

POLAND ENERGY TRANSITION

The Path
to Sustainability
in the Electricity
and Heating Sector

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Foreword

Over the past decade, Poland has achieved significant progress towards sustainability - by considerably reducing energy intensity and decoupling energy growth from economic growth. Despite this, Poland is facing serious local environmental challenges, having today 36 out of the 50 most polluted cities in Europe.

The Polish government has put fighting smog as one of its highest priorities. The Prime Minister has declared a war against smog, and recently launched a Clean Air Priority Program that our World Bank team has had the privilege to help design.

In that context, this report, produced in close collaboration with the Polish Ministry of Environment, aims to provide the government with options to scale up and accelerate the energy transition to cleaner electricity and district heating generation mixes. It hopes to provide ways for the government to both address serious local air pollution and commitments to combat global climate change.

The report draws three main conclusions from the analyses and consultations carried out during the last six months:

- Despite impressive progress towards sustainability, Poland's coal-dominated energy sector imposes heavy health costs on its population. A recent World Bank report estimated that the cost of ambient air pollution in the country amounts to about US\$31-40 billion, equivalent to 6.4-8.3 percent of GDP in 2016. Moreover, deterioration of ambient air quality is responsible for a significant health burden - with an estimated 44,500 premature deaths per year.
- The ambitious strategy to scale up renewable energy sources in the power and district heating generation mix is economically justified, if local and global environmental benefits are accounted for. Poland is moving in the right direction on energy transition with its envisioned targets on renewable energy, but achieving the more ambitious targets under the European Union Emission Trading Scheme requires intensified efforts to scale up and accelerate the penetration of clean energy.
- Active labor market policies can help mitigate employment impacts, which are expected to be negligible at national level and modest at local level given a dynamic economy and tight labor markets in the coal-producing Silesian region. However, a "just transition" should leave no one behind - by providing social safety nets and support to coal miners and all affected population during the transition to sustainable and equitable growth.

Given the upcoming COP 24 meeting in Poland, this report could not be more timely. The recent IPCC report called for urgent and intensified efforts to mitigate the risks of climate change. We hope that this report will provide insights on the pathways and policy options for Poland's energy transition towards sustainability. The World Bank Group looks forward to working with the Government of Poland in their quest for a low-carbon development path.

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Acronyms and Abbreviations

ALMP	Active labor market programs	LNG	Liquefied natural gas
CAPEX	Capital expenditures	MJ	Megajoule
CER	Certified emission reductions	NDC	Nationally Determined Contributions
CGE	Computable General Equilibrium	NPV	Net present value
CNY	Renminbi	NO _x	Nitrogen oxide
CO ₂	Carbon dioxide	OPT+L	Optimized with Incorporation of Local Environmental Costs
CSO	Civil society organizations	OPT+LG	Optimized with the Incorporation of Local and Global Environmental Cost
DH	District heating	PLN	Polish zloty new
EC	European Commission	PM	Particulate matter
EE	Energy efficiency	PPP	Purchasing Power Parity
EEA	European Environment Agency	PV	Photovoltaics
EPM	Electricity Planning Model	RE	Renewable energy
ETI	Energy transition indices	RISE	Regulatory Indicators for Sustainable Energy
EU	European Union	SDG	Sustainable Development Goals
ETS	Emission Trading Scheme	SFB	Single-family buildings
GDP	Gross Domestic Product	SO ₂	Sulfur dioxide
GIOŚ	Chief Inspectorate for Environmental Protection	TOE	Tons of oil equivalent
GW	gigawatt	TSO	Transmission System Operator
GWh	gigawatt-hour	TFEC	Total final energy consumption
HOB	Heating-only boilers	TPES	Total primary energy consumption
IEA	International Energy Agency	USD	US dollar
IPCC	Intergovernmental Panel on Climate Change	WEF	World Economic Forum
JRC	Joint Research Centre	WHO	World Health Organization
kW	kilowatt		
kWh	kilowatt-hour		
LC:	Least Cost No Environmental Constraints		

Abstract

This report explores options to scale up and accelerate the energy transition to cleaner electricity and district heating generation mixes and reconcile the government's concerns over the serious local air pollution and commitments to combat climate change.

The report draws three main conclusions from the analyses and consultations carried out during the last six months:

- Despite impressive progress towards sustainability, Poland's coal-dominated energy sector imposes heavy health costs on its population. A recent World Bank report estimated that the cost of ambient air pollution amounts to about US\$31-40 billion, equivalent to 6.4-8.3 percent of GDP in 2016. Moreover, deterioration of ambient air quality is responsible for a significant health burden with an estimated 44,500 premature deaths per year.
- The ambitious cleaner strategy to scale up renewable energy sources in the power and district heating generation mix is economically justified, if local and global environmental benefits are accounted for. Poland is moving in the right direction on energy transition with its envisioned targets on renewable energy, but achieving the more ambitious targets under the European Union Emission Trading Scheme requires intensified efforts to scale up and accelerate the penetration of clean energy.
- Active labor market policies can help mitigate employment impacts, which are expected to be negligible at national level and modest at local level given a dynamic economy and tight labor markets in the coal-producing Silesian region. However, a "just transition" should leave no one behind and provide social safety nets and support to coal miners and all affected population during the transition to sustainable and equitable growth.

EXECUTIVE SUMMARY

Poland has made impressive achievements in decoupling energy growth from economic growth but must now deal with serious local and global environmental threats due to its heavy reliance on coal.

While its GDP increasing by 7-fold since the early 1990s Poland has made impressive achievements in reining in its energy and electricity consumptions. These impressive results are in many ways unique considering that the country was also undertaking comprehensive economic and political reforms to transition from a command and control to a market economy and establish a democratic regime.

Between 1987, when its energy demand peaked, and 2016, Poland reduced its energy intensity by 30 percent—more than any other country reviewed in IEA’s Energy Efficiency Report 2017. Without the energy efficiency gains, Poland’s total primary energy supply would have reached 272 million tons of oil equivalent (TOE) today, almost triple the current level. About 600 million tons CO₂ emissions were thus avoided.

Between 2000 and 2016, the shares of renewable energy (RE), mainly biomass and wind, and natural gas in the electricity generation mix more than quintupled, reducing the coal share by 12 percentage points.

However, Poland’s energy sector faces serious environmental problems, because of the heavy reliance on coal in the energy and elec-

tricity sectors. If not addressed urgently, they could jeopardize the country’s progress toward sustainability. The deterioration of ambient air quality has already had dire impacts on Polish health and quality of life. Of the 50 most polluted cities in Europe, 36 are in Poland. A recent World Bank report (World Bank, 2018a) estimated that the cost of ambient air pollution amounts to about US\$31–40 billion, equivalent to 6.4–8.3 percent of GDP in 2016. This compares well with the annual cost of air pollution around €26–30 billion recently estimated by the European Commission (EC) and the Poland Ministry of Entrepreneurship. Moreover, deterioration of ambient air quality is responsible for a significant health burden with an estimated 44,500 premature deaths per year. Furthermore, Poland is among the 20 highest emitters of carbon dioxide in the world. The Ministry of Environment has estimated that, without adaptation measures, between 2021 and 2030 costs due to extreme weather and climate change will reach 120 billion PLN, or €30 billion.

Both the recent World Bank’s Regulatory Indicators for Sustainable Energy report and the World Economic Forum study (WEF and McKinsey 2018), prepared with analytical support from McKinsey & Company, found that Poland trails most EU-28 countries in readiness for energy transition as well as the policies and regulations for both energy efficiency and renewable energy. Introduction Section C presents the detailed findings of these two studies.

This study focuses on the transition of the power and district heating sectors towards a sustainable and inclusive development path by 2030

This study focuses on Poland's power and district heating sectors up to 2030 in order to identify optimum least-cost paths to meet emission reduction targets. Decarbonizing electricity is a necessary first step towards deeper decarbonization in other sectors, for example through the electrification of the transport sector. Achieving long-term local and global environmental targets requires more in-depth analyses that cover all the economic sectors. However, an economy-wide study to 2050 on Poland's pathways to contribute to the EU's target of carbon neutrality, including the industrial, transport and agriculture sectors, requires broader and deeper analyses, cooperation with all concerned government departments, and more time and resources than the present study.

The study analyses are carried out using two analytical models: (a) the World Bank Electricity Planning Model (EPM), a partial-equilibrium optimization model for electricity and district heating production and scenario analyses; and (b) an econometric and a computable general equilibrium (CGE) model to assess the impacts of reduced coal production and coal mine employment on local communities and the national economy.

The EPM model is used to carry out an integrated optimization of Poland's power and heating subsectors during 2018-2030. It has been adapted to the characteristics of the two subsectors and covers more than 250 power plants, cogeneration, and heating-only boilers (HOB). One of the innovative characteristics of the model is to link the impacts of the optimum generation mixes on coal production and coal mine employment. The latter results are then used first in an econometric model to evaluate spillover effects on communities near coal mines based on detailed data on employment rates, migration, firm level indi-

cators at the municipal and postal code level; and then in a CGE model that matches the main features of the Polish economy to assess national impacts.

Finally, the analyses were carried out in two stages:

- In the first stage, four optimized pathways were explored: (a) Without incorporating local or global environmental costs (OPT-No ENV); (b) Incorporating only local environmental cost (OPT-L, the external costs of local air pollutants are listed in Annex 2); (c) Incorporating local environmental and global environmental costs based on a carbon shadow price of US\$ 30/ton of CO₂ during the study period (OPT-LG); and (d) Incorporating local environmental and global environmental costs based on a carbon shadow price increasing from US\$ 37/ton of CO₂ in 2018 to US\$ 50/ton of CO₂ by 2030 following the World Bank Carbon Price Guideline (OPT-LG+). These optimized pathways are used as benchmarks to evaluate three alternatives of energy transition in the electricity and district heating sectors.
- In the second stage, three options were explored: (a) The first reflects the envisioned policies now being discussed: power and district heating consumption of hard coal remains the same up to 2030, and RE penetration in the power generation mix would rise to 32 percent by 2030 (Envisioned Targets); (b) The second aims to meet the EU ETS target of reducing CO₂ emissions by 43 percent from 2005 to 2030 in the power and co-generation sectors, which translates in limiting the power and district heating CO₂ emissions to 98 million tons by 2030 (EU ETS). The EU ETS targets correspond to the EU Nationally Determined Contributions (NDC) targets committed to the Paris Climate Agreement. These targets are EU-wide, not specific to Poland. In this study the EU targets are used as a proxy for Poland, an EU member state;

and (c) The third explores the implications of Extended Efforts beyond the EU ETS targets, leading to a limit of the power and heating CO₂ emissions to 85 million tons by 2030 in response to the recent IPCC call for urgent and extended efforts in order to cut risks related to extreme heat, drought, and floods, and to poverty (Extended Efforts).

The envisioned RE targets are a significant step in the right direction, but achieving the EU ETS targets will require intensified efforts to accelerate penetration of clean energy.

The technical and economic results of the analyses are provided in the Table below.

Considered Options	Net Present Value (NPV) of Costs (US\$M)			Emissions			
	Economic Costs	Global Environment Costs	Local Environment Costs	CO ₂ (mt)	PM (kt)	NO _x (kt)	SO ₂ (kt)
OPT-No ENV	113,953	42,803	46,803	149	30.6	165.6	290.5
OPT-L	119,815	37,288	37,364	139	25.2	165.2	255.2
OPT-LG	124,716	30,344	34,583	117	24.5	160.7	243.1
OPT-LG+	129,486	40,220	32,446	88	21.6	130.8	200.1
Envisioned Targets	118,097	40,597	45,495	134	30.1	154.5	280.0
EU ETS	123,510	37,146	42,406	98	26.8	126.5	232.8
Extended Efforts	126,704	35,725	41,314	85	25.6	114.7	215.9

Considered Options	Generation Mixes (%)					
	Electricity			Electricity and Heat		
	Coal	Gas	RE	Coal	Gas	RE
OPT-NoENV	72.7	7.9	19.0	75.5	6.1	18.1
OPT-L	72.7	7.9	19.0	70.1	11.5	18.1
OPT-LG	66.0	14.7	19.0	64.9	16.7	18.1
OPT-LG+	49.0	18.6	32.0	51.8	19.8	28.1
Envisioned Targets	60.6	7.0	32.0	66.2	5.4	28.1
EU ETS	44.1	12.6	42.9	53.5	9.7	36.5
Extended Efforts	37.7	14.4	47.5	48.6	11.1	40.0

Note: The sums of percentages may not add up to 100 because of the rounding

The analysis found that if the external costs of local air pollutants alone are considered (OPT-L), not only can they be reduced by 2030 but so can CO₂ emissions from power and heating. Incorporating both local and global environmental costs (OPT-LG+) would achieve the optimal results—local air pollutant emissions could plunge, and power and heating CO₂ emissions could be cut to 88 million tons by 2030, meeting the EU ETS targets, a major reduction from 150 million tons of CO₂ under OPT-No ENV.

Incorporating local and global environmental costs (OPT-LG and OPT-LG+) could increase the net present value (NPV) of economic costs by 9–14 percent from 2018-2030, depending on carbon prices, compared to OPT-No ENV. In the meantime, the NPV of local and global environmental costs under the OPT-LG and OPT-LG+ are significantly lower than those under the OPT-No Env from 2018-2030. Therefore, the incremental costs of the OPT-LG and OPT-LG+ would be fully justified by the environmental benefits of reduced emissions. The carbon price matters: if the price is \$30/ton CO₂, power and heating CO₂ emissions could be reduced to 117 million tons by 2030, but at the World Bank Carbon Price Guideline of \$37/ton CO₂ in 2018 rising to \$50/ton CO₂ by 2030, the CO₂ emissions could be reduced to just 88 million tons by 2030.

The results indicate that the currently Envisioned Targets will diversify the electricity 2030 generation mix by reducing the coal share to 61 percent and increasing the renewable energy share to 32 percent. Gas would cover the remaining 7 percent. However, in this scenario local air pollutants and CO₂ emissions from the power and district heating sectors would still be high, reaching 134 million tons—far above the EU ETS targets of 98 million tons by 2030. Since the government plans to keep the hard coal consumption at the same level from now to 2030, the number of coal mine jobs would maintain the same at around 80,000 by 2030.

Achieving the EU ETS target in 2030 would require intensified efforts to increase

the penetration of clean energy sources in the power and heating sectors. To meet the targets of EU ETS, the power sector would decisively embark on a greener path with a reduction of the coal share in the generation mix by almost half from 80 percent today to 44 percent in 2030. Gas share would increase to 13 percent and renewables sources would increase to 43 percent, almost at parity with coal. This option would dramatically reduce local air pollutants and CO₂ emissions. The NPV of economic costs to achieve the EU ETS target would be 5 percent more than that in the Envisioned Targets option from 2018-2030, which would be offset by the reduced NPV of local and global environmental costs. The implicit carbon price of about \$37–50/ton CO₂ is much lower than the penalty of €100 or \$115/ton CO₂ resulting from non-compliance of EU ETS targets. The reduced coal production under the EU ETS option could cut direct coal mining jobs by 20 percent compared to the Envisioned Targets option.

The Extended Efforts option requires a major shift in current policies to scale up and accelerate renewables: the RE share in power generation would need to reach 47 percent by 2030, surpassing the coal share of 38 percent by 2030. This option would cut local air pollutants and CO₂ emissions the most. The net present value of the economic cost incurred in this option from 2018-2030 would be about 7 percent higher than that in the Envisioned Targets option, but fully justified by the environmental benefits of reduced emissions. The Extended Effort option could shrink direct coal mining jobs by 25 percent compared to the Envisioned Targets option.

Local communities would suffer from the modest spillover effects of reduced coal production and fewer jobs but the impacts on the national economy would be negligible. The spillover effects would be small and felt mostly in communities within about 10 kilometers from the coal deposits and in such upstream service industries as transport and storage, utilities, and machinery and equipment rentals. The direct impacts on jobs and out-migration are mostly suffered by men. There is little

to no effect on average wages and manufacturing jobs. As to the national economy, under any option, GDP growth and the national unemployment rate would fall by less than 0.1 percent.

Past waves of coal sector restructuring had negative but small impacts on employment, and for several reasons the effects of new declines will probably be even smaller: (a) Because of the demographic transition, younger cohorts will be significantly smaller by 2030, and increases in educational achievement mean they will be significantly more skilled. That means natural attrition may almost be enough to achieve the decline in coal employment. (b) Past declines in coal were part of the broad adjustment to a market-based economy that may have exacerbated the negative impacts. (c) Today clean energy is an alternative source of jobs. For example, improving the energy efficiency of residences in Poland could create as many as 100,000 jobs a year. (d) Silesia, the most coal-dependent region, is also highly industrialized, with high demand for labor. (e) Labor markets are much tighter today than in the 1990s; for several years, Poland's unemployment rate has been in single digits.

A path to sustainability is challenging but feasible, and in Poland's best interest.

The analysis shows that to achieve sustainability, local and global environmental costs need to be integrated in decision making processes. The energy policies need to be integrated with the environmental, urban, transport, and industrial policies, with close attention to social impacts. Poland can avoid a “pollute now, clean up later” path followed by most developed countries, and adopt sound policies and cleaner technologies for the transition to sustainability. The policies need to be better attuned to the new global realities of energy transition and the country's global commitments.

The four key pillars can guide energy transition to sustainability in the power and heat-

ing sectors: *First*, the country can continue to rein in future energy consumption, particularly for the residential and transport sectors. While Poland has delinked energy growth from economic growth, there is still considerable potential for energy efficiency gains. Since coal for heating in single-family buildings (SFBs) contributes the most to local air pollution in Poland, the most cost-effective way to reduce both particulates and CO₂ emissions is to switch from noncompliant solid fuel boilers to efficient boilers, natural gas, heat pumps, and RE heating systems, together with thermal retrofits of the SFBs. For transport, the government has adopted ambitious e-mobility target of one million electric vehicles by 2025, but in the short and medium term, more aggressive fuel standard regulation would limit the growth of air pollution and maintain the energy intensity of the sector in check.

Second, intensified efforts are required to shift to a greener energy mix. With a dramatic cost reduction in recent years, renewable energy is now a low-cost and secure resource at centralized and decentralized levels. Wind power and solar photovoltaics (PV) have the most potential for rapid and effective development. Poland should consider learning from more advanced countries and move directly for “net billing” policy for off-take of decentralized RE generation. The policy can go a step further with the power sector reforms and the development of an ancillary service market to encourage storage. A significant increase in the share of RE in the power generation mix will require strengthening of the transmission network to take advantage of future connection with the European system in the early years to reduce disruption from intermittent RE electricity. In the longer term, a reinforced system would allow taking advantage of Poland's strategic position to become a hub of power exchanges between western and eastern European countries.

