to lower price. Other possibilities for lowering sector energy intensity arise from the alternative 'green' electricity generation, the share of which in Ukraine is only 5-8% (MECI 2020). Yet while its development would potentially generate significant benefits for the whole energy sector, it could not function without the abovementioned fundamental energy reforms completion, including market pricing, governance, and infrastructure modernization policies.

Possible extensions of the thesis include partial adjustment analysis (or alternative) that would distinguish between the short- and long-term effects of key drivers on energy demand and efficiency. Improved data collection will also allow higher disaggregation by economic sectors and account for alternative energy sources.

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APPENDIX A

ELECTRICITY MARKET STRUCTURE BEFORE AND AFTER THE REFORM

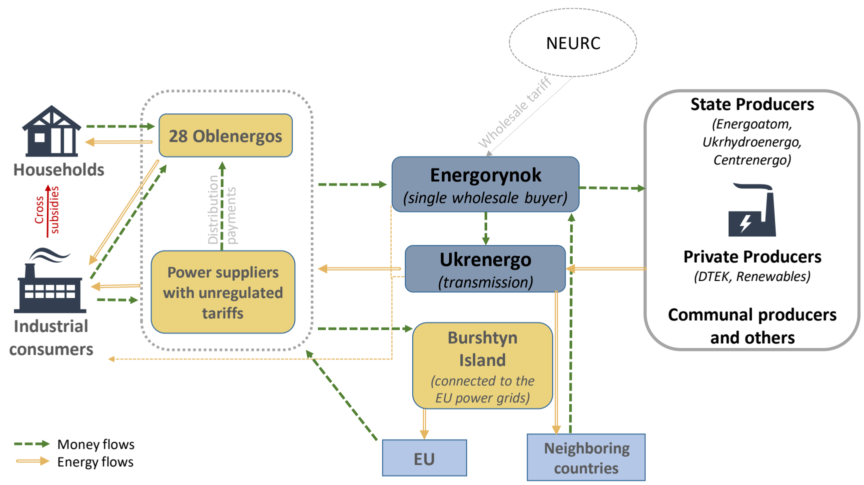

Figure A.1 Electricity market scheme before the reform.

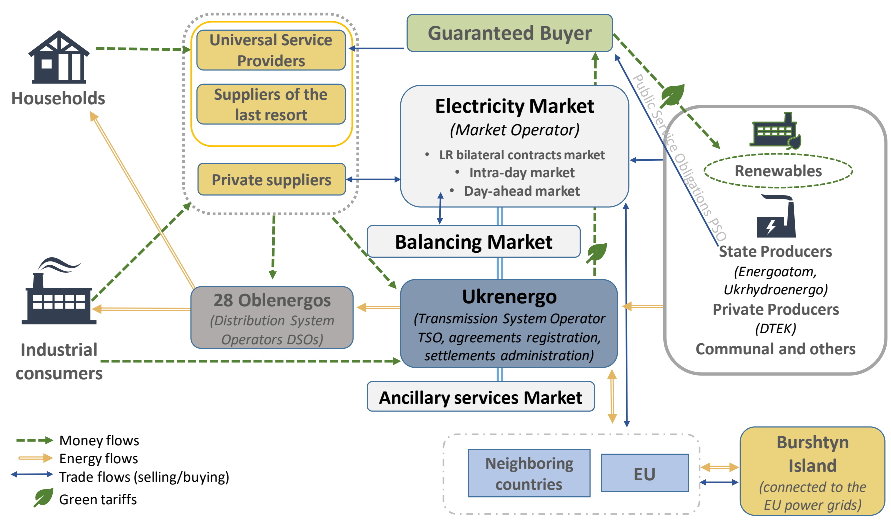

Figure A.2 Electricity market scheme after the reform.

Source: author's design using OECD 2019, NEURC reports, Energyreform 2020.