The government has an ambitious plan to move into off-shore wind generation. Because the costs of off-shore wind are still significantly higher than those of on-shore, to bring down the costs, Poland can learn from Denmark's

experience of off-shore wind auctions. International experience has demonstrated that bringing off-shore wind generation on line takes time, and it is crucial to set up a central agency or one-stop-shop services for approval, licensing and permits, spatial planning, and certification, in coordination with such agencies as Environment, Maritime, Defense, and Transmission System Operator (TSO). Otherwise, fragmented and conflicting approvals from different agencies could bring off-shore wind development to a halt.

Finally, increasing natural gas penetration during the transition is important to reducing local air pollution from heating, particularly in the SFBs, and making the power system more flexible for intermittent RE.

Third, the energy supply needs to be safer and more secure. Greening the energy mix with locally sourced RE would contribute to that. Diversifying the supply of natural gas, which is an increasingly global commodity, will also make the energy mix more secure. This study demonstrated that the cost of energy transition is manageable and fully justified by the environmental benefits of reduced emissions.

Finally, it is important to provide safety nets for coal mine workers as they will be affected by the transition to lower reliance on coal. Coal mine closures affect workers at different stages of their careers. It will be important to assess the competences of those who will lose their jobs, and they should have enough notice to give them time to plan their transition. Post lay-off assistance to help support displaced workers should be designed so that it does not dilute incentives to look for jobs. Policies that support workers rather than regions are most promising. Fostering the creation of clean energy jobs sector can also support re-employment of displaced coal workers in, for example,

programs to make residential buildings more energy-efficient. Active labor market programs (ALMPs) are useful for fostering re-employment of former coal workers, as in situations where displaced workers have skills for which there is labor demand but they need help to access the demand. When the skills of displaced workers do not match employer needs, institutional or on-the-job training will be necessary. Where labor demand is low, small business support services could be offered.

In conclusion

Over time coal has contributed enormously to Poland's economic and social development, but local and global environmental trends mean that transition to cleaner energy is inevitable, and technological progress has made reliance on cleaner energy affordable and cost-effective. Globally, the energy sector is moving toward sustainability to meet the Paris agreement targets and reduce impacts of local air pollution on the quality of life and health of the population.

More than 60 percent of Poland's installed coal power generation capacity is over 30 years old (IEA, 2017a). The replacement of these plants presents the opportunity to reduce air pollution and the country's carbon footprint by shifting from coal to cleaner fuels for power generation. The decisions on the type of replacement of these generation capacities will strongly shape the future emission trends, because of the lock-in effect--any coal power plants built today would still be in operation after 30 to 40 years, or they could become stranded assets if climate change or local air pollution worsens. Poland's energy can be put on a sustainable path, and the window of opportunities for sustainability is closing.

Introduction

SETTING THE STAGE: IMPRESSIVE ACHIEVEMENTS BUT ENVIRONMENTAL CHALLENGES AHEAD

Key Messages

- Over the last three decades, while its GDP increasing by 7-fold, Poland has slashed its energy and electricity consumption. Between 1987, when demand peaked, and 2016 it reduced its energy intensity by 30 percent—more than any other country covered in the IEA *Energy Efficiency Report (2017a)*, even Hungary and Czech Republic that were undergoing comparable reforms.
 - Between 2000 and 2016, renewable energy, mainly biomass and wind, and natural gas increased their shares in the electricity generation mix more than five-fold, pushing down the coal share by 12 percentage points.
 - However, the heavy reliance of Poland's energy sector on coal is causing serious environmental problems. If not addressed urgently, they could jeopardize the country's progress toward sustainability. Of the 50 most polluted cities in Europe, 36 are in Poland. A recent World Bank report (2018a) estimated that the cost of ambient air pollution amounts to about US\$31-40 billion, equivalent to 6.4-8.3 percent of GDP in 2016. Moreover, deterioration of ambient air quality is responsible for a significant health burden with an estimated 44,500 premature deaths per year. The country is also among the world's 20 highest emitters of CO₂. The Ministry of Environment has estimated that between 2021 and 2030, unless adaptation measures are taken, extreme weather and climate change will cost Poland 120 billion PLN (€30 billion).
 - Both the recent World Bank's Regulatory Indicators for Sustainable Energy report, and the World Economic Forum study, prepared with analytical support from McKinsey & Company, found that Poland trails most EU-28 countries in readiness to energy transition as well as the policies and regulations for both energy efficiency and renewable energy.
-

Successful decoupling energy growth from economic growth

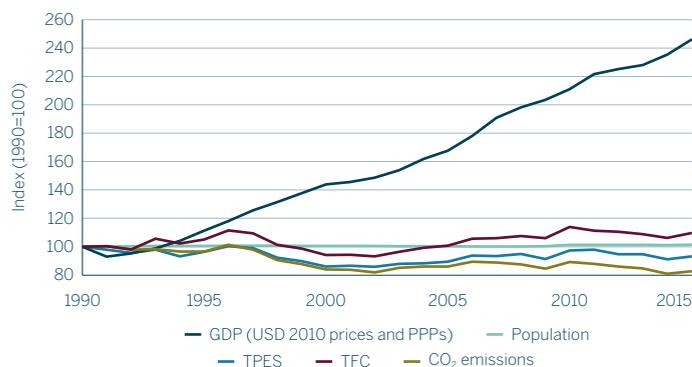
As Poland has made impressive achievements in delinking energy growth from economic growth during its transition from a command-and-control to a market economy in 1990–2016, the country managed to increase its gross domestic product (GDP) by 7-fold with only a slight increase in total final energy

consumption (TFEC) and with a slight decrease in total primary energy consumption (TPES; see Figure I.1). Without these energy efficiency improvements since 1990, Poland’s total primary energy supply would have reached 272 million tons of oil equivalent (TOE), almost triple the current level. The CO₂ emissions related to energy consumption that were avoided in the process amounted to about 600 million tons.

Poland’s improved use of its energy resources is illustrated by the facts that:

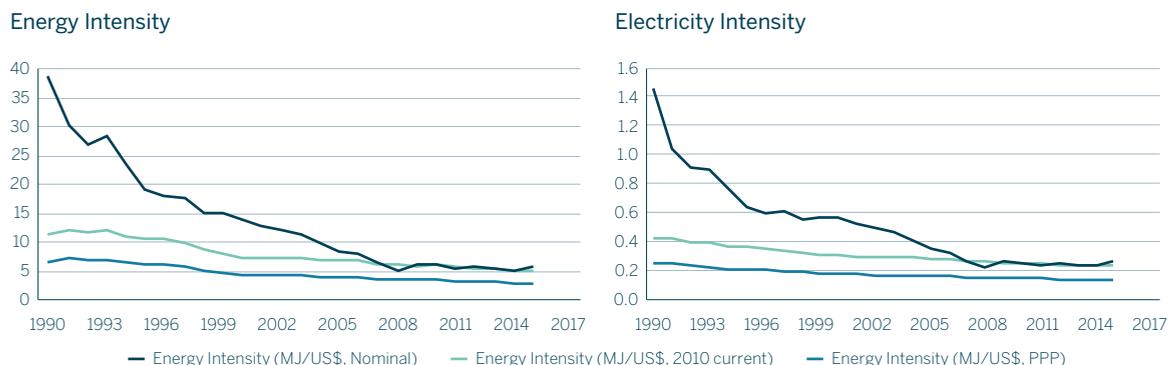
- *Energy intensity has declined:* Measured as the amount of primary energy needed to produce one unit of nominal GDP, it dropped from an average annual rate of 11 percent for 1990–2000 to an average of 6 percent for 2000–2015. Energy intensities, in megajoule (MJ)/US\$ current GDP and MJ/US\$ purchasing power parity (PPP), also declined significantly but at lower rates (Figure I.2).
- *Electricity intensity declined* at more than 9 percent for 1990–2000 and about 7 percent for 2000–2015. Poland has one of the largest district heating markets in Europe, covering about half the population.

Figure I.1 Delinking Economic Growth from Energy Consumption, 1990–2015



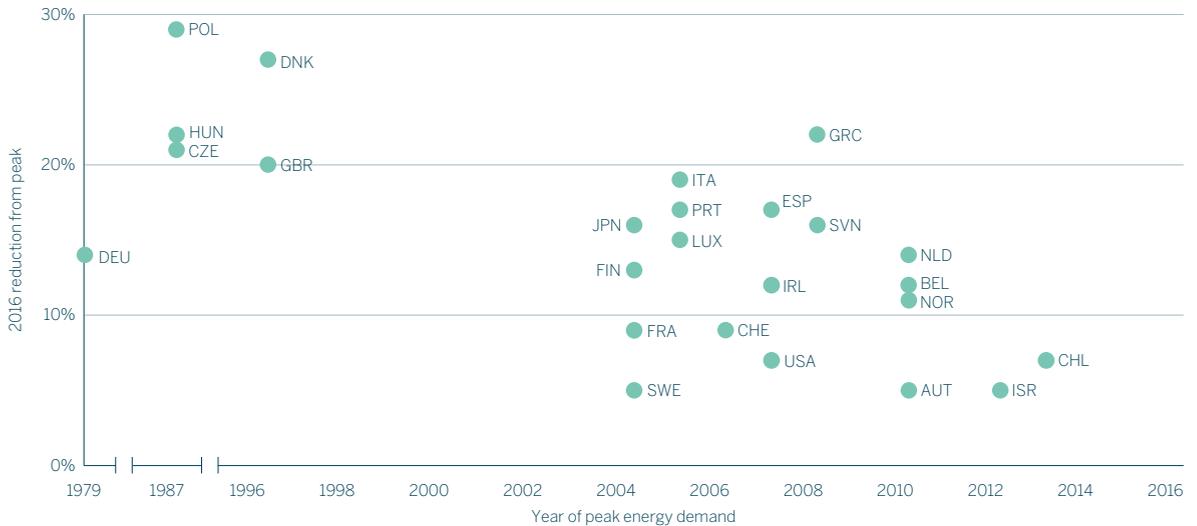
Source: IEA, 2017b

Figure I.2 Declining Energy and Electricity Intensities, 1990–2017



Source: Data from World Bank Statistics, World Bank, 2018b

Figure I.3 Poland has the Largest Energy Intensity Reduction from 1987 to 2016



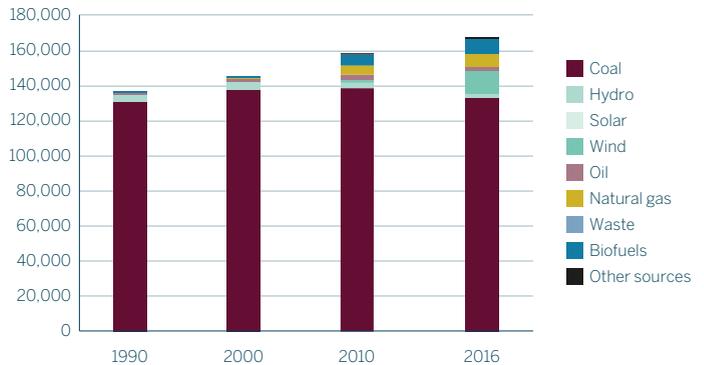
Source: IEA, 2017b

- Poland reduced energy intensity more than any other EU member, about 30 percent as, registered in 2016 compared with 1987, the year of its peak demand (Figure I.3). (IEA, 2017b)
- An impressive diversification of the power generation mix took place between 2000 and 2016, as efforts to promote RE and natural gas quintupled their share in the mix. Meanwhile, gas and RE, mainly wind and hydro, not only met all the growth in electricity demand but also helped bring down the coal share by about 4 percent (Figure I.4).

Low-energy-intensive growth began with the Energy Act in 1997 and was sustained thereafter by 27 policy initiatives and regulations that promoted energy efficiency and distributed RE solutions (Annex 1).

The impressive achievements since the early 1990s are in many ways extraordinary for a country undergoing difficult and comprehensive economic and political reforms to transition to a market economy and establish a democratic regime. However, without immediate action the severe problems confronting Poland’s energy sector could jeopardize these achievements.

Figure I.4 Doubling the Share of Renewable Energy in Electricity Production over the Past Decade (GWh)



Source: IEA, 2017b

Emerging Threats to Sustainability

Local Environmental Threats

For historical and social reasons, Poland’s energy sector has been heavily reliant on coal, which accounted for (a) 50 percent of TPES, compared to 17 percent on average in IEA countries and about the same in the EU-28; and (b) about 80 percent of electricity gener-

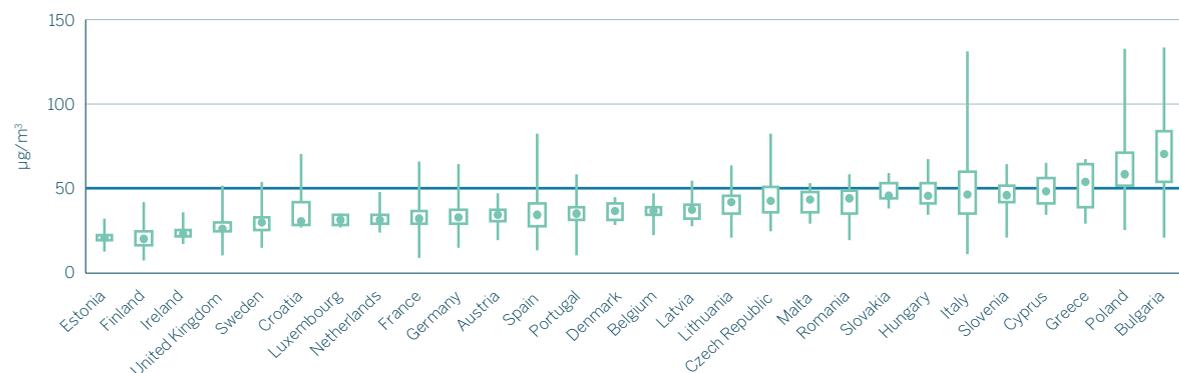
ation, compared to averages of 28 percent in IEA countries and 23 percent in the EU-28. The heavy reliance on coal has led to serious local and global environmental concerns.

Ambient air quality is deteriorating. In 2017, according to the World Health Organization, of the 50 most polluted cities in Europe 36 are in Poland.¹ On December 18, 2017, Radio Poland reported that: “Poland’s Chief Inspectorate for Environmental Protection said the particulate matter (PM_{2.5}) concentra-

tion in Warsaw on Monday morning exceeded 115 micrograms per cubic meter (µg/m³) while PM₁₀ concentration was at 125 µg/m³. *The World Health Organization’s recommended maximum 24-hour mean is 25 µg/m³ for PM_{2.5} and 50 µg/m³ for PM₁₀.*”

In 2015, Poland’s PM₁₀ concentration was the second highest in the EU-28. It exceeded both the WHO standard and the daily limit set by the EU of 50 µg/m³ (Figure I.5). PM_{2.5} concentration was the highest (Figure I.6).

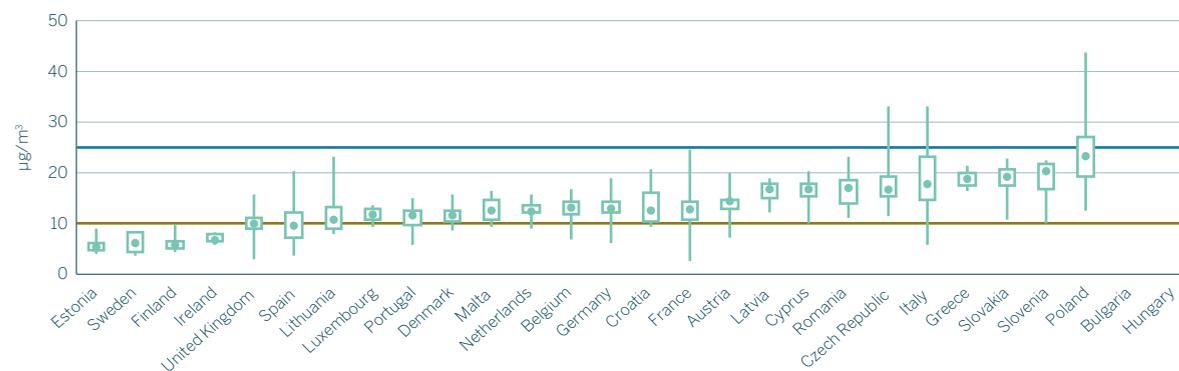
Figure I.5 Poland has the Second Highest PM₁₀ Concentration in the EU-28 in 2015



Source: EEA 2017.

Notes: (1) The graph is based, for each Member State, on the 90.4 percentile of daily mean concentration values corresponding to the 36th highest daily mean. For each country, the lowest, highest, and median percentile 90.4 values (in µg/m³) at the stations are given. The rectangles mark the 25 and 75 percentiles. At 25% of the stations, levels are below the lower percentile; at 25% of the stations, concentrations are above the upper percentile. The daily limit value set by EU legislation is marked by the blue line. (2) Based on Air Quality e-reporting database (EEA, 2017).

Figure I.6 Poland has the Highest PM_{2.5} Concentrations in the EU-28 in 2015



Source: EEA, 2017

Notes: (1) The graph is based on annual mean concentration values. For each country, the lowest, highest, and median values (in µg/m³) at the stations are given. The rectangles give the 25 and 75 percentiles. At 25% of the stations, levels are below the lower percentile; at 25% of the stations, concentrations are above the upper percentile. The target value set by EU legislation is marked by the blue line. (2) Based on Air Quality e-reporting database (EEA, 2017)

1. <https://www.nytimes.com/2018/04/22/world/europe/poland-pollution.html>.

In its assessment of exposure and disease burden,² the WHO stresses that “air pollution is a clear marker for sustainable development, as sources of air pollution also produce climate pollutants (like CO₂ or black carbon).” *The 2030 Agenda for Sustainable Development*, adopted by the United Nations in September 2015 has three air pollution-related indicators, which fall under the WHO’s reporting responsibility: mortality rate attributable to household and ambient air pollution for the health goal (Sustainable Development Goal [SDG] 3); annual mean levels of fine particulate matter (PM_{2.5}) in cities, population-weighted for the urban SDG (11); and proportion of population with primary reliance on clean fuels and technologies for the sustainable energy goal (SDG 3; WHO 2016).

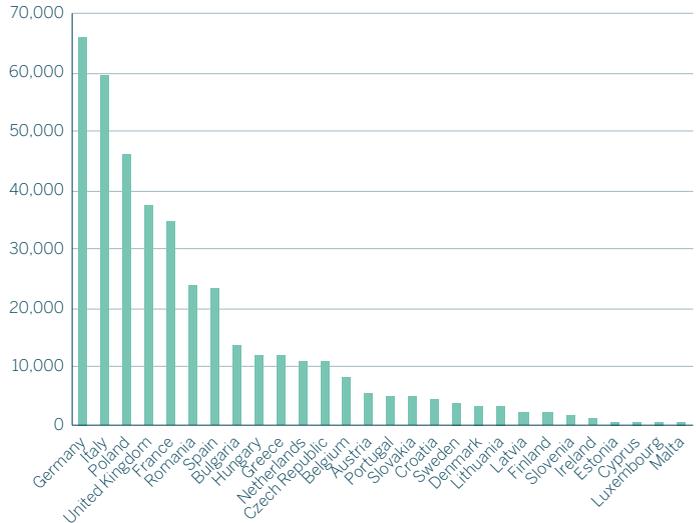
In *Air Quality in Europe—2015 Report*,³ the European Environmental Agency (EEA) estimated that in 2012, PM_{2.5} emissions alone caused an estimated 44,500 premature deaths in Poland, the third highest after Germany and Italy, two more populated countries (Figure I.7). The World Bank report also estimated that the cost of ambient air pollution amounts to about US\$31-40 billion, equivalent to 6.4-8.3 percent of GDP in 2016 (World Bank, 2018a). This compares well with the annual cost of air pollution around €26–30 billion recently estimated by the European Commission (EC) and the Poland Ministry of Entrepreneurship.

Global Environmental Threats

Despite Poland’s progress in controlling energy consumption and diversifying the energy mix, coal still accounted for about 80 percent of total electricity generation in 2016 (Figure I.3).

In 2015 Poland was among the 20 highest emitters of carbon dioxide in the world. Its emissions from fuel combustion amounted to about 1 percent of global emissions—as much

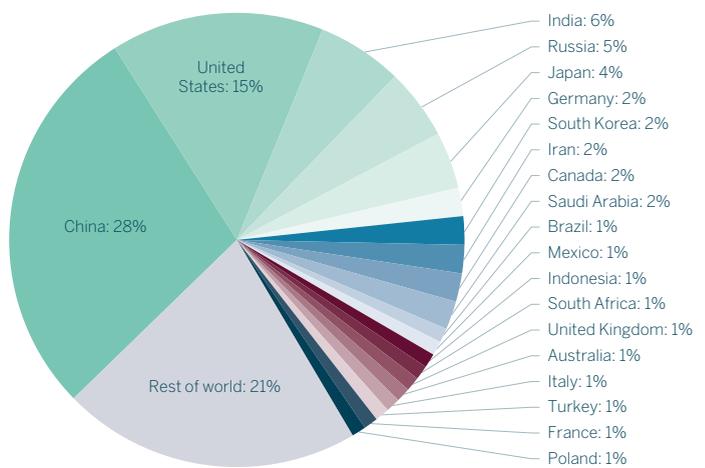
Figure I.7 Poland has the Third Highest Deaths Attributable to Ambient Air Pollution in the EU28 in 2014



Source: EEA 2018

as developed EU members like France and the United Kingdom (Figure I.8). According to IEA databases, its CO₂ intensity was about 0.31kg/USD (PPP), which is higher than the average EU-28 and world intensities.

Figure I.8 Poland Accounts for Only 1 percent of Global Carbon Emissions from Fuel



Source: (Union of Concerned Scientists, 2018)

2. A global assessment of exposure and disease burden. World Health Organization 2016, <http://who.int>.
 3. <https://www.eea.europa.eu/downloads/945260c75bd34248ab696d46a85e9573/1461254126/premature-deaths-attributable-to-air-pollution.pdf>.

Readiness for the Energy Transition

The World Bank Regulatory Indicators for Sustainable Energy (RISE) report investigates policies and regulations that enhance sustainable energy – including electricity access, energy efficiency, and renewable energy and a pilot study on clean energy. RISE presents indicators that can be compared across 133 economies—and over time, from 2010 to 2017. The RISE report measures the level of policy adoption in countries related to the Sustainable Development Goal 7 indicators pillars. RISE can help national policymakers benchmark the energy sector framework against regional and global peers (World Bank 2018c).

The RISE report found that Poland trails OECD countries in both energy efficiency and renewable energy policies and regulations (Figure I.9). Poland has a higher energy efficiency score than renewable energy, reflecting its achievements in reducing energy intensity. For renewable energy, while the country has an excellent legal framework, RE financial incentives and transmission network strengthening can help scale up RE (Figure I.10).

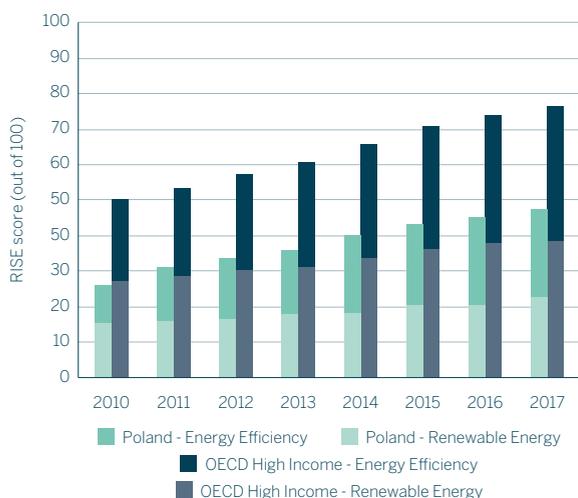
A new WEF report provides “energy transition indices” (ETIs) for 114 countries that “provide both a high-level assessment of countries globally and individually against a defined benchmark” to base decision-making on a fact-based framework as “governments face new challenges and opportunities to ensure energy systems deliver on the triple goals of energy access and security, contribution to economic growth, and sustainability” (World Economic Forum and Mckinsey, 2018).

The results of the in-depth analyses also offer an assessment of country performances:

- The system performance scores are based on three imperatives: economic development and growth (5 indicators), environmental sustainability (4), and security and access (4).
- The transition readiness scores are based on six enabler dimensions: capital and investment (3 indicators), regulation and policy (3), stable institutions (3), infrastructure and innovative business environment (4), human capital and consumer participation (2), and energy system structure (3).

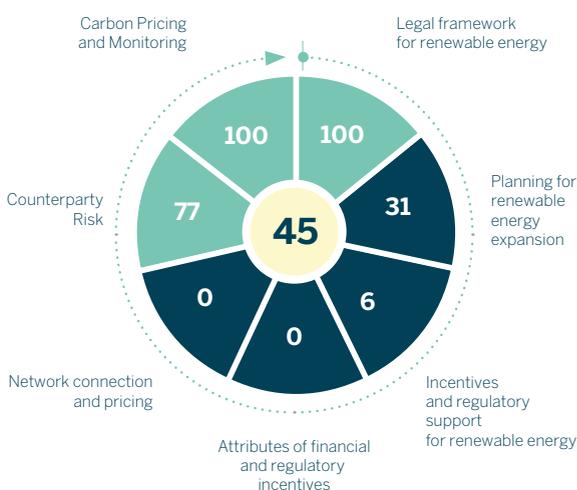
The spider graphs in Figure I.11 show Poland’s scores against the averages of the 114

Figure I.9 Poland’s Energy Efficiency and Renewable Energy Policies Need Improvement

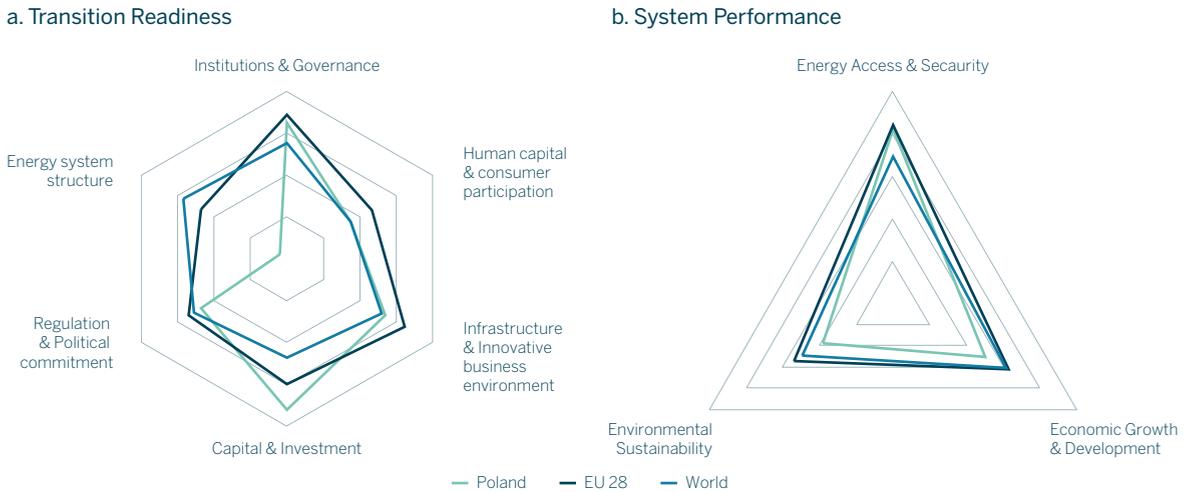


Source: RISE, World Bank 2018c

Figure I.10 Financial Incentives and Network Strengthening Can Help Scale Up RE in Poland



Source: RISE, World Bank, 2018c

Figure I.11 Scores for System Performance and Transition Readiness

Source: Based on data from WEF 2018

countries covered (WEF 2018) and the EU-28 averages (computed by the study team based on the WEF data).

- On sector performance: Poland scored as well as or better than the average of the 114 WEF countries except for energy system structure, where it scored much lower, and to a lesser extent regulation and political commitment. Among the EU28 it scored less, especially on energy system structure, than the average except on capital and investment, where its score was higher.
- On readiness for energy transition: Poland scored better than the WEF study average for energy access and security and close to the EU28 average, but it scored less than the averages for the 114 WEF countries and the EU28 on economic growth and development and environmental sustainability.

Figure I.12 presents the performance/readiness matrix provided by the WEF report (bottom panel) and the same matrix for the EU28 countries (top panel) (World Economic Forum, 2018). For the transition, Poland is classified among emerging countries, close to Vietnam and behind Thailand. Compared to EU28 countries, Poland is better positioned only than Bulgaria for the transition to sustain-

ability. It trails all other EU countries on system performance, readiness for transition, or both.

The main impediments to Poland's transition to sustainability highlighted in the WEF study are structural; they arise from lack of integration of energy and environment policies, a timid approach to technological innovation, inadequate incentives for efficient use of resources, and a quite outdated energy structure that is not aligned with the country's market economy.

This study is designed to inform government decisions about the scale and pace of the energy transition in line with the "war on smog" and the government's commitment to combat climate change. It explores different options for electricity generation and district heating to reduce local air pollution and CO₂ emissions and meet Poland's contribution to the EU ETS CO₂ emission reduction targets by 2030. The options are designed to identify what would need to be done to meet certain emission reduction targets at least cost. The study also assesses the impacts of energy transition in the power and district heating sectors on coal mine employment, local communities, and the national economy. Finally, it recommends energy and social policy measures to put the electricity and district heating sectors on a sustainable path.

The fact that the study was limited to electricity and district heating and goes no farther than 2030 leaves many questions unanswered about the country's long-term emissions trajectory and Poland's contribution to meeting the EU's goal of carbon neutrality by 2050. The

study also excluded the industry, transport, and agriculture sectors. An economy-wide study to 2050 would require broader and deeper analyses, close cooperation with all the relevant government agencies, and more time and resources than those available for the present study.

Chapter 1

METHODOLOGY: THE QUEST FOR SUSTAINABILITY

Key Messages

- This chapter outlines the approach and methodology used for the study and briefly describes the two models used: (a) the World Bank Electricity Planning Model (EPM), a partial-equilibrium- optimization model for electricity and district heating production and scenario analysis; and (b) an econometric and a CGE model to assess how less coal production and fewer mine jobs could affect both local communities and the national economy.
 - The innovative characteristics of the EPM model recognizes constraints that apply to operating power systems and coal mines. This model has been adapted to Poland's power and heating sector characteristics, which incorporates over 250 power and co-generation plants and heating-only boilers (HOB). Its integrated analysis of the power system generation mix and the operation of coal mines from 2018 to 2030 facilitates investment and operational decisions.
 - The reductions of coal production and coal mine employment in selected EPM scenarios are first used in the econometric model to evaluate the spillover effects on communities near coal mines with detailed data on employment, migration, and firm-level indicators at the municipal and postal code level; and then to assess the impacts on the national economy using a CGE model calibrated to the main features of the Polish economy.
 - The study first analyzed four optimized pathways to be used as benchmarks: (a) without external environmental costs; (b) incorporating local air pollution costs only; (c) incorporating local air pollution costs and a carbon price at \$30/ton CO₂; and (d) incorporating local air pollution costs and a carbon price based on the World Bank Carbon Price Guideline of \$37/ton CO₂ in 2018 rising to \$50/ton CO₂ by 2030.
 - Then, the study evaluated three alternative options to explore energy transition in the electricity and district heating sectors: (a) The first reflects the "Envisioned Targets" still being discussed: Power and district heating consumption of hard coal remains the same up to 2030, and renewable energy in the power generation mix would amount to 32 percent by 2030 (Envisioned Targets); (b) The second aims to achieve the 2030 EU ETS targets of 43 percent CO₂ emission reduction from 2005 to 2030 in the power and co-generation sectors, which translates in limiting power and district heating CO₂ emissions to 98 million tons by 2030. These EU ETS targets are also in line with the EU NDC targets committed to the Paris Climate Agreement. These targets are EU-wide, not specific to Poland. In this study, as Poland is an EU member state, the EU targets are used as proxy for Poland; and (c) The third option explores Extended Efforts, beyond the EU ETS targets, limiting power and heating CO₂ emissions to 85 million tons by 2030 in response to the recent IPCC appeal for urgent and extensive efforts to cut the climate change risks related to extreme heat, drought, floods, and poverty.
-

The study approach built on recent work to estimate the effects of emission reduction targets for electricity generation and coal production in Poland (World Bank, 2017b). The World Bank energy optimization planning model (EPM—Electricity Planning Model) was calibrated to Poland’s power and heat sectors specific characteristics⁴. The study then applied the EPM results first to an econometric and then to a CGE model to estimate the impacts of lower coal production and employment on both local communities and the national economy. These analyses were designed to identify policy and structural changes that would help the country to achieve sustainability.⁵

The Electricity and Heating Model

Overview

The preliminary energy planning assessment, based on the EPM,⁶ a partial-equilibrium optimization model for electricity and heat production, is designed to support investment and operational decisions about coal production and use. For each scenario, the model determines (a) the dispatch of individual power stations over a specified period; (b) optimal selection of new projects to meet demand and emissions constraints; and (c) production and closure decisions for individual mines.

Integrating coal production and electricity and heat generation is useful for deciding how emissions of carbon and other pollutants can be effectively mitigated through a mix of fuel switching (e.g., coal to gas or to renewables) and through associated decisions on mines. Based on the current generation mix, demand projections, reliability and cost parameters, emissions targets, technology choices, and coal supplies, the model helps policymakers address the following questions:

- What is the best approach for planning to meet emissions targets?
 - What is the optimal mix to replace Poland’s coal fleet with other technologies, such as gas and RE?
- Which coal mines will supply fuel to the most efficient plants?
 - How does imposing emissions targets change the ranking of mines to keep open or to close?
 - Does the equation change by taking into account the number of employees at each mine?
 - Taking the cost of transportation into account, which are the cheapest mines to operate?
 - To what extent does supplying coal to plants that must be kept in service (e.g., for co-gen facilities that provide heat and electricity) change the equation for certain mines?

4. It should be noted that the EPM model does not include transmission and distribution, demand side energy efficiency, and storage investments.

5. Energy sustainability here means “access to adequate and reliable supplies of environmentally and socially acceptable forms of energy at competitive prices, without compromising the energy and environmental needs of future generations.” The definition is adapted from the report of the UN Commission on Environment and Development “Our Common Future,” published in 1987 (the Brundtland Report). Local and global environmental concerns have heightened since 1987.

6. EPM was developed using the General Algebraic Modeling System (GAMS, www.gams.com) with an Excel front end; IBM’s CPLEX solver is used to deal with the Mixed Integer Programming (MIP) problem.

By imputing costs to all activities (e.g., plant capital and operating costs, mine operating and closing costs, and emission control costs), the model determines where costs are lowest across the relevant value chain (i.e., coal mining, transport, and use in power plants and heating-only boilers (HOBs)), while meeting local through global emissions reduction targets.

The Polish version of the EPM covers more than 250 power plants and HOBs. The results of integrated analysis of the generation mix and the operation of coal mines from 2017 to 2030 can facilitate investment and operational decisions for

- Power plants: annual generation per plant, retirements and plant additions, annual fuel use by type.
- HOBs: fuel supply (i.e., coal and gas or switching from coal to gas) needed to meet heating demand, expressed as HOB capacity factor.
- Emissions controls: installation of equipment at individual plants and how they are operating to reduce pollutants.
- Coal mines: production and supply to connected power plants, whether the mine is open or closed, number of employees, plant transportation costs, and productivity per employee.

The model determines how, based on amount of coal produced, power generation by downstream plants should be adjusted. It optimizes coal production by capturing the productivity of individual mines (number of employees per ton of coal produced), the minimum technical production level necessary to supply coal-fired plants, and the mine's costs; it also takes into consideration the lowest economically feasible employment and production levels.

Optimization Parameters and Constraints

For the 2018–30 period, the model has been set up in annual increments, with each year

divided into 30 “load blocks” between peak and off-peak. The model incorporated

- Plant characteristics: capacity, heat rate, minimum loading, energy limits, pollution emission factor, and links to coal mines
- Renewable energy (RE) profile for solar and wind
- Capital costs for power plants and emission controls
- Limits on emissions reduction for each control in terms of its efficiency and cost
- Fuel price forecasts for all eight categories of fuels modeled (among them imported coal, coking coal, lignite, and gas)
- Coal Mine characteristics: maximum and minimum production limits, costs, and productivity ratio (workers per ton of coal production)
- Cost of transporting coal from mines to power and heating plants
- For the 30 blocks, annual load curve for 2017 and forecasts for 2018–30
- The price duration curve for each load block
- Emission limits for each policy scenario
- Pollution abatement costs
- Minimum reserve needed to keep the power system reliable.