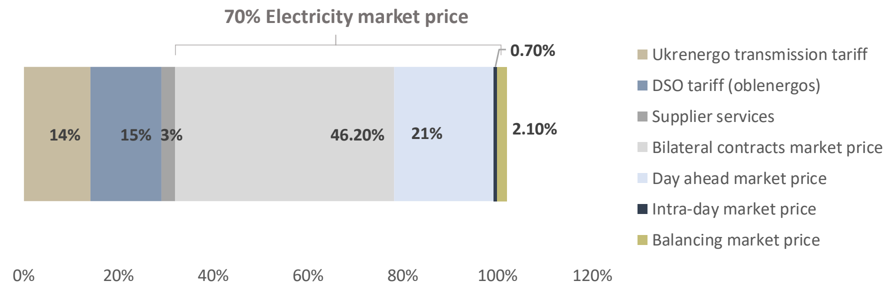

Figure A.3 Electricity price formation after the reform.

Source: Ukrenergo, NEURC 2019.

GAS MARKET STRUCTURE AFTER THE REFORM

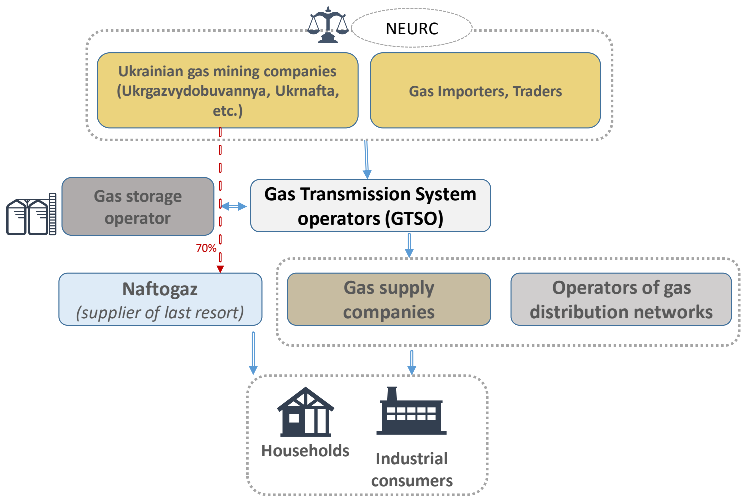

Figure A.4 Gas market model after the reform.

Source: author's design using CUTIS, Naftogaz.

Note: Before the reform, Naftogaz was the main connecting point between the Ukrainian gas mining companies/importers and gas supply/distribution companies (not unbundled at the time). Ukrtransgas, Naftogaz subsidiary, was performing transmission functions.

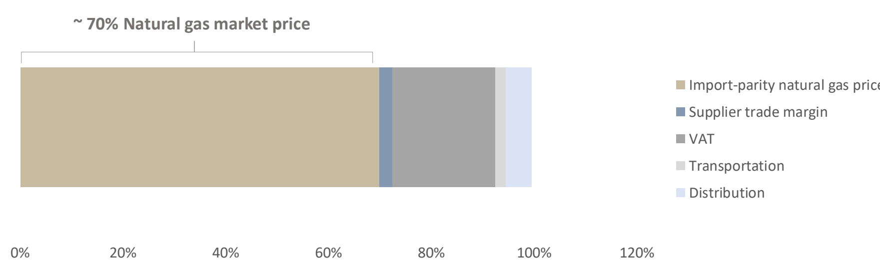

Figure A.5 Natural gas final industrial price formation.

Source: based on the data from several Oblgaz suppliers.

Note: shares of the components are not constant during the year and are presented for the representation of the tariff structure only.

APPENDIX B

DETAILED DESCRIPTION OF THE VARIABLES

Table B.1 Variables description

Variable	Explanation	Measurement	Source
TPES	Total Primary Energy Supply	*ktoe*	*Ukrstat, Enerdata*
Consumption	Total final consumption by energy source	*ktoe**	*Ukrstat*
priceMix1	weighted price for residential and industrial consumption based on consumption shares, where industrial electricity price is weighted 50/50 between class I and class II electricity consumption	*based on energy_source: see prices*	
priceMix2	weighted price for residential and industrial consumption based on consumption shares, where industrial electricity price is weighted 20/80 between class I and class II electricity consumption	*based on energy_source: see prices*	
Energy loss	Energy losses in transmission or transformation of energy sources (by sector of economy or aggregated).	*ktoe*	*Ukrstat*
	Prices		
Gas industrial	real average industry tariff for industrial users without VAT	*UAH/1000 m3*	*NEURC, Naftogaz, Tmgaz, Verkhovna Rada, Slovo i Dilo, Ukrstat, Ukrenergo, Energosberezhenie Index Minfin; other open data sources.*
Gas residential	real final price for residential users, January yearly	*UAH/1000 m3*	
Coal	real final price for all consumers	*UAH/tonn*	
Electricity industrial	real industry tariff for industrial users without VAT weighted 20/80 or 50/50 (robustness check) between voltage classes	*UAH/1000 kWh*	
Electricity residential	real final price for residential users, January yearly	*UAH/1000 kWh*	
Oil consumers	real price per oil barrel in Ukraine	*UAH per barrel*	
Oil residential	real price for oil for residents proxied as a real fuel price converted to barrels	*UAH fuel price A-95 per barrel*	
	Sector-specific		
Sector VA	Value Added in a sector	*mln const 2016 UAH (basic prices)*	*Ukrstat*
Sector output	in market prices (cosntant) (основні ціни)	*mln UAH in const 2016 UAH*	*Ukrstat*

Table B.1 − Continued

Variable	Explanation	Measurement	Source
	Energy-source-speccific		
Subsidies to energy producers	Subsidies (total and for residential controlled tariffs) to producers since 2001.	*mln UAH in const 2016 UAH*	*NEURC*
Electric power losses	Transmission and distribution of electric power as a share of total output; a proxy for modernization of transmission networks.	*Share of output*	*NEURC*
Privatization	1- for a year when large privatization of more than 25% for more than 3 objects happened in a sector and 0 otherwise.	*dummy*	*SPFU*
Naftogaz share	Share of Naftogaz companies in the energy-source production. Proxy for sector monopolism since 1998.	*share*	*Razumkov, Verkhovana Rada*
	MACRO		
Population growth	chain-type y/y growth rate of the total Ukrainian population growth	*rate*	*based on Ukrstat data*
Per capita GDP, GDP	Per capita GDP, GDP.	*mln const 2016 UAH (basic prices**)*	*Ukrstat*
KI/L	The ratio of aggregate investments in fixed capital for given industries (or aggregated for the economy) to the aggregate labor costs at a base case scenario.	*ratio*	*Ukrstat, IO tables*
Share of High Technological export	High technology export*** as a percentage of all manufactured export in a given year; a proxy for technological change.	*share*	*World Development Indicators*
Corruption Perception index	An index combining various international surveys and institutional assessments of corruption; ranges from 0 to 100 and converted into a 0-10 scale, where 10 means – 'very clean' and 0 – 'highly corrupt'.	*index*	*Transparency International*
Energy depletion of GNI	The ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years) as a percentage of GNI.	*index*	*World Bank*
Governance Index	Composite governance index which aggregates indices of Control of Corruption, Regulatory Quality, Rule of Law, and Government Effectiveness compiled by the World Bank; ranges from -2.5 to 2.5, where higher values indicate better outcome.	*index*	*World Development Indicators*
Events dummy	A dummy variable for the periods which might affect calculations results: exclusion of Crimea in aggregations for the data starting from 2010, the start of the war with Russia in 2014/15. 1- for where the event occurs and 0 otherwise.	*dummy*	

Table B.1 − Continued

Variable	Explanation	Measurement	Source
Final consumption expenditures	Households' final consumption expenditures for the residential sector index construction.	*mln const 2016 UAH*	*Ukrstat*
Industry share	Share of industry in GDP excluding construction (mining and processing industries only); proxy of structural change in the economy.	*share*	*Ukrstat, own calculations.*
Input-Output tables data			
Energy costs	Sum of electricity and gas costs with a minor share of water supply, costs for oil and coke products (made from coal) by sectors of the economy; deflated by sector-specific deflators.	*mln const 2016 UAH*	*Ukrstat IO tables.*
Gross output	Gross output by sector deflated by sector-specific deflators.	*mln const 2016 UAH*	*Ukrstat IO tables.*
Total costs	Calculated as a difference between output in basic prices and gross profit, deflated by sector-specific deflators.	*mln const 2016 UAH*	*Ukrstat IO tables.*
Total purchase of G&S	Total purchases of goods and services by the sector (intermediate consumption), deflated by sector-specific deflators.	*mln const 2016 UAH*	*Ukrstat IO tables.*
Labor costs	Labor costs by sector deflated by sector-specific deflators.	*mln const 2016 UAH*	*Ukrstat IO tables.*

Notes: *1 gigawatt-hour is equal to 85.984522785899 tons of oil equivalent for electricity consumption conversion into ktoe; **prices for a unit of good produced without any tax payable, plus any subsidy receivable, excluding separate transport charges; ***products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery, weighted average.