The model optimizes total discounted power generation and heating system costs over the study period related to capital investments for new power plants; fuel, non-fuel variables, and fixed operations and maintenance costs of all power plants and HOBs; power imports (represented as a price duration curve); investment in new emissions controls and their operating costs; penalties for not meeting power demand and reliability thresholds; and costs associated with jobs lost in mine closures.⁷

The model recognizes constraints that apply to operating the Polish power system and coal mines, such as

- Capacity of power plants and HOBs, maximum capacity factor and minimum load

7. The model includes a linear production-to-labor ratio for each coal mine that is used to compute the number of employees needed given the level of production endogenous to the model.

- level for coal plants, and maximum percentage of imported coal that plants and HOBs can use
- Maximum coal supply limit from each mine and each mine-power plant link
- Minimum production of each coal mine below which the mine must be closed
- Limits on power imports
- Profile of variable RE (wind and solar generation profile for 30 blocks that are derived from hourly profiling that accounts for their correlation to load)
- Meeting electricity demand for each load duration curve block
- Limits on CO₂ and local pollutants
- Maintenance of the minimum reserve.

The results of the coal mine closures and labor outputs in the selected scenarios will be used in a social impact model to assess the impacts on the national economy and regional labor and spillover effects.

Social Impact Model

The economic impacts of less coal production and fewer jobs are estimated using two complementary approaches:

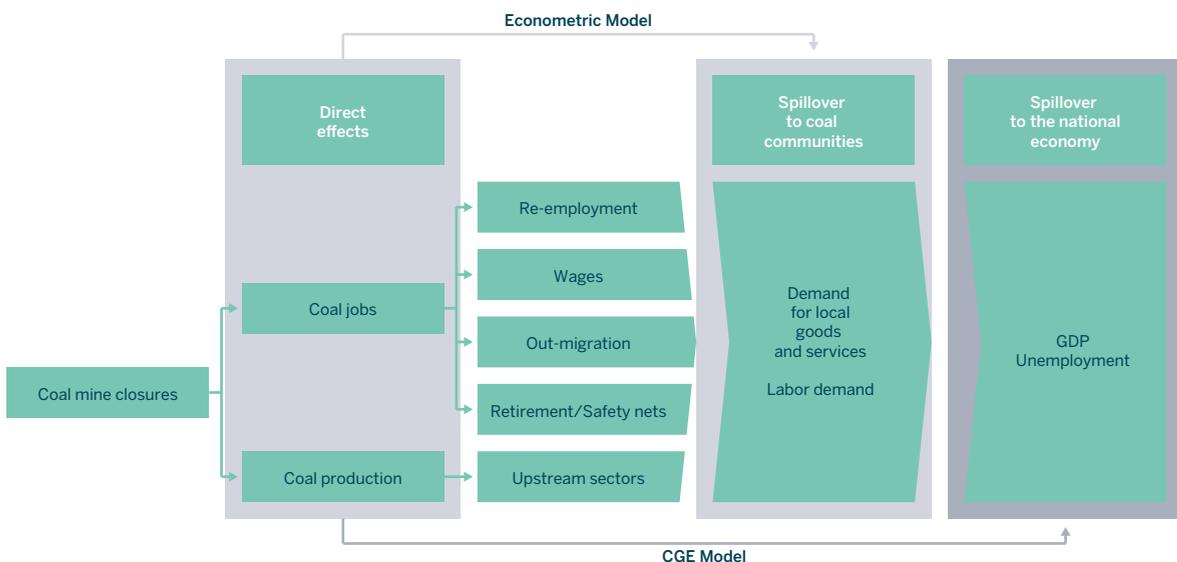
- First, the impacts on coal areas and communities are disentangled, using an econometric model with detailed data on employment and migration for about 2,500 municipalities, and firm-level outcomes at the postal code level.
- Second, the impacts on the national economy are estimated using a CGE model calibrated to match the main features of the Polish economy.

As shown in the second chapter, both models are consistent and generate a similar set of findings. Figure 1.1 shows a simplified version of the two models.

Econometric Model

The econometric model estimates how the decline in coal employment will affect demand for goods and services in the local economy (Winkler, forthcoming). Intuitively, a decline in coal employment would lower incomes and thus the purchasing power of households whose main livelihood relates to coal. The magnitude of the impacts would be affected by the ability of displaced workers to find new jobs without moving, the decline in wages, the number of households that must move to another

Figure 1.1 Econometric and CGE Models to Estimate Spillover Effects



area, and the pensions and safety nets available to displaced coal workers. For example, if they can easily find a job without migrating, the spillover impacts on the local economy would be negligible. However, the steeper the drop in wages, holding constant the fall in employment, the larger the spillover impacts (Winkler, forthcoming).

The econometric model assumes that impacts would depend on the proximity to coal deposits: the closer a municipality or a firm is to a coal deposit, the more spillover effects it is likely to suffer if coal jobs are cut. (It is important to mention that this is not imposed on the model; the model is flexible: it estimates the spillover impacts based on distance to the coal deposits and lets the data speak for themselves.)

The econometric model makes it possible to disentangle the spillover impacts of a general decline in demand for local goods and services from the impacts of a decline in coal sector demand for intermediate inputs from upstream industries. Using data from the input-output matrix for Poland, the analysis first identified which sectors are most dependent on the coal sector, measuring dependence as the share of the sales to the coal sector in total upstream sector sales. The model uses the decline in coal production predicted by the EPM for each scenario as an input. The main hypothesis is that the larger the share of the coal industry in a sector's total sales, the more that sector will suffer if coal production drops. The final impacts would be mediated by such factors as the ability of non-coal sectors to redirect production to other industries or locations, and the extent to which affected firms can engage in different economic activities.

CGE Model

CGE is a multisector, dynamic general equilibrium model. It considers three possibilities: First, the closure of mines has an immediate direct impact on employment as coal work-

ers become jobless. Second, this initial direct impact has negative effects on sectors that are buyers or suppliers of products and services to the coal industry, in this case business administration, agriculture, communication, construction, electricity, finance, manufacturing, mining, real estate, trade, transport, and water. Third, the final impacts will depend on how well the economy can adapt to the shock. The model makes it possible to consider impacts on different types of workers, across such dimensions as age, gender, and education level.⁸ Annex 3 describes the details of the CGE model.

Unlike the econometric model, the CGE model does not consider impacts on local coal areas. Instead, it estimates economy-wide impacts on GDP and the unemployment rate. Intuitively, because it aggregates the impacts on coal and non-coal areas, it assesses the net effects. While this is a limitation, it also has the advantage of incorporating the general equilibrium effects of the initial coal shock. The CGE model also has the advantage that it takes into account the possibility that a decline in coal production and coal-based energy may be compensated (partially or fully) by an increase in oil and gas energy, with associated implications for employment.

A serious limitation of both the CGE and the econometric model is that they do not incorporate the direct and indirect impacts that emerging RE may have on employment creation through positive health or environmental externalities. This will bias downward the results by overestimating the negative economic impacts of the energy transition.

The Emission Reduction Pathways

Finally, the analyses were carried out in two phases (Table 1.1):

8. For a detailed description of the other blocks of the model see Marouani and Robalino (2012), "Assessing Interactions among education, social insurance and labor market policies in Morocco," *Applied Economics*, volume 44, No 24, pp. 3149-3167.

Table 1.1 Assumptions of Options Explored*

	CO₂ emissions in power & heat sector in 2030	Externalities	RES share (2020)	RES share (2030)	Coal production for Heat & Power sector
OPT-No ENV	Unconstrained	No externalities	>19%	>19%	Unconstrained
OPT-L	Unconstrained	Local Pollution Costs included	> 19%	> 19%	Unconstrained
OPT-LG	Unconstrained	Local and Global Costs included, CO ₂ price at \$30/ton	> 19%	> 19%	Unconstrained
OPT-LG+	Unconstrained	Local and Global Costs included, CO ₂ price: \$37/ton in 2018 to \$50/ton in 2030	> 19%	> 19%	Unconstrained
Envisioned Targets	Unconstrained	No externalities	> 19%	> 32%	The same level from 2018 to 2030
EU ETS	98 million tons	No externalities	> 19%	> 32%	Unconstrained
Extended Efforts	85 million tons	No externalities	> 19%	> 32%	Unconstrained

* All prices are in 2018 USD

- Four optimized pathways were identified as benchmarks to evaluate the options for the electricity and district heating sectors:
 - (a) Without consideration of external environmental costs (OPT-No ENV). The penetration of RE in the power generation mix was constrained to 19 percent and in the district heating mix to 15 percent by 2020 because these targets are specified in the Poland Renewable Energy Directive;
 - (b) Incorporating only the external environmental costs of local air pollution⁹ (OPT-L);
 - (c) Incorporating the social costs of local air pollution and global climate change based on a carbon shadow price of CO₂: \$30/ton of CO₂ (OPT-LG) during the study period; and
 - (d) Incorporating the social costs of local air pollution and global climate change based on shadow price of CO₂ rising from \$37/ton of CO₂ in 2018 to \$50 in 2030 (OPT-LG+).¹⁰
- Three alternative options were explored:
 - (a) The first reflects the envisioned government targets, still under discussion, would hold consumption of hard coal for power and district heating the same up to 2030, and RE penetration in the power generation mix would reach 32 percent by 2030 (Envisioned Targets);
 - (b) The second aims to achieve the EU ETS targets of reducing power and co-generation CO₂ emissions by 43 percent from 2005 to 2030,

9. The external environmental costs of local air pollutants are based on estimates for Poland from Štreimikienė (2015) and EEA (2014), and the values are provided in Table A2.4 in Annex 2.

10. Based on the low assumption in World Bank future CO₂ prices in Guidance Note for Economic Analysis (World Bank 2017c), \$/ tCO₂e (constant prices) provided in Table A2.6 in Annex 2.

which translates in limiting power and district heating CO₂ emissions to 98 million tons by 2030. The EU ETS targets are in line with the EU NDC targets, and are EU-wide. In this study the EU targets are used as proxy for Poland (EU ETS).

- (c) The third explores the Extended Efforts surpassing the EU ETS targets by limiting power and heating CO₂ emissions to 85 million tons by 2030 in response to IPCC appeal for urgent and extended efforts needed to cut the climate change risks related to extreme weather events and poverty (Extended Efforts).¹¹

11. <https://www.theguardian.com/environment/2018/oct/08/global-warming-must-not-exceed-15c-warns-landmark-un-report>.

Chapter 2

ANALYSIS RESULTS: THE NEED FOR ACCELERATED EFFORTS TO ACHIEVE SUSTAINABILITY

Key Messages:

- If external costs of local air pollutants alone are incorporated, not only can local air pollutants be reduced by 2030 but so can power and heating sector CO₂ emissions. Incorporating both local and global environmental costs would achieve the optimized results: a dramatic drop in local air pollutant emissions, and a cut in power and heating CO₂ emissions to 88 million tons, meeting the EU ETS targets. Taking into account the external costs of both local and global environmental costs could increase the net present value (NPV) of economic cost by 9–14 percent than the option without external costs, depending on carbon prices, but would be fully justified by the NPV of the environmental benefits of reduced emissions. The carbon price can make a major difference: a price of \$30/ton CO₂ could reduce power and heating CO₂ emissions to 117 million tons by 2030, but a sliding scale from \$37/ton CO₂ in 2018 to \$50/ton CO₂ by 2030 would cut the carbon emissions to 88 million tons.
 - The Envisioned Targets option would significantly diversify the electricity generation mix, a good move for energy transition, but local air pollutants and CO₂ emissions would stay high, way above the EU ETS targets of 98 million tons in power and district heating emissions by 2030.
 - Achieving the EU ETS targets requires intensified efforts to scale up and accelerate the penetration of clean energy. The share of coal in power generation would need to be almost halved, from 80 percent today to 44 percent by 2030, with RE penetration rising to 43 percent and gas to 13 percent. This scenario would dramatically reduce local air pollutants and CO₂ emissions. Although the net present value of the economic costs would be higher by 5 percent than in the Envisioned Targets scenario, the environmental benefits would more than compensate. The implicit carbon price is about \$37–50/ton CO₂, much lower than the penalty of €100 or €115/ton CO₂ if the EU ETS targets were not met. This option could also reduce direct coal mine jobs by 20 percent compared to the Envisioned Targets option.
 - The Extended Efforts option requires a major shift in current policies to scale up the RE share in power generation to 47 percent by 2030, reducing the coal share to 38 percent. Local air pollutants and CO₂ emissions would ultimately be lowest in this option. Though it would cost 7 percent more than the Envisioned Targets scenario in terms of NPV of economic costs from 2018-2030, the environmental benefits would be far more significant. The reduced coal production could lead to a 25 percent reduction in direct coal mine jobs by 2030 over the Envisioned Targets option.
 - Though mining suppliers and communities within 10 km of coal deposits would feel the spillover effects of less coal production and fewer mining jobs, the impact on the national economy would be negligible. Under any option, GDP growth would fall by less than 0.1 percent and the impact on the national unemployment rate would be similar. Previous waves of restructuring in the coal sector had negative but small impacts on employment, and the effects of new declines would probably be even milder, given demographic changes and the structural transformation Poland has been experiencing for several decades.
-

Environment Costs Matter

The main results of the options are presented in the following sections (all assumptions can be found in Annex 2). Tables 2.1 summarizes the results of the analyses.

Optimized without External Environmental Costs (OPT-No ENV) (Figure 2.2): This benchmark pathway does not account for the high discounted local and global environmental costs of nearly \$90 billion born by the society.

Optimized Incorporating Local Environmental Costs (OPT-L) (Figure 2.3):

Table 2.1 Economic and Technical Results of the Analysis

Considered Options	Net Present Value (NPV) of Costs (US\$M)			Emissions			
	Economic Costs	Global Environment Costs	Local Environment Costs	CO ₂ (mt)	PM (kt)	NO _x (kt)	SO ₂ (kt)
OPT-No ENV	113,953	42,803	46,803	149	30.6	165.6	290.5
OPT-L	119,815	37,288	37,364	139	25.2	165.2	255.2
OPT-LG	124,716	30,344	34,583	117	24.5	160.7	243.1
OPT-LG+	129,486	40,220	32,446	88	21.6	130.8	200.1
Envisioned Targets	118,097	40,597	45,495	134	30.1	154.5	280.0
EU ETS	123,510	37,146	42,406	98	26.8	126.5	232.8
Extended Efforts	126,704	35,725	41,314	85	25.6	114.7	215.9

Considered Options	Generation Mixes (%)					
	Electricity			Electricity and Heat		
	Coal	Gas	RE	Coal	Gas	RE
OPT-NoENV	72.7	7.9	19.0	75.5	6.1	18.1
OPT-L	72.7	7.9	19.0	70.1	11.5	18.1
OPT-LG	66.0	14.7	19.0	64.9	16.7	18.1
OPT-LG+	49.0	18.6	32.0	51.8	19.8	28.1
Envisioned Targets	60.6	7.0	32.0	66.2	5.4	28.1
EU ETS	44.1	12.6	42.9	53.5	9.7	36.5
Extended Efforts	37.7	14.4	47.5	48.6	11.1	40.0

Note: The sums of percentages may not add up to 100 because of the rounding

- If only the external costs of air pollution are incorporated in the optimization, both local air pollutants and CO₂ emissions would be reduced.
- Since the main source of air pollution is coal for heating, the share of coal in the heating mix would be reduced from 85 percent under OPT-No ENV to 61 percent under OPT-L, and the gas share for heating would rise to 24 percent by 2030.
- The net present value of economic costs would increase by \$6 billion from 2018-2030, or 5 percent, compared to OPT-No ENV, but would be more than compensated by the reduced local and global environmental costs borne by the society of US\$15 billion.

Optimized Incorporating Local and Global Environmental Costs (OPT-LG (Figure 2.4) and OPT-LG+ (Figure 2.5)). These options account for the financial costs and externalities that are not reflected in financial prices. Incorporating both local and global environmental costs would achieve optimal results:

- Local air pollutants would be dramatically reduced, and CO₂ emissions relating to power and heating could be cut to 88 million tons by 2030, meeting the EU ETS target.
- With higher carbon prices, the share of coal in power generation would drop from 80 percent today to 49 percent by 2030, with RE rising to 32 percent and gas to 19 percent by 2030.
- Depending on the carbon price, this could push up the discounted economic cost by 9–14 percent from 2018-2030 compared to OPT-No ENV, but the cost would be outweighed by the environmental benefits.
- The carbon price matters: at \$30/ton CO₂ emissions would be reduced to 117 million tons by 2030; if the higher prices prevail, CO₂ emissions would be just 88 million tons by 2030.