APPENDIX C

COSTS DECOMPOSITION ANALYSIS FOR SELECTED SECTORS

C.1 ENERGY COSTS DECOMPOSITION

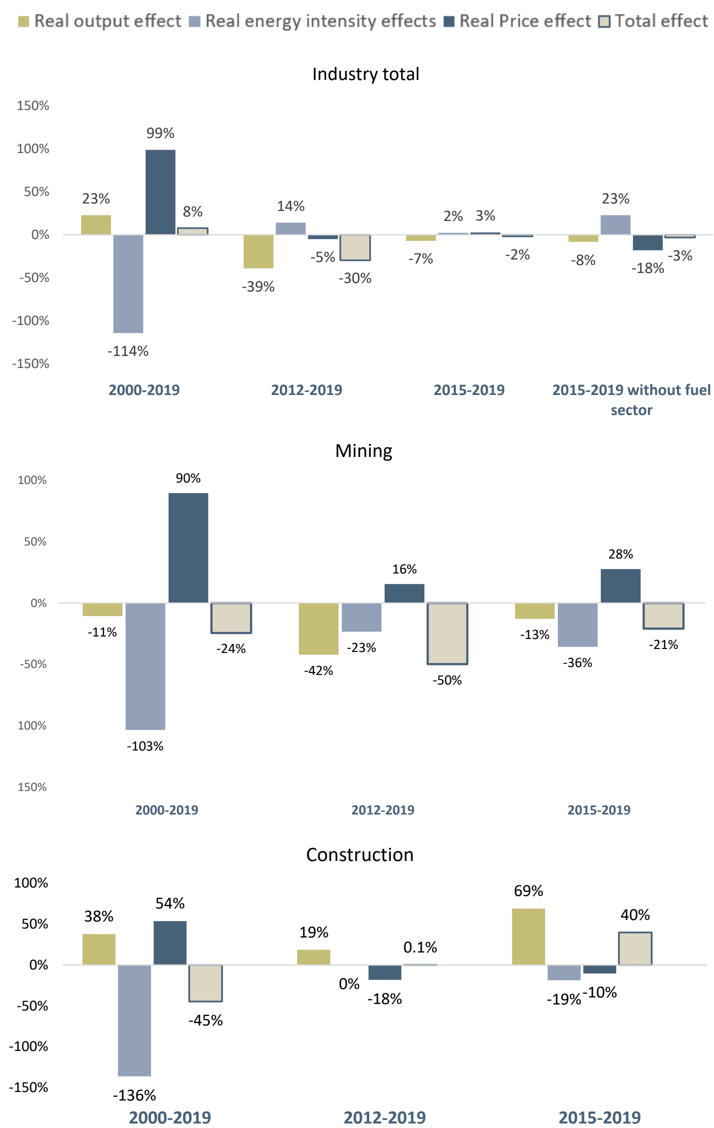

Figure C.1 Energy costs decomposition by economic sector.