Figure 2.1 Achieving EU ETS targets is affordable

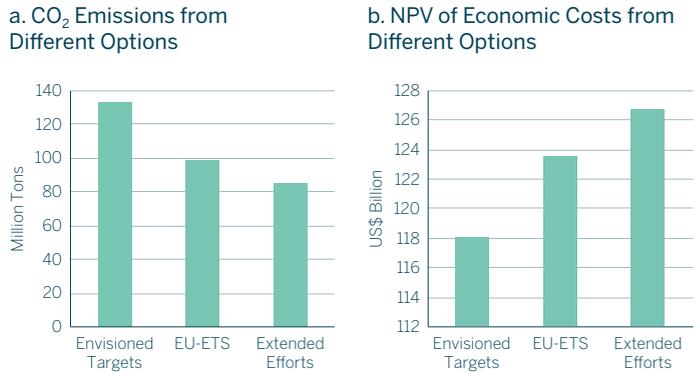


Figure 2.2 OPT-No ENV: Power Generation Mix [GWh]

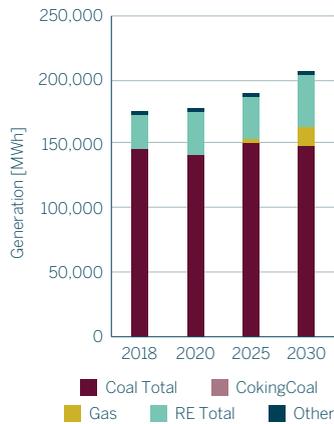


Figure 2.3 OPT+L: Power Generation Mix [GWh]

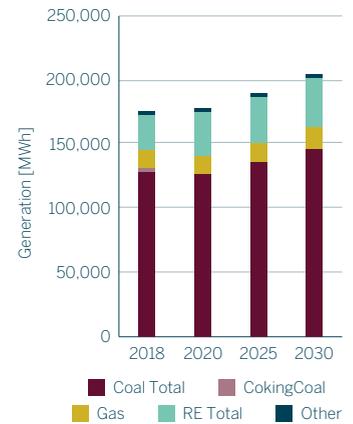


Figure 2.4 OPT-LG: Power Generation Mix [GWh]

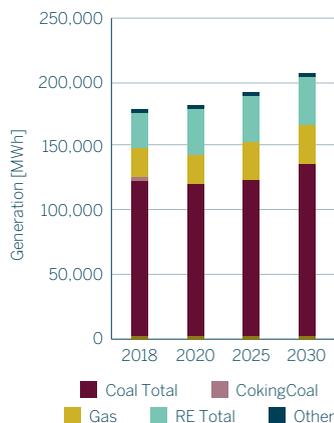
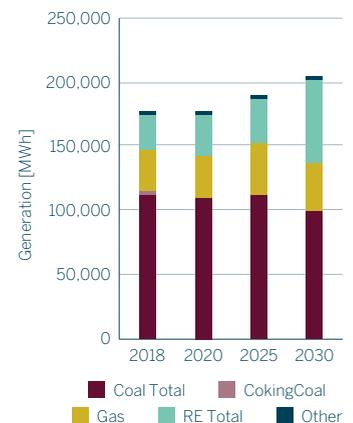


Figure 2.5 OPT-LG+: Power Generation Mix [GWh]



Meeting the EU ETS Targets Requires Intensified Efforts

Envisioned Targets. The envisioned targets are steps in the right direction with the government’s envisioned RE targets, and would cut power and heating CO₂ emissions to 134 million tons by 2030 and reduce the share of coal in the power mix to 61 percent by 2030 (Figures 2.6).

EU ETS (Figure 2.7). Meeting the ETS targets require intensified efforts to accelerate the penetration of clean energy:

- The share of coal in power generation would need to be almost halved, from 80 percent today to 44 percent in 2030, with RE penetration rising to 43 percent and gas to 13 percent by 2030.
- This option would dramatically reduce local air pollutants and CO₂ emissions.
- The net present value of economic costs would increase by \$5.4 billion from 2018-2030, or 5 percent, compared to Envisioned Targets option, but would be justified by the reduced local and global environmental costs borne by the society of US\$6.5 billion.

- The implicit carbon price to achieve the EU ETS targets is \$37–50/ton CO₂—much less than prospective penalties of €100, or \$115/ton CO₂ if the EU ETS targets were not met.
- This scenario would reduce direct coal mine employment by 20 percent, compared to the Envisioned Targets option.

Extended Efforts (Figure 2.8). The Extended Efforts option requires a major shift in current policies to more actively promote clean energy:

- By 2030 the RE share in power generation would need to reach 47 percent, with the coal share dropping to 38 percent.
- This option would bring local air pollutants and CO₂ emissions down the most.
- It would cost only 7 percent more than the Envisioned Targets option and would be fully justified by its environmental benefits.
- This option could lead to a 25 percent reduction in direct coal mine jobs by 2030 than the Envisioned Targets option.

Sensitivity analyses were undertaken to test the robustness of the results in case of lower coal prices than assumed in the study. Two prices were considered through the

Figure 2.6 Envisioned Targets: Generation Mix [GWh]

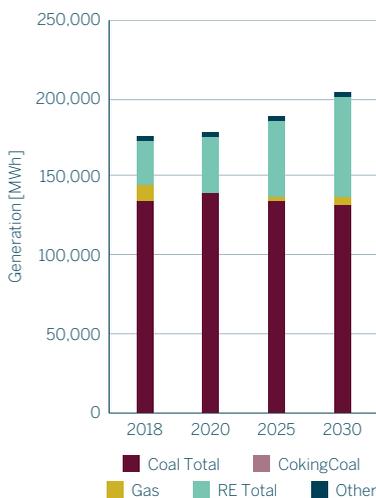


Figure 2.7 EU-ETS: Generation Mix [GWh]

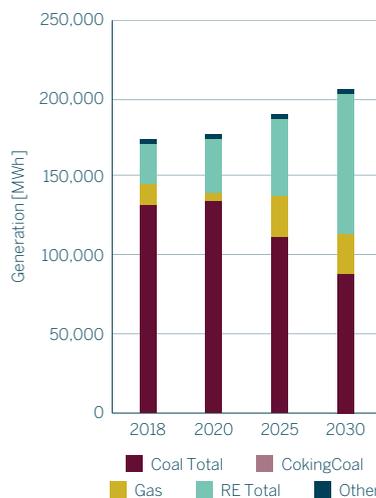
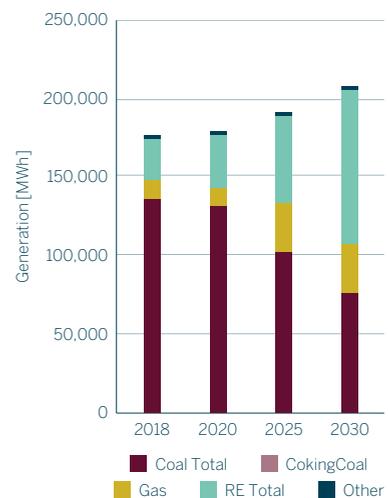


Figure 2.8 Extended Efforts: Generation Mix [GWh]



study period: US\$ 70/ton and US\$ 50/ton. The results show that lower coal prices displace gas with very slight changes to RE shares, indicating the robustness of the conclusion to scale up RE development.

The conclusion is unavoidable: current growth trends and their social costs are unsustainable; the envisioned targets would put Poland’s the power and heating sector on a more sustainable path. But meeting the EU ETS targets will require more efforts. The transition to sustainability requires recognition of local and global environmental costs in the decision-making process and considering new and coordinated policies and effective results-oriented implementation.

Modest Impacts on Local Communities but Negligible on the National Economy

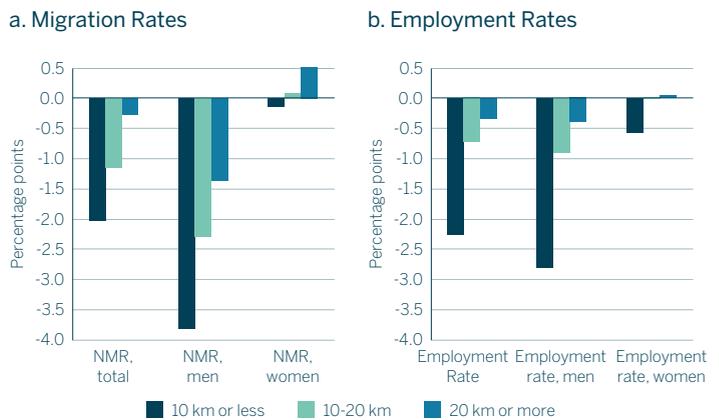
Energy transition programs can have significant social consequences. A simple static approach naïvely suggests that the impacts could be large. In Poland, almost 90,000 people, from both the hard coal and lignite mines, depend directly on the coal sector for their incomes. Adding in workers in coal power plants, the number surpasses 110,000 workers (JRC, 2018). Moreover, other industries are affected by what happens in the coal sector, among them machinery, clothing, and security services; indirectly, an estimated 140,000 jobs also depend on Poland’s coal industry (JRC, 2018). Thus, more than 250,000 families would be affected by erosion of coal production and jobs. Since these jobs are often a family’s main source of income, the number of affected people could be considerably higher. However, these figures do not consider the fact that workers, businesses and regions may be able to find and create new jobs, cushioning the final impacts on the economy.

In fact, the ultimate economic impact of a reduction in coal jobs and production will depend primarily on (a) whether displaced

workers can find a job in another sector, occupation, or location; (b) whether businesses can create new, less coal-dependent, firms; and (c) the generosity of retirement packages and severance payments—and their cost for current and future taxpayers. Factors such as demographic changes and overall economic activity will also shape the eventual impact of the energy transition on labor markets.

Though previous declines in coal employment and coal production in Poland were negative, they had little impact on local communities. A previous decline equivalent to that envisioned by the Extended Efforts scenario was accompanied by more out-migration from coal areas. In particular, net migration rates declined by an additional 2 people net flows per 1,000 inhabitants from areas within 10 kilometers of the coal deposits compared to areas further away (Figure 2.9 a). Employment rates—the percentage of employed people as a share of the working age population—also declined, by 2.3 percentage points more within the 10-km distance from the deposits than in non-coal areas (Figure 2.9 b). Both impacts on migration and employment were only suffered by men, and include both the direct impacts on former coal miners as well as the indirect impacts on other workers.

Figure 2.9 Extended Efforts Scenario: Change in Migration and Employment



Note: Only dark blue bars are statistically different from zero. The net migration rate is the number of individual inflows minus the number of individual outflows, per 1,000 inhabitants. Each bar shows the decline in net migration and employment rates in municipalities within the radius compared to those outside as coal production declines according to the Extended Efforts Scenario. The employment figures exclude those in firms with 9 employees or less.

These effects are small but they demonstrate that changes in the coal industry do come with costs that may not be suffered by everyone but hit some socioeconomic groups harder.

For some sectors past energy transitions were harder than others. Firms selling non-tradable products were particularly vulnerable because they depend almost exclusively on local purchasing power. Thus, when coal production declined by an amount equivalent to that of the Extended Efforts scenario, the number of businesses dealing with non-tradables fell by more than 2.5 percent more in areas within 10 kilometers of coal

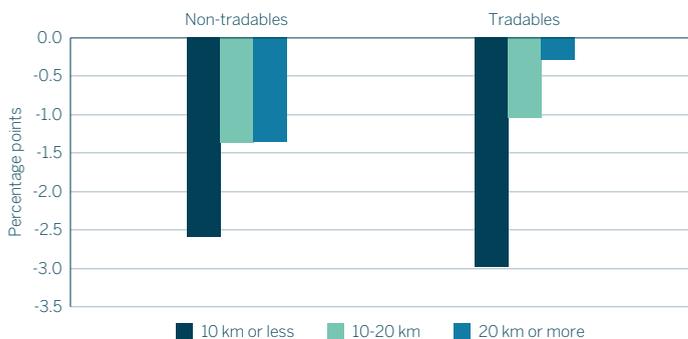
deposits (Figure 2.10). Slightly further away the impacts were smaller (about 1.4 percent) but also significant. However, there were no impacts on jobs in manufacturing, which is highly diversified and need not depend heavily on local consumers for its survival. These impacts reflect pure spill-over effects outside the coal sector.

The dramatic reduction in the coal industry that Poland has experienced since the 1990s has tested the capacity of coal areas to recover. Firms that depend closely on the coal sector to buy their products and services were severely affected; in fact, they cut employment by 40 percent when coal production fell by the magnitude contemplated in the Extended Efforts scenario (Figure 2.11). This is a large effect, particularly considering that national employment rates were not much affected by the past transition. This suggests that while some firms shrank or closed, cushioning mechanisms were in place. Since few displaced workers migrated, these findings hint that either new businesses in non-coal-dependent sectors were successful, or that existing businesses expanded.

Several factors suggest that any new restructuring of the coal sector would have at most smaller effects than those experienced in the 1990s. First, the earlier changes were part of a major change in how the economy was organized, with privatization of several state-owned enterprises and transformation of the public administration as part of the general transition to a market-based economy. The resultant major disruptions in the labor market are unlikely to be repeated. Second, today Poland’s economy is highly resilient and labor markets are tight, with the national unemployment rate comfortably in the single digits in recent years. Strong labor demand suggests high capacity to absorb displaced workers. Third, the availability of new forms of clean energy may in themselves create new job opportunities.

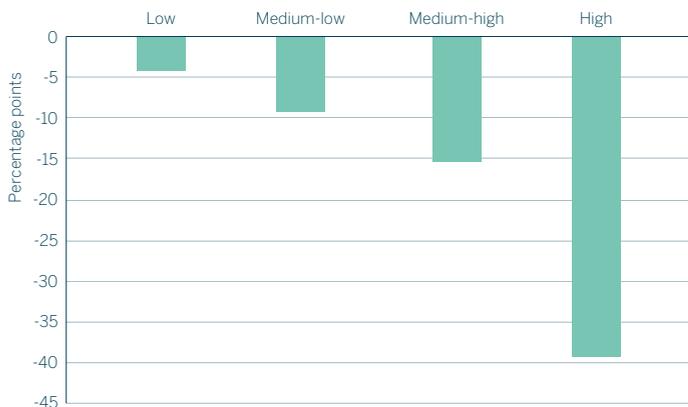
Moreover, coal regions in Poland are substantially more economically diversified today than they were in the 1990s. In Silesia, mining value-added currently represents only

Figure 2.10 The Extended Efforts Scenario and the Number of Non-Mining Firms



Source: Data from the REGON firm registry, 1995-2009. Excludes SOEs.
 Note: Only dark blue bars are statistically different from zero.

Figure 2.11 Effect of Decline in Coal Production on Supplier Jobs by Degree of Dependence

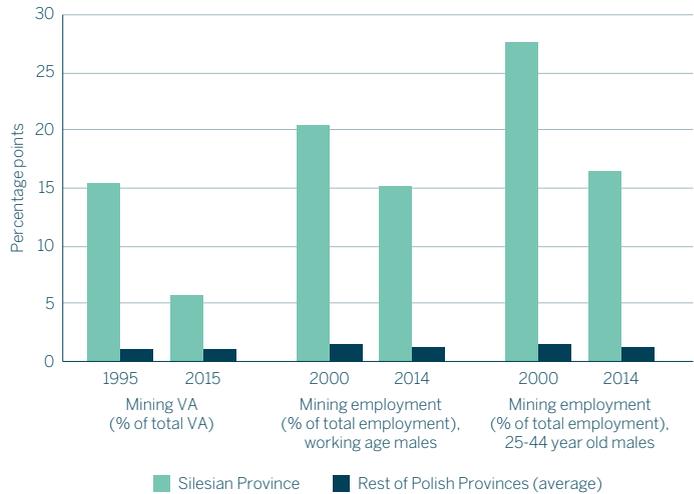


Source: Orbis data for a balanced panel of firms, 2000-19.
 Note: Each bar shows the average decline in percentage points in number of private supplier employees when coal production as in the Extended Efforts scenario.

about 5 percent of total value-added. And while in 2000 prime-age coal workers represented over 25 percent of total employment, today their share is down to about 16 percent (Figure 2.12). The region has become a major manufacturing center, particularly for the automotive industry, which tends to require the same type of skills as mining. Moreover, the region is strategically located close to richer EU markets. By 2017, its unemployment rate was well below the national average, and 5 of the 10 Polish cities with the highest average private-sector wages were located there (Jan Witajewski-Baltviks, 2018).

Finally, the aging of the population will be contributing to a smoother transition. Younger cohorts throughout Poland are significantly smaller both numerically and as a share of total population (Figure 2.13). While in 1995 there were about 330,000 men aged 20 to 29 in Silesia (14 percent of the province’s male population), in less than 10 years the number is expected to fall to about 215,000 (10 percent). When that happens, it will be harder for coal mines to recruit workers, especially since the younger generations tend to be better-educated and aspire to other types of jobs. For example, while in 2000 only about 8 percent of young male cohorts

Figure 2.12 Economic Dependence on Coal: Silesia and the Rest of Poland



Source: Institute of Statistics data.

were college graduates, in 2017 37 percent were. Thus, natural attrition would reduce the coal workforce faster than in the past, so that the spillover impacts would also be smaller. A recent study found that most coal workers are already near retirement age, and that a large reduction in coal employment in about 12 years is feasible without any layoffs (Jan Witajewski-Baltviks, 2018).

Figure 2.13 Demographic Change in Silesia, 1995–2030



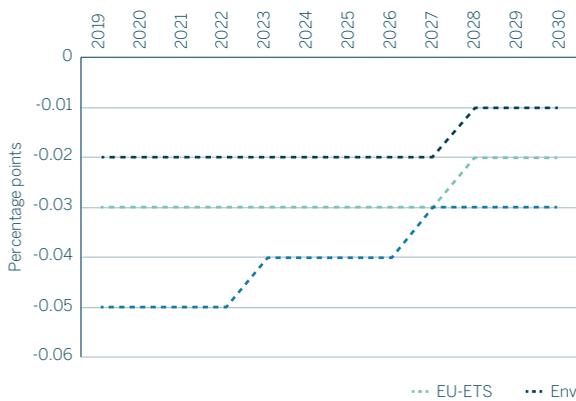
Source: Data from Eurostat and the Polish Institute of Statistics.

These conjectures are supported by a rigorous modeling strategy: The CGE model calibrated to the Polish economy shows that even in the most dramatic scenario, a reduction in coal production will have negligible effects on GDP and unemployment, not even reaching 0.1 percent by 2030 (Figure 2.14).

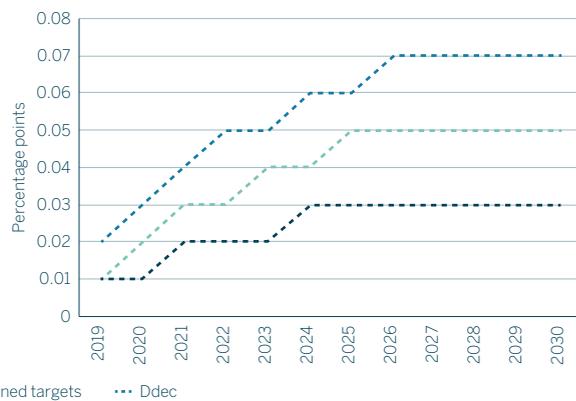
Among the reasons are that coal workers constitute only a small fraction of total employment in Poland, and that an increase in their supply through layoffs together with a strong demand for labor contribute to creating jobs in such labor-intensive sectors as manufacturing, electricity, and unskilled services.

Figure 2.14 Coal Transition has Negligible Impacts on the National Economy

a. Impacts on GDP Growth



b. Impacts on the Unemployment Rate



Source: Simulations using the CGE model.

Chapter 3

THE PATH TO SUSTAINABILITY: CHALLENGING BUT FEASIBLE

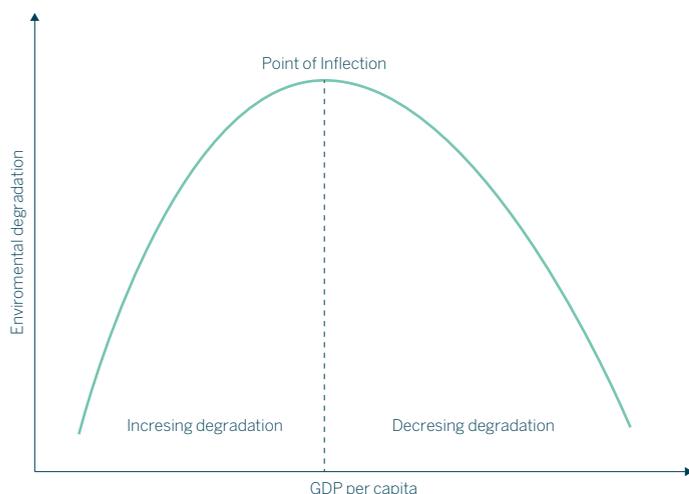
Key Messages

- Because energy and electricity permeate all aspects of people's lives and economic production, energy policies and regulations must be integrated with related policies, such as environment, urban, transport, and job policies.
 - Policies governing the transition to sustainability should be anchored in the principles of (a) integration of energy and environmental policies to incorporate external environmental costs; (b) avoidance of the "pollute early and pay later" formula followed by most developed countries; and (c) close coordination and collaboration between relevant agencies (horizontal) and between central and local levels (vertical).
 - Poland can continue on its low-energy-intensive development path by tapping the still-large potential for energy efficiency, shifting to a greener energy mix, and leapfrogging to the most advanced technologies available. The country may consider better aligning decision-making processes with the changing structure of energy consumption and recognizing the emerging challenges and opportunities to ensure that energy systems contribute to economic growth and sustainably meet citizen needs for mobility and comfort.
 - The options explored in this study indicate that the additional costs of the transition to sustainability are less than the benefits that will result from lower local and global emissions.
 - Finally, the declines in the coal sector would likely have less impact than past coal sector restructuring on employment, and the growing energy efficiency and clean energy markets could largely compensate for coal jobs lost. The vibrant manufacturing sector in the main coal areas will also help absorb any displaced workers. However, policies to facilitate the transition of coal workers to new jobs will be central to a smooth transition.
-

For an energy and electricity sector that now depends heavily on coal, progression toward sustainability must resolve inherent tensions between securing the energy supply and protecting the environment. Abundant, low-cost domestic coal has helped Poland reduce its dependence on foreign energy supplies, making the energy system less vulnerable to supply disruption and sudden price hikes. However, in its quest for economic growth Poland has suffered considerable environmental damage.

Electricity and district heating, major components of the total energy system, are usually guided by energy policies and regulations. Like energy in general, they permeate all aspects of people's lives and economic processes. That is why energy policies and regulations guiding them must be integrated with related policies. In other words, an effective energy policy should purposefully embrace all important relationships within the energy sector and between it and other elements of the economy and society. This calls for a new paradigm for future policies.

Figure 3.1 Kuznets Curve for Environmental Degradation



Source: (Desmond McNeill, 2011)

Leapfrogging to a New Paradigm

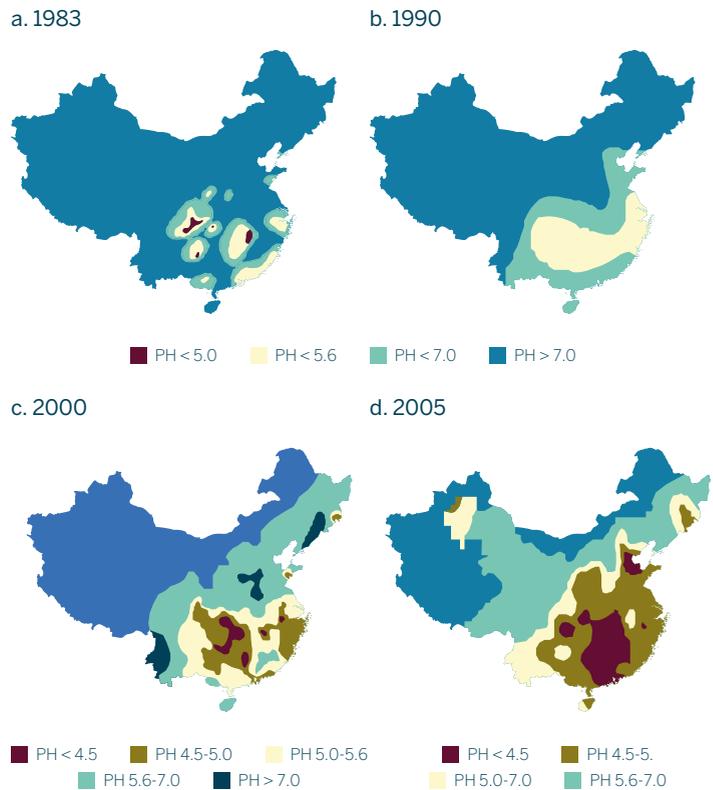
The new paradigm requires:

- **Integration of energy and environmental policies.** A major hurdle to achieving a sustainable energy future in most countries is that environmental externalities are not integrated into energy policy, planning, and investment decisions. Although full integration of externalities poses huge challenges, failing to consider them in decision-making ensures that development will not be sustainable.
- **Avoidance of “pollute early, pay later.”** This requires tunneling through the looming obstacles of rising local pollution linked to income levels suggested by the Kuznets Curve (see Figure 3.1)— An integrated energy and environmental policy is fundamental to a successful transition to sustainable growth of the electricity and heating subsectors.
- **Comprehensive approaches.** Electricity and district heating policies must be part of a comprehensive energy policy that addresses the needs of all social and production sectors and takes into account securing adequate supplies through all the links of the different fuel chains.
- **Horizontal and vertical coordination.** Central government ministries and agencies need to build consensus for the policy framework and coordinate their activities for its implementation. Energy policy is traditionally seen as an aspect of economic policy, but urban development and transportation policies must be closely coordinated with it because of how they influence the quantities and types of energy that will be needed. Energy policies should be closely coordinated with and integrated into the war on smog and climate policies. This

study also demonstrate the importance of linking energy and environmental policies with job policies for coal miners. There is anecdotal evidence that state organizations sometimes send conflicting messages to lower government levels, which suggests a need for horizontal coordination. The local governments in turn should chart courses of action for implementing policy. They must take advantage of the synergies and opportunities for cooperation between the diverse regions of the country, which calls for vertical coordination.

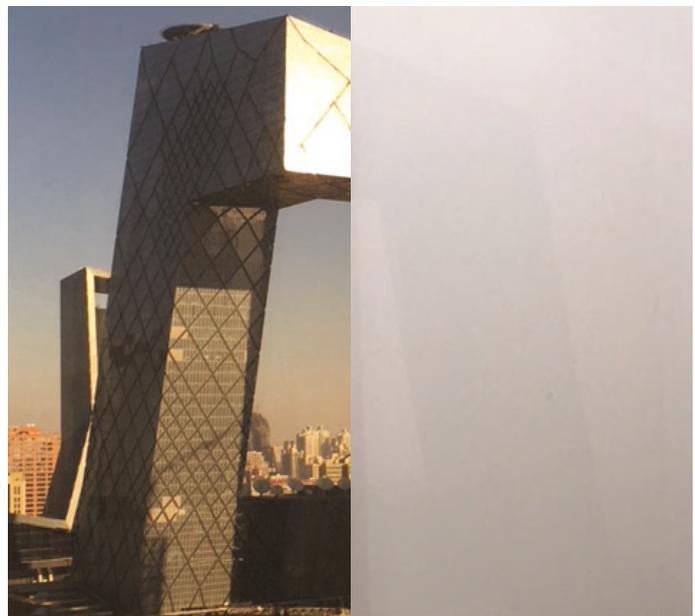
Recent experience in China shows local pollutant emissions can exceed the limits of the environment's absorption capacity, and concerned government efforts on energy transition can clean up air pollution. After China launched economic reforms in the second half of the 1980s and there was a surge in energy and especially power consumption mainly based on coal, the dramatic increase in local pollution has had highly damaging impacts: (a) exacerbation of the harm caused by acid rain, especially where energy and electricity consumption are high, and significantly reduced agricultural yields, which threaten the country's fundamental food security goals (Figures 3.2); and (b) darkening skies over major and medium-size cities (Figure 3.3), severely undermining health through higher rates of pulmonary disease, mostly affecting children and seniors. These manifestations having made the Chinese public intensely aware of the damage done by local pollution, the government launched a momentous nationwide Air Pollution Prevention and Control Action Plan, which specifically mandated the most polluted region to reduce its annual average $PM_{2.5}$ concentration by 25 percent between 2012 and 2017. To achieve this target costs Chinese Yuan Renminbi (CNY) 1.8 trillion (US\$280 billion) nationwide, and CNY 250 billion (US\$40 billion) for the most polluted region. The amounts were primarily used to limit coal consumption and promote cleaner energy. The ambitious targets to reduce $PM_{2.5}$ concentration were achieved in 2017, and air pollution has been significantly improved.

Figure 3.2 China: Progression of Acid Rain, 1983–2005



Source: Energy Research Institute.

Figure 3.3 Dark Skies in Beijing



Making the Transition to Sustainability

The four inter-related themes that should guide the development of a policy for sustainability—reining in future energy consumption; shifting to a greener energy mix; enhancing supply security; and providing a social safety net for coal miners—can be summarized as follows:

- **First, Poland needs to continue to control energy consumption by tapping remaining opportunities for energy efficiency.** Poland has successfully delinked energy and electricity growth from economic growth. Maintaining low-energy-intensive economic growth is fundamental: without it, the objectives of supply security and environmental safeguarding may be jeopardized. But keeping this fundamental objective at the forefront will be more difficult in the future than it was in the last two decades.
- **Second, to safeguard the environment, intensified efforts are needed to shift to a greener energy mix.** Environmental degradation caused by the present energy system, particularly use of coal, has already had severely adverse effects on human health and amenities and, arguably, on agricultural productivity. Accelerating and expanding RE penetration is vital. It can also contribute to a more secure energy supply and mitigate the energy price volatility associated with fossil fuels.
- **Third, the energy system must be better prepared to withstand supply disruptions, and it is vital energy installations be made more secure.** Poland has not taken full advantage of its integration into the global energy economy and the far-reaching technological (decreasing prices of RE technologies, digitization, etc.) and structural (increased integration of the global gas market and of regional electricity markets) advances that are changing the global energy landscape and creating the opportunity to diversify energy balances and to increase the pene-

tration of cleaner RE and more flexible gas units. Meanwhile, concerns about the security of supply, particularly of gas imports, and about the vulnerabilities of such critical infrastructure as LNG import terminals must be addressed.

- **Fourth, a “just transition” should leave no one behind - by providing social safety nets and support to coal miners and all affected population during the transition to sustainable and equitable growth.** Active labor market policies can help mitigate employment impacts. The growing energy efficiency and clean energy markets could largely compensate for coal jobs lost.

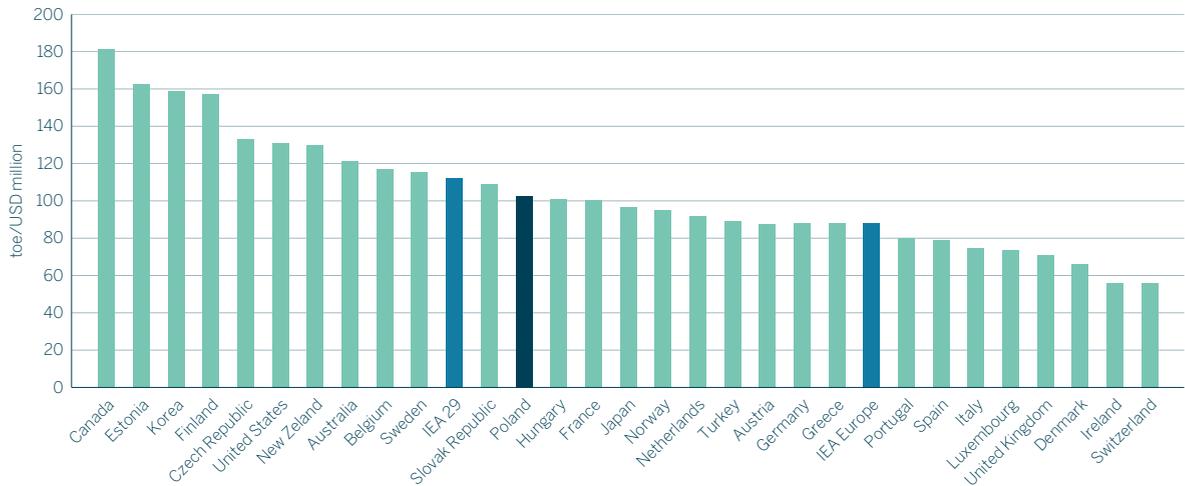
Curbing Future Energy Consumption

Keeping energy consumption growing at a rate substantially lower than economic growth will become more difficult, largely because electricity consumption might grow faster given government plans to deploy more electric cars (the e-mobility program) and digitization and with increasing demand for large databases that will require more servers.

Poland has already decoupled energy growth from economic growth. However, the efficiency potential is still significant because its energy intensity is higher than those of IEA Europe and advanced countries like Spain, the United Kingdom, and Denmark (Figure 3.4).

For Poland, energy efficiency must continue to be the foundation of its quest for long-term sustainable development. This will require

- enforcing regulations governing energy-using capital stock;
- adopting advanced technologies for the most efficient energy use in all energy-consuming sectors (leapfrogging), giving priority to those with the most growth potential; and
- launching a strong communications program to involve the whole society in an endeavor that is vital to the energy security and well-being of future generations.

Figure 3.4 Energy Intensities of Selected Countries

Source: IEA (2016a), Energy Balances of OECD Countries 2016, www.iea.org/statistics/.

Note: GDP in real numbers for USD per purchasing power parity (PPP), in 2010 values.

Continued efforts will depend on clear policy guidelines that stress energy savings as a major objective of sustainable development. These guidelines should include

- a clear baseline and a reliable energy reporting and accounting system to properly assess achievements;
- a measurable target outcome for each of the main energy-consuming sectors;
- a focus over a relatively short period on the largest, least-efficient consumers for maximum leverage in energy-efficiency gains; and
- reliance on a two-pronged approach with differentiated policies for efficient use of energy-consuming equipment and the acquisition of new capacity.

A recent study (World Bank, 2017a) recommended acceleration of boiler replacement, fuel switching, and thermal retrofits for heating; enacting and enforcing anti-smog resolutions; and tightening solid-fuel quality standards. These are essential for boiler replacement and fuel switching in single-family buildings and could be supported by the Anti-Smog and Energy Efficiency Fund and subsidies for the poor.

Shifting to a Greener Electricity Generation and District Heating Mixes

Several energy modeling exercises have shown that Poland could meet its long-term energy needs using advanced technology to produce clean fuels derived mostly from RE sources. The scenarios explored indicate that if local and global environmental concerns are to become the basis for investments in technologies for electricity and district heating use and production, the RE share would have to climb to 43 percent in the EU ETS option and 47 percent in the Extended Efforts option.

This important scale-up is driven by the dramatically lowered costs of RE technologies, especially intermittent ones like wind and solar PV. Wind and solar are close to becoming low-cost options, despite their intermittency, and are in general securer sources at centralized and decentralized levels. Recent wind and PV auctions are also driving costs down and it is expected that the results of large-scale auctions would lead to further RE penetration, especially wind and PV, at the centralized and decentralized level. High RE penetration in 2030 to put the sector on a sustainable path would call for integration options to safeguard the safety and integrity of the system.

As previously mentioned, Poland scored very low on the energy/electricity system structure compared to the averages of the 114 countries in the WEF study and the EU28. The low power sector score is not competitive and is compromised by a fragile transmission system, as was made clear by the failure of attempts to transmit power from Germany to Austria. Encouraging communities to rely on local systems to meet their energy demand is the right response to delayed capital-intensive investments in transmission. These efforts could be reinforced by promotion of decentralized rooftop PV. However, this approach has limits because Poland is further integrating into the European grid. With a stronger transmission system well-connected with neighboring countries, Poland could become the hub for power trading between western and eastern European countries and improve the performance of its own power sector.

The generation mix to put electricity on a sustainable path includes more reliance on gas generation, which will increase the flexibility of the system to deal with intermittent RE. In Germany and Denmark, existing coal power plants are retrofitted to increase their flexibility to accommodate more RE in the grids, and should be considered in Poland. For example, coal power plants in Denmark are able to regulate at 3–4 percent per minute, with a minimum 10-percent capacity factor. Denmark also showcases an excellent example of heat storage for coal-based cogeneration plants to increase their flexibility in the winter to accommodate more wind in the grids. These options will ease the integration of RE generation into the system at the early stage of the scale up.

Poland also scored lower than Europe as a whole on infrastructure, business development, and innovation. Scaling up RE technologies to the level of the EU ETS will require not only a stronger transmission network to take advantage of connection with the European system to increase the flexibility of the system but also increased digitization and more sophisticated metering to allow power trading between distributed generators and transmission companies and utilities based on the value

of the kWh to the system. Advanced European countries are moving to net billing after two-way metering was contested by utilities as the share of RE increased significantly in countries like the Netherlands and Germany. Poland's Virtual Storage approach has been successful at this early stage of RE penetration but might face the same problems as two-way metering. Poland should leapfrog to approaches based on the same principles that justified the move to net metering and begin deploying the most advanced metering that would lead to a fair power trade and demand response to optimize use of power assets and empower customers.

The government has an ambitious plan to charter off-shore wind territory. The costs are still significantly higher than for on-shore wind, but Poland can learn from Denmark's use of off-shore wind auction schemes to bring down the costs. International experience also demonstrates that development of off-shore wind takes time; a clear conclusion is the importance of setting up a central agency or one-stop shop services for approval, licensing and permits, spatial planning, and certification, in coordination with other relevant agencies, such as Environment, Maritime, Defense, and TSO (Box 3.1). Otherwise, the fragmented and conflicting approvals from, e.g., ocean, maritime, defense, and environmental agencies could block off-shore wind development.

Finally, increasing natural gas penetration during the transition is important to reduce local air pollution from heating, particularly in the single family buildings, and make the power system more flexible to accommodate more RE.