C.1 ENERGY COSTS DECOMPOSITION - Continued

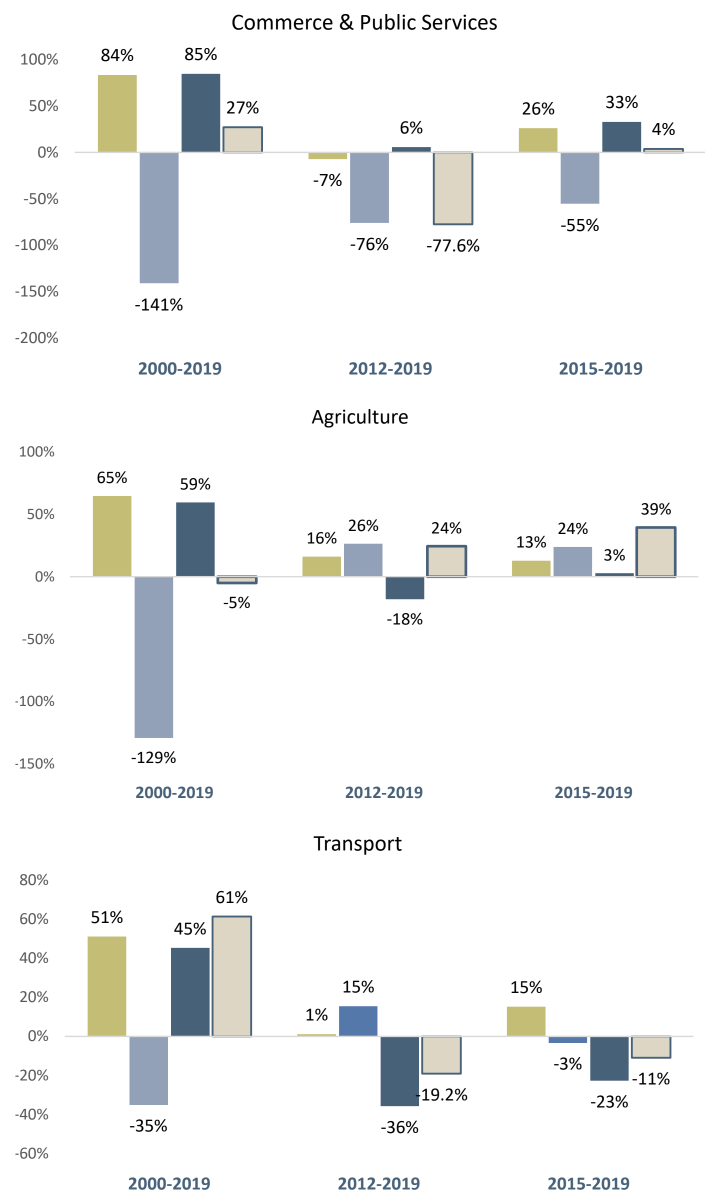

Figure C.1 - Continued Energy costs decomposition by economic sector.