Making Energy Supply Safer and More Secure

Poland's wish to enhance its energy security is justifiable, but international experience demonstrates that security issues from geopolitical uncertainties, price volatility, and natural disasters are manageable. Furthermore, "a fundamental structural change has occurred in natural gas trade due to: (a) the LNG supply becoming substantially more diversified and

Box 3.1 Preparing for Off-shore Wind Scale up

Costs and Risks of developing Offshore wind are high— careful planning and piloting will reap huge gains for Poland

- Preparing to go offshore and join the leading countries in this field is commendable. Poland could learn much from the successes and failures of other countries. *Clear decisions about the appropriate legal framework in advance of any substantial projects are vital.*
- Envisage pilot and demonstration projects for offshore development. *The aim of initial demonstration should be to gain experience in offshore specific technology and approaches—not to demonstrate turbine technology.*

Two major tasks should be undertaken as soon as possible and their results assessed prior to full-scale development of medium-to-deep offshore programs. They include the preparatory activities to create an enabling environment and demonstration projects. The preparatory activities include at a minimum the following:

- **Defining the legal regime and institutional arrangements:** These should assess current responsibilities and functions of institutions involved in regulating offshore activities and gradually developing a legal and institutional framework that can improve coordination for offshore wind.
- **Addressing grid development and integration issues:** This activity should define appropriate high-voltage connection points and circuits, as well as respective responsibilities, and schedule for development and completion an offshore grid code as an extension of the existing codes and regulations.
- **Developing a database and identifying appropriate sites:** This is particularly crucial for offshore development. This could be achieved through (a) the development of a master GIS that will assemble data on wind speed, undersea and bathymetric data, wave height, and so forth; (b) the initiation of wind speed measurements and computational model studies using a standardized (national) approach in consultation with industry; and (c) requirement of at least 12 months of wind measurements on site prior to preparation of the feasibility study.
- **Determining government support for a two- to three- year program:** This would preferably be done through developing prefeasibility level cost estimates for select projects and determining the level of government support and incentives.

The demonstration project and knowledge building task require the following:

- **Pilot projects (for immediate development):** Two to four potential sites should be selected and wind measurements conducted for at least 12 months to begin pilot projects. The projects should be in the range of 30–50 MW with approximately 10 turbines. The objective at this stage is to gain knowledge and experience on foundations, logistics, erection, and maintenance. The government support is expected to be higher for these projects.

competitive with the entrance of two new big players (US and Australia); (b) LNG becoming an avenue for internationalization of the gas market; and (c) LNG providing a benchmark price for international gas trade even in the cases that do not involve long-distance transportation of gas” (Razavi, 2018) Poland has taken advantage of these structural changes by signing the first contract for importing LNG from the United States and is exploring how to secure another source of supply.

Energy supply uncertainties and risks can be mitigated and effectively addressed with a comprehensive national energy policy that stresses supply diversity, energy efficiency, RE, and a more market-oriented oil and gas

sub-sector to attract needed investments and technologies.

Creation of a path to greener development in an economy dependent on coal will require innovative actions to reconcile energy supply security with environmental protection and to reinforce international cooperation in using the most advanced energy technologies.

Deployment of local RE resources on a large scale and achieving energy efficiency gains are among the most cost-effective solutions to mitigate supply uncertainties, and risks. They would also reduce damaging local pollution and help meet Poland’s commitment to combat climate change. Aggressive deployment of these technologies would attract investments

and create opportunities for high-skilled jobs in manufacturing and lower-skilled jobs in maintaining RE assets, especially PV systems.

Strengthening the transmission system would not only improve integration into the grid of renewable electricity generation but also make the supply more reliable. Developing the transmission system on an ad hoc basis would lead to unpredictable disruptions.

Building up the transmission system also provides an opportunity to better protect the installations, change the design of power systems, and develop measures to minimize restoration time. Digitization is essential to produce the data necessary to efficiently manage the electricity sector and meet consumer requirements. All these considerations will, however, raise the construction and operating costs of power systems. Safety of the installations entails that “the usual economic considerations may have to be strained to new limits, and in some instances ignored” (Pansini 2004).

Providing Displaced Coal Miners with Social Safety Nets and Access to New Jobs

Despite past waves of restructuring, coal regions continue to depend on the sector as a source of direct and indirect jobs. While the results of this report show that the aggregate impacts of a reduction in coal employment and production are negligible, they are not equally distributed. Coal regions and unskilled coal workers may suffer disproportionately. Thereby, the political economy aspects of the coal transition should not be disregarded. The role of trade unions and their importance for Silesia’s cultural identity imply that from a political economy perspective, even relatively small job losses may create substantial resistance.

Nevertheless, one overarching message emerged in Chapter 3: Poland’s demographic aging may do most of the work in accelerating the transition away from coal.¹² Young cohorts

entering the labor market are rapidly getting smaller, making it increasingly harder for coal mines to recruit the workers they need to keep their labor force constant. Moreover, younger cohorts are significantly more skilled than older cohorts, and the coal industry may not offer the jobs they aspire to. For instance, in 2030 the share of young male workers without a college degree is expected to be less than half that of 1995. Moreover, a simple labor demand and supply model suggests that coal wages, which are already substantially higher than the average for Poland, would go up even more as the supply of potential coal workers shrinks, and higher labor costs would challenge the financial situation of the sector even more.

The rest of this chapter offers policy recommendations based on the findings of this report and the lessons learned compiled in the report *Managing Coal Mine Closure: Achieving a Just Transition* (World Bank, 2018d)

Policies drafted should take into account the fact that reductions in coal employment affect workers at different stages of their careers. While early retirement would be an option for older workers, options to facilitate the transition of younger workers to new jobs would be necessary. In Poland, more than 90 percent of coal workers are 54 or younger (Figure 3.5 a). Since coal workers may retire in their 40s, about half may qualify for early retirement options. Young workers not fully invested in the coal sector would be more likely to engage in training or be re-employed locally or elsewhere. In Poland, workers aged 15 to 24 represent only about 5 percent of all coal workers. Middle-age workers, who constitute about a third of coal workers, are more tied to the community and may therefore require more assistance to cope with joblessness.

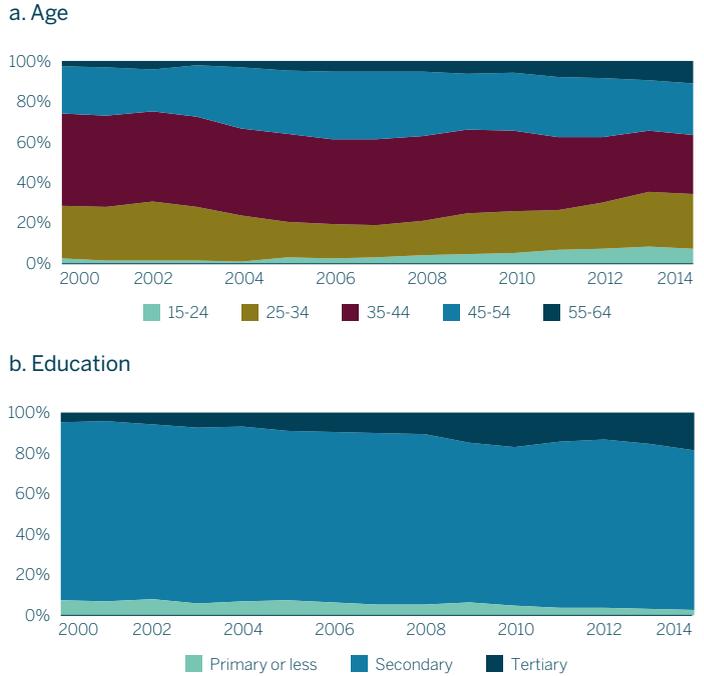
It will be important to assess the skills and competences of those who will lose their jobs, and they should be given enough notice to plan the transition ahead of time. Since about 90 percent of coal workers are high school graduates (Figure 3.5 b), assessing their skills

12. This hypothesis is confirmed by Witajekowski-Baltvilks et al. (2018)

for re-employment elsewhere may be necessary. It is recommended that social service programs be launched before workers leave their jobs to (a) establish eligibility, and assess interest in, temporary income support, ALMPs, or retirement options; (b) profile worker skills to inform each of appropriate training and assistance options; and (c) provide initial job counseling and placement services, preferably at the work site.

Silesia is much more diversified today than it was 20 years ago and can well absorb less-skilled coal workers. Since coal jobs require a spectrum of skills, those with a technical or college degree would also have good chances of finding a job in another sector or region, but the skills of most workers in the sector may be less transferable. Their jobs disproportionately involve such routine manual tasks as controlling machines and processes and making repetitive physical motions and such nonroutine manual tasks as operating vehicles, mechanized devices, or equipment, and performing work that requires manual dexterity. Nevertheless, a large fraction of jobs in Silesia also rely heavily on routine manual skills, such as manufacturing jobs in the auto, metallic and non-metallic products, chemicals, pharmaceuticals, wood and paper products, and furniture industries (Figure 3.6 a). Jobs in construction, transport, and storage also require nonroutine manual skills similar to those in the coal sector (Figure 3.6 b).

Figure 3.5 Characteristics of Coal Workers, 2000–2014, Percent

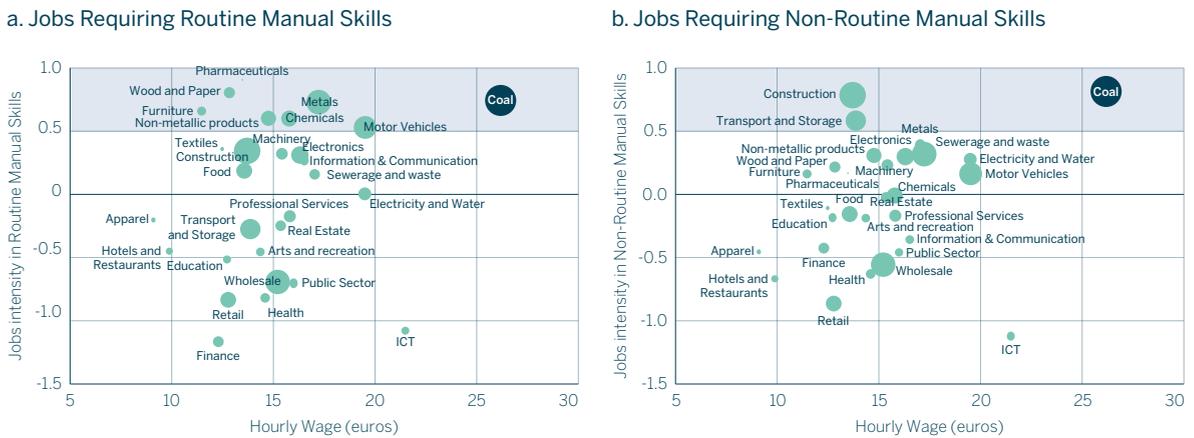


Source: LFS data.

Note: The data only identify mining generally. However, this was used as a proxy for coal workers because they represent the majority of mine workers.

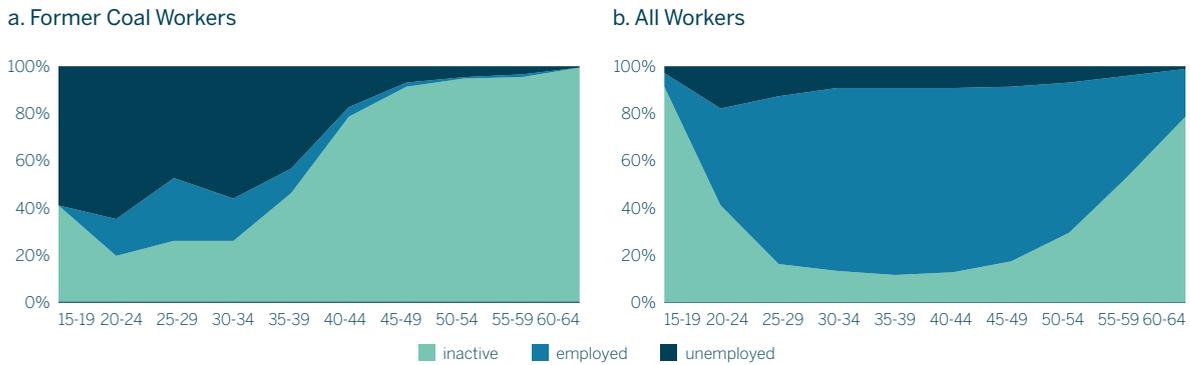
transport, and storage also require nonroutine manual skills similar to those in the coal sector (Figure 3.6 b).

Figure 3.6 Feasible Job Opportunities for Coal Workers in the Silesian Region



Note: Each bubble shows the average skill intensity of jobs and the average hourly wage of each sector. The sample consisted of male workers in Silesia with a high school education, aged 20 to 39 years. The size of the bubble is proportional to the number of jobs in the sector. The blue rectangle highlights jobs with skill requirements similar to those of the coal sector. Skill intensity is measured using the Acemoglu and Autor (2011) methodology. The task content of jobs from O*NET is applied to the 3-digit ISCO 08 occupational classification from the Structural Earnings Survey (2010).

Figure 3.7 Labor Market Outcomes, Former Coal Workers and Other Workers. By Age, Percent



Source: Data from LFS 2000–2014.

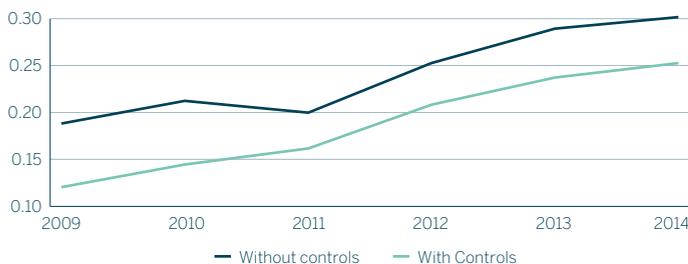
An important factor that may deter the transition of coal workers to jobs in other sectors is a large pay gap—coal mine hourly wages tend to be substantially higher than hourly wages in other sectors. In fact, in Poland former coal workers, even young ones, are more likely than the average to remain economically inactive. While nationally only about 10 percent of all Polish people aged 40 to 44 are not working or looking for a job (Figure 3.7 a), 80 percent of former coal workers in the same age group are inactive in the labor market (Figure 3.7 b). To increase the incentives for coal workers to remain economically active, redundancy payments may not be conditional on employment status—a lesson learned from the Mining Social Package’s redundancy payments, which used to contain a conditional payment that was reduced for those who found a job. Since

about one-third of beneficiaries had no interest in looking for a job, the package introduced in 2015 removed the conditionality clause to strengthen worker incentives to remain economically active after leaving the coal mines (Witajekowski-Baltvilks, 2018). In addition to removing the conditionality clause, redundancy payments may be phased out gradually to smooth the transition out of coal.

Coal wages are not only high but have been rising over time, even when comparing coal and non-coal workers with the same characteristics, such as educational attainment (Figure 3.8). In addition to encouraging inactivity among former coal workers, this has other unintended consequences: (a) It weakens incentives to invest in human capital, as the coal wage premium tends to reduce the returns to education (Black, McKinnish, and Sanders (2005)). (b) It may increase labor costs in industries where unskilled manual labor is in demand because they may have to bid higher to attract workers. Ensuring that future growth in coal wages tracks labor productivity growth would facilitate the transition of workers and regions as coal employment falls. This could be achieved by tying wage growth to indicators of coal production per worker at the mine level, or by using measures of regional value added per worker from the official statistics.

ALMPs are an important tool for re-employment of former coal workers. These typically have three components, used alone or in combination: First, employment services are effective

Figure 3.8 The Coal Wage Premium



Note: Each line shows the earnings premium associated with working in the coal sector. The vertical axis is the change in the probability of being in the top 60 percent of the earnings distribution in 2008. The coefficients are estimated using OLS and are all statistically significant at the 1 percent level. Controls include age, education, gender, and region fixed effects. Winkler (forthcoming) shows the regression tables for different specifications using the pooled sample.

tive for displaced workers who have skills that are in demand but who need help accessing the demand. These services include labor exchange services that can refer workers (e.g., electricians, security guards) to non-coal industries; vocational counseling to assess individual interest in and aptitude for a different occupation; and transit assistance to facilitate migration to regions with better labor market prospects. Encouraging the use of the public employment office to search for jobs could be beneficial for former coal workers, who are less likely to do so than others who are unemployed. This could be promoted on-site before they leave their jobs.

Second, institutional or on-the-job training is necessary when the skills of displaced workers do not match employer needs. Only 22 percent of former mining workers aged 20–24 who are not currently employed attend school, compared to about 65 percent of other jobless individuals of the same age. The gap is also significant for workers aged 25–29. To improve the employability of displaced workers, it is important to create the right incentives for former coal workers to return to school. This policy could be particularly effective if targeted to younger workers without family responsibilities who are still not fully invested in the coal sector. For older workers who are the main providers in the family, more flexible options combining more specific skills training with on-the-job learning may be a better fit.

Third, services to support small businesses could be offered if some displaced workers cannot find jobs despite a strong labor demand. The most common services are technical assistance, micro credits and grants, and small business incubators that offer an entrepreneurial environment, professional networking, and mentoring opportunities all in one place.

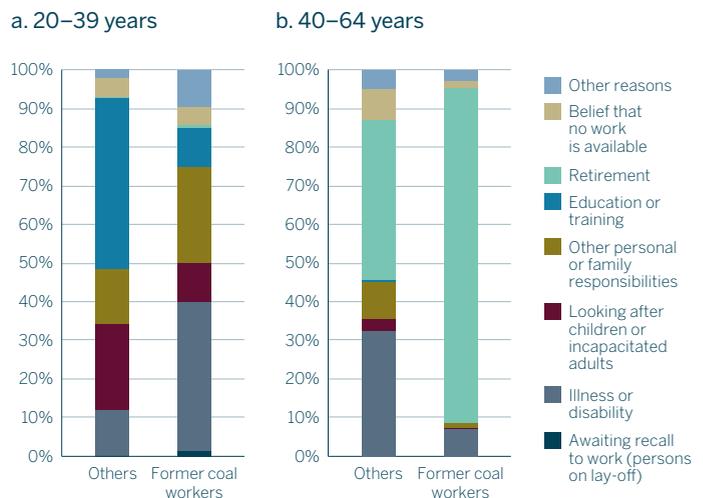
Fostering the creation of clean energy jobs can also support re-employment of displaced coal workers. The potential of this policy should not be underestimated. According to some calculations, improving the energy efficiency of residential buildings in Poland can create as many as 100,000 jobs a year (Lewandowski, 2018). More importantly, most of this increase in labor demand would be directed to unskilled

workers, who are the bulk of those displaced when coal mines close.