C.2 TOTAL PRODUCTION COSTS DECOMPOSITION

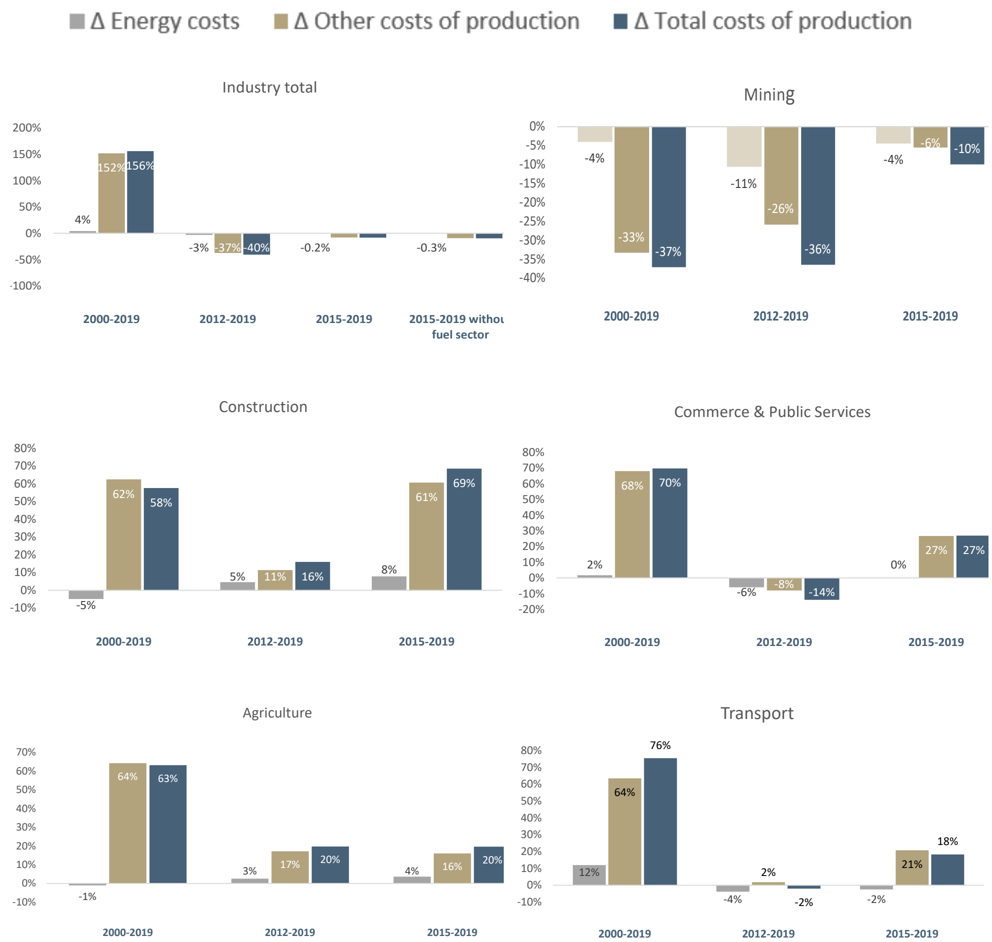

Figure C.2 Total production costs decomposition by economic sector.

APPENDIX D

INDEX DECOMPOSITION REGRESSIONs

Table D.1 Energy Intensity regression results

Variable/Model	OLS	FE	RE
Intercept	3.949**		4.775**
	(1.528)		(2.684)
Log (priceMix1)	-0.212***	-0.137***	-0.143***
	(0.049)	(0.037)	(0.044)
Population growth rate	-0.611	-0.147	-0.147
	(3.964)	(0.884)	(0.292)
Log (Real per capita income)	0.024	-0.158	-0.158
	(0.184)	(0.282)	(0.283)
KI/L	-6.848***	-7.034***	-7.018***
	(2.471)	(1.113)	(1.107)
$(KI/L)^2$	7.155**	7.653***	7.610***
	(2.999)	(0.771)	(0.738)
Events dummy	-0.054	-0.055***	-0.055***
	(0.073)	(0.016)	(0.015)
FE vs RE Hausman test	chisq = 0.246, p-value = 0.9997		
Time effect	Yes	Yes	Yes
Energy sector effect	Yes	Yes	Yes
Observations	96	96	96
R squared	0.59	0.59	0.59

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Standard errors in parentheses are White robust SE.

Table D.2 Test related to energy intensity decomposition regressions.

Test	H_0	Result
Breusch-Godfrey/Wooldridge serial correlation test	No serial correlation.	p-value <6.878e-05
B-P/LM and Pasaran CD tests of cross-sectional independence	Residuals are not correlated across entities.	CD: p-value = 0.373 LM: p-value = 0.0008
Breusch-Pagan Lagrange Multiplier for random effects	No panel effect (i.e. OLS better).	p-value < 2.2e-16
The Dickey-Fuller test to check for stochastic trends.	Series has a unit root.	p-value = 0.023

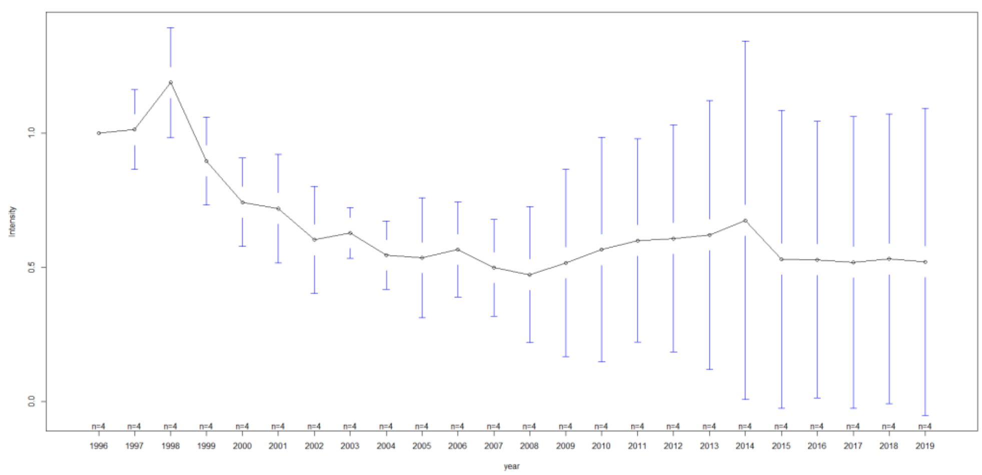

Figure D.1 Mean energy intensity across time.

APPENDIX E

ROBUSTNESS CHECKS

Table E.1 Total energy demand. Alternative specifications.

Variable	Log Energy consumption	
Log (Real price)	-0.386***	-0.246*
	(0.127)	(0.139)
Lag (Log Real Price)	-0.009	
	(0.146)	
Events dummy	-0.046	-0.068*
	(0.028)	(0.035)
Log (Sector VA)	0.385***	0.385**
	(0.129)	(0.141)
Energy Depletion of GNI	0.216**	
	(0.088)	
High technological export	-0.055**	-0.029
	(0.026)	(0.021)
Governance	-0.261***	
	(0.089)	
Corruption Perception i-x		-0.406***
		(0.137)
Industry share		4.77*
		(2.54)
Time fixed effect	Yes	Yes
Industry fixed effect	Yes	Yes
Observations	413	413
R squared	0.27	0.26

* p < 0.10, ** p < 0.05, *** p < 0.01

Note: Standard errors in parentheses are Arellano robust SE.

Table E.2 Energy demand by energy sectors. Alternative specifications.

Variable	Log Energy consumption				
	Electricity	*Gas*	*Gas*	*Oil*	*Coal*
Log (Real price)	0.127	-0.062	-0.140	-0.14	-1.081*
	(0.152)	(0.091)	(0.098)	(0.110)	(0.576)
Calc dummy	-0.063***	0.071	-0.0004	-0.0003	-0.14***
	(0.022)	(0.089)	(0.074)	(0.066)	(0.035)
Log (Sector VA)		0.219**		0.257*	
		(0.103)		(0.136)	
Energy loss	0.07	0.330**			
	(0.169)	(0.149)			
High tech. export			-0.013	-0.012	
			(0.025)	(0.027)	
Log (Subsidies to producers)	0.151*				
	(0.077)				
KI/L ratio	-0.059*	-0.227***	-0.18**		-0.167
	(0.068)	(0.041)	(0.072)		(0.227)
Industry share	5.065***	6.178***			2.44
	(1.91)	(2.286)			(4.69)
Naftogaz share			4.47***	4.72***	
			(1.576)	(1.53)	
Time fixed effect					
Industry fix. eff.					
Observations	120	104	104	102	87
R squared	0.32	0.46	0.52	0.23	0.29

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Standard errors in parentheses are Arellano robust SE.

Table E.3 Fixed effect regression results by indexes with Arellano serial correlation and heteroskedasticity robust standard errors.

Variable	Activity	Efficiency	Intensity
Log (priceMix1)	0.089*	-0.143***	-0.137***
	(0.047)	(0.046)	(0.037)
Population growth rate	-0.213	0.475	-0.147
	(0.881)	(0.869)	(0.883)
Log (Real per capita income)	0.507***	-0.481**	-0.158
	(0.077)	(0.202)	(0.282)
KI/L	-6.203***	-2.581***	-7.034***
	(0.633)	(0.777)	(1.114)
$(KI/L)^2$	6.315***	2.958***	7.653***
	(0.845)	(0.547)	(0.771)
Events dummy	-0.044*	-0.023***	-0.055***
	(0.025)	(0.008)	(0.016)
Time effect	Yes	Yes	Yes
Energy sector effect	Yes	Yes	Yes
Observations	96	96	96
R squared	0.61	0.76	0.59

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table E.4 Fixed effect regression results by indexes with HAC serial correlation and heteroskedasticity robust standard errors.

Variable	Activity	Efficiency	Intensity
Log (priceMix1)	0.089***	-0.143***	-0.137***
	(0.029)	(0.043)	(0.051)
Population growth rate	-0.213	0.475	-0.147
	(0.931)	(0.991)	(0.947)
Log (Real per capita income)	0.507***	-0.481***	-0.158
	(0.073)	(0.143)	(0.189)
KI/L	-6.203***	-2.581*	-7.034***
	(1.373)	(1.501)	(1.964)
$(KI/L)^2$	6.315***	2.958*	7.653***
	(1.691)	(1.763)	(2.276)
Events dummy	-0.044	-0.022	-0.055*
	(0.035)	(0.019)	(0.031)
Time effect	Yes	Yes	Yes
Energy sector effect	Yes	Yes	Yes
Observations	96	96	96
R squared	0.61	0.76	0.59

* p < 0.10, ** p < 0.05, *** p < 0.01