Migration is another important mechanism to cope with labor market displacement in Poland because former mining workers who move to another location are more likely to be employed than those who stay behind. However, only prime-age workers with secondary or tertiary education seem to use this strategy. Providing assistance to overcome credit constraints and lack of information about jobs in other regions for workers with less education or with mobility barriers may be an effective way to facilitate their re-employment elsewhere.

Because coal mine jobs can undermine worker health, it will be important to understand whether the reluctance of young displaced coal workers to re-enter the labor market is due to a high reservation wage, discouragement, or inability to work due to disability or illness. In fact, in Poland almost 40 percent of former coal workers aged 20–39 are inactive for health reasons (Figure 3.9). It will be important to provide a safety net for this group. Disability seems less prevalent for coal workers aged 40 to 64 years, but this could be driven by the fact that they are entitled to a pension, and thereby they may report being “retired” even if they are unable to work for physical reasons.

Figure 3.9 Reasons for Inactivity, Former Coal Workers and Other Workers, by Age Group, Percent



Source: Data from LFS 2000–2014.

Minimizing Spillover Effects

Previous coal mine closures had negative but small effects on local labor markets. Some workers coped by moving to other regions, but this did not prevent employment rates from declining in the affected areas. The spillover effects of coal mine closures on migration and employment affect municipalities within a 10–20 km radius from the coal deposits (Winkler, forthcoming). Taking into account employment in nontradable sectors that depend heavily on the purchasing power of the local community, the spillover effects reach as far as 100 km away from the coal deposits.

In contrast to these adjustments to employment levels, in coal regions wages have remained mostly stagnant. When wages are rigid, most adjustments to a labor market shock take place through changes in employment levels. This has serious implications for the distributional incidence of the shock. If all the adjustment takes place through a decline in employment, the shock is mostly experienced by those who lose their jobs. But if local wage levels also fall in response, the negative

impacts are more equally distributed across the local population. It would be important to stimulate dialogue in local communities to provide workers and firms with more options about how to respond to a decline in coal production. Layoffs do not have to be the only option; local communities may prefer a temporary wage freeze or a reduction in the number of hours of work while coal miners search for jobs outside the sector. Where this is the case, laws and regulations may have to adjust accordingly. Another major reason to promote wage flexibility is that affected areas would benefit from a more competitive manufacturing sector.

Policies targeted to helping regions affected rather than workers should be carefully designed. Large subsidies or other benefits could have the unintended consequence of postponing—instead of preventing—the negative effects of a reduction in coal employment. If they raise prices and labor costs, these policies can damage the competitiveness the region needs to support a successful manufacturing sector. In contrast, policies to protect workers are less distortionary and better targeted to those who need assistance most.

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ANNEX 1

Poland: Energy Efficiency and Renewable Energy Policies¹³

(Source: IEA Polish Energy Policy until 2030)

#	Title	Year	Policy Status	Policy Type	Policy Target
1	Loans from the National Fund for Environmental Protection and Water Management	2015	In force	Economic instruments; fiscal and financial incentives; loans	Industry; industrial processes, residential appliances, energy utilities, Co-generation of Heat and Power
2	Act on obligation to provide information on energy consumption by energy-using products	2015	In force	Regulatory instruments, other mandatory requirements	Multisectoral policy
3	National Energy Efficiency Action Plan for Poland, 2014	2014	In force	Policy support	Multisectoral policy
4	Elimination of low-emission sources through support of energy efficiency and development of dispersed renewable energy sources. Part 2: pilot program KAWKA	2013 (Feb 28 th)	In force	Economic instruments; fiscal and financial incentives; grants and subsidies	Multisectoral policy, existing buildings, buildings Building code, energy performance, buildings Building type—residential, buildings Nonresidential—new buildings
5	Energy-efficient street lighting	2013	Ended	Economic instruments: fiscal and financial incentives, grants and subsidies; economic instruments: fiscal and financial incentives, loans	Lighting
6	Energy-efficient houses	2013	In force	Economic instruments: fiscal and financial incentives; grants and subsidies	Buildings: existing and new Building type: residential
7	Low-emission urban transport: GAZELA BIS	2013	In force	Economic instruments: fiscal and financial incentives; grants and subsidies	Transport: Transport systems; infrastructure
8	Energy-efficiency target declared in response to the EU Directive (2012/27/EU)	2013	In force	Policy support: strategic planning	Multisectoral Policy

13. <https://www.iea.org/policiesandmeasures/pams/poland/name-24723-en.php>

#	Title	Year	Policy Status	Policy Type	Policy Target
9	Energy-Efficient Public Buildings: LEMUR	2013	In force	Economic instruments: fiscal and financial incentive; grants and subsidies; loans	Buildings: nonresidential Buildings: residential
10	Report summarizing energy-efficiency measures implemented in Polish voivodeships, 2008–11	2013	In force		Buildings: existing buildings Multisectoral policy
11	Second National Energy Efficiency Action Plan (2011)	2012	In force		Multisectoral policy
12	Sustainable Energy Financing Facility (PoSEFF ²)	2011 (updated 2015)	In force	Economic instruments: fiscal and financial incentives; loans	Multisectoral policy
13	Energy Efficiency Act of 15 April 2011	2011	In force	Information and education: information provision; regulatory instruments Economic instruments: market-based instruments; white certificates	Multisectoral policy
14	Executive orders to the Energy Efficiency Act - connected with the white certificate scheme	2011	In force	Policy support	Multisectoral policy
15	Energy Efficiency in Industry program	2011	Ended		Industry
16	Energy loan for energy saved	2010	Ended	Economic instruments: fiscal and financial incentives; loans Economic instruments: market-based instruments	
17	National Environmental Policy for 2009–12 and the 2016 outlook	2009	In force	Policy support: strategic planning	Multisectoral policy
18	Program for renewable energy and high efficiency cogeneration projects	2009	Ended	Economic instruments: fiscal and financial incentives; loans	Energy utilities: CHP
19	Polish Energy Policy until 2030	2009	In force	Policy support: strategic planning	Industry: industrial subsectors; cross-industry; energy utilities Multisectoral policy

#	Title	Year	Policy Status	Policy Type	Policy Target
20	Green Investment Scheme (GIS)	2009	In force	Economic instruments: fiscal and financial incentives; grants and subsidies Policy support: institutional creation Economic instruments: market-based instruments; greenhouse gas emissions trading	Multi-Sectoral Policy
21	Act on making available information on the environment and its protection, social participation in environmental protection and on environmental impact assessments	2008	In force	Information and education: information provision Policy support: institutional creation	Multisectoral policy
22	Energy Efficiency Action Plan	2007	In force	Policy support: strategic planning	Multisectoral policy
23	Red Certificate System	2007	In Force	Economic instruments: market-based instruments	
24	Act on electricity production from cogeneration	2007	Ended	Regulatory instruments' monitoring	Energy utilities: CHP
25	Energy Policy of Poland Until 2025	2005	Superseded	Policy support: strategic planning	
26	Poland 2025—Long-term Strategy for Sustainable Development	2000	Ended	Policy support: strategic planning	Multisectoral policy
27	Baltic Energy Efficiency Group (BEEG)	1998	Ended	Policy support: strategic planning; institutional creation Information and Education: information provision	Multisectoral Policy
28	Energy Law Act	1997	In force	Regulatory instruments: other mandatory requirements; obligation schemes	Multisectoral policy

ANNEX 2

Assumptions for the Electricity Planning Model for Poland

The study team gathered data used in the model from government reports, special studies, specialized databases, and interviews. The following tables provide the data for load, generators, fuel prices, environmental parameters, and mines.

Load and Energy Assumptions

Table A2.1 shows expected demand through 2030. The medium gross demand growth is compatible with the Polish Transmission System Operator (TSO) analysis through 2030.

Table A2.1 Gross Energy Growth Projections

Year:	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Medium: [TWh]	175	176	178	180	182	185	187	190	193	195	198	202	205

Data Assumptions on Generators

Table A2.2 Generation Characteristics and Costs by Generator Type

	Number of Plants	Capacity MW	CAPEX per kW \$/kW	FOM per MW \$/MW-yr	VOM	Efficiency %	CF max %
Existing Plants							
TPP Coal	91	218		50,000	2.5	36	0.79
TPP Gas	5	259		27,000	1.5	40	0.85
TPP Lignite	32	287		50,000	3.0	38	0.66
TPP Coking Coal	1	320		50,000	2.5	32	0.69
TPP Municipal Waste	1	24		80,000	2.5	29	0.80
TPP Oil	1	347		25,000	2.5	31	0.84
TPP Biogas	1	230		80,000	0.0	28	0.69
TPP Biomass	3	278		80,000	2.5	34	0.85
Hydro Run of River	16	61		45,000	0.0	100	0.35
Photovoltaic (PV)	17	12		12,000	0.0	100	0.18
Wind On-Shore	16	376		40,000	0.0	100	0.29
Power Import	1	500		0	0.0	100	0.98
Heating-only Boilers (HOB)	37	946		16,203	3.9	83	0.36

	Number of Plants	Capacity MW	CAPEX per kW \$/kW	FOM per MW \$/MW-yr	VOM	Efficiency %	CF max %
Plants Being Built							
TPP Coal	9	465	1,597	50,000	2.3	41	0.78
TPP Gas	6	349	745	27,000	1.7	52	0.85
TPP Lignite	1	485	2,016	50,000	3.0	45	0.71
TPP Municipal Waste	2	40	3,048	80,000	2.5	28	0.80
Possible New Capacity							
TPP Coal			1,429	50,000	2.5	47	0.84
TPP Gas			921	27,000	1.9	56	0.85
TPP Lignite			2,000	50,000	3.0	46	0.81
TPP Municipal Waste			3,048	80,000	2.5	28	0.80
TPP Biomass			2,000	80,000	5.0	33	0.84
PV			1,024	12,000	0.0	100	0.18
Wind Offshore			3,192	90,000	0.0	100	0.40
Wind On-Shore			1,318	40,000	0.0	100	0.29
HOB Gas			100	10,000	2.0	95	0.50
HOB Biomass			500	18,500	5.0	91	0.50

Table A2.3 shows average emission factors for each power plant type. The CO₂ emission factors are adapted from KOBIZE (2018), and the emission factors for SO_x, NO_x, and PM are calculated using average fuel heat content, power plant efficiency, and average pollutant content in power plant exhaust. These values are summarized in Table A2.4.

Table A2.3 Pollutant Emission Factors by Generator Type, Ton/MWh

	CO ₂	PM	NO _x	SO ₂
Existing Plants				
TPP Coal	0.8464	0.00007	0.0007	0.0009
TPP Lignite	0.9391	0.00014	0.0015	0.0020
TPP Gas	0.4472		0.0005	
HOB	0.4138	0.00039	0.0008	0.0026
Plants Being Built				
TPP Coal	0.7630	0.00002	0.0004	0.0006
TPP Lignite	0.7446	0.00004	0.0008	0.0012
TPP Gas	0.3429		0.0003	

	CO ₂	PM	NO _x	SO ₂
Possible New Capacity				
TPP Coal	0.6263	0.00002	0.0003	0.0005
TPP Lignite	0.7284	0.00004	0.0008	0.0011
TPP Gas	0.3106		0.0003	
TPP Biomass		0.00003	0.0008	0.0004
HOB Gas	0.1758		0.0002	
HOB Biomass		0.00001	0.0003	0.0001

Environmental Parameters

Emissions costs and total emissions are compiled separately. Damage costs for local pollutants, based on Štreimikienė (2015) and EEA (2014), are expressed in \$/ton of pollutant. Table A2.6 shows the emissions costs for NO_x, SO_x and total particulate matter (PM) using the 2010 values in Table A2.5.

Table A2.7 shows the evolution of the CO₂ based on the latest World Bank guidelines for economic analysis. The model is evaluated using the low price estimation.

Table A2.8 sets out the Polish power and heating sector emissions of CO₂ and local pollutants. Total PM, NO_x and SO_x are drawn from European databases.

Table A2.4 Costs of Damage Caused by Local Pollutants

	-Poland \$/ton
2010	
NH ₃	15,247
NMVOC	592
NO _x	7,712
SO ₂	8,219
PM	30,344
2020	
NH ₃	10,740
NMVOC	161
NO _x	11,250
SO ₂	9,594
PM	29,220

Table A2.5 Abatement Costs for Global and Local Pollutants

Pollutant	Environmental Costs [\$/ton]
NO _x	7,712
SO ₂	8,219
PM	30,344
CO ₂	30

Source: Štreimikienė 2015.

Table A2.6 World Bank Future CO₂ Prices
\$/ tCO₂e, Constant Prices

Year	Low	High	Average
2017	37.0	75.0	56.0
2018	38.0	77.0	57.5
2019	39.0	78.0	58.5
2020	40.0	80.0	60.0
2021	41.0	82.0	61.5
2022	42.0	84.0	63.0
2023	43.0	86.0	64.5
2024	44.0	87.0	65.5
2025	45.0	89.0	67.0
2026	46.0	91.0	68.5
2027	47.0	94.0	70.5
2028	48.0	96.0	72.0
2029	49.0	98.0	73.5
2030	50.0	100.0	75.0

Source: World Bank: Guidance Note for Economic Analysis
(World Bank, 2017c)

Table A2.7 Local and Global Energy Pollutant
Emissions

Source	Year	CO ₂ [mt]	Total PM [kt]	NO _x [kt]	SO _x [kt]
OECD Stats Air Emissions	2016		34	192	274
ETS data	2016	153.7			
ETS data	2015	153.7			
ETS data	2014	152.3			

Mine Production Assumptions

Generators that use different types of coal may be supplied domestically or by imports. Polish mines are characterized by estimated reserves, annual production rate, minimum staff needed for operations, and the cost per ton. TableA2.8 shows the averages for these. The minimum amount of coal extracted is also established, but the average is not shown because it is mine dependent.

A matrix connects these mines to the generation plants that use coal, and the relationship is characterized by the price of coal and the costs of transportation to the plant.

Table A2.8 Characteristics of Polish Mines

Fuel	Number of Mines	Reserves Mt	Production Rate t/year	Staff Per Thousand Tons pp/1000t	Cost Per Ton \$/t
Local coal	21	2,784	63,124,168	23.8	82
Lignite	6	935	63,800,000	2.0	15
Coking coal	7	465	14,031,220	8.8	100

Pricing Assumptions

Fuel prices and power imports are mainly drawn from the IEA WEO (2017) report and the IRENA Biomass Report (2014).

Power imports are priced based on the day-ahead market clearing prices for Germany and Austria shown in the PHELIX index Day Ahead Prices (EPEX 2018).

Table A2.9 Fuel Costs, \$/MBTU

Fuel	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Local coal	2.9	3.2	3.3	3.5	3.7	3.8	4.0	4.2	4.4	4.5	4.7	4.8	4.9	5.1
Imported coal	3.8	3.8	4.0	4.2	4.4	4.6	4.8	5.1	5.3	5.5	5.6	5.8	5.9	6.1
Lignite	2.1	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	2.6	2.7
Coking coal	3.9	4.2	4.5	4.9	5.2	5.6	6.0	6.4	6.8	7.0	7.2	7.4	7.6	7.8
Oil	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2	23.2
Gas	5.2	5.7	6.2	6.7	7.2	7.7	8.3	8.9	9.4	9.8	10.2	10.6	10.9	11.3
Biomass	9.1	9.9	10.6	11.4	12.1	12.9	13.7	14.4	15.2	15.9	16.7	17.5	18.2	19.0

Source: IEA New Policies Scenario in WEO 2017.

ANNEX 3

Computable General Equilibrium Model for Poland

The general equilibrium model applied in simulating energy transition in Poland is a multisector, sequential dynamic general equilibrium model. It is designed to assess the impact energy reforms may have on the labor market in Poland. Three factors are considered: (1) Closure of coal mines has an immediate direct impact on employment as coal workers become jobless. (2) This initial direct impact can have negative ramifications on other sectors that trade as buyers or suppliers of products and services with the coal industry. (3) The ultimate impacts depend on the extent to which the economy can absorb the initial shock. The model makes it possible to consider heterogeneous impacts on different types of workers, across such dimensions as age, gender, and education level.

The main features described here relate to the modeling of the energy demand and labor market blocks.¹⁴

The Production and Demand Block

The economy is disaggregated into 15 sectors. Within sector, production factors are subdivided into capital, energy, and two labor categories, unskilled and skilled.

The production function is nested (Figure A3.1). At the highest level, the production of each sector is assumed to be a Leontief function (complementarity between output and inputs) of value-added and non-energy intermediate consumption. Demand for capital, energy, and the two skill levels is modelled through a nested constant elasticity of substitution (CES) function

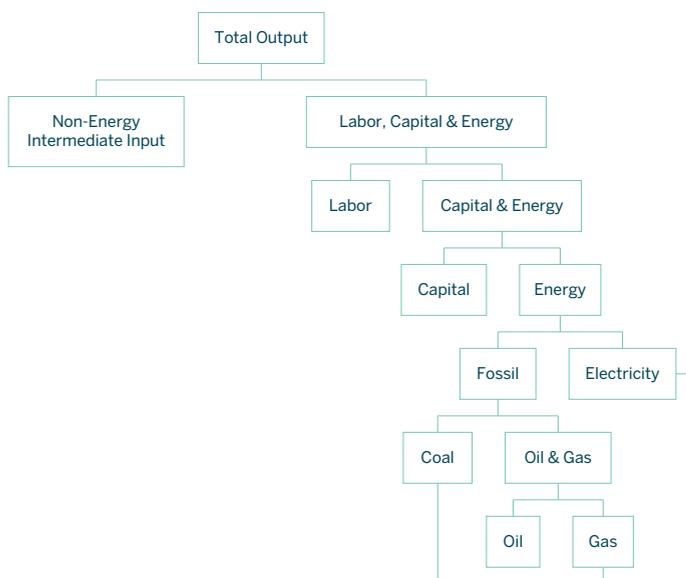
at two levels, which makes it possible for the different factors to have differentiated elasticities of substitution.

The capital-energy bundle is also decomposed into capital and energy following a CES function. At the next level, energy is a CES function of fossil energy and electricity. Finally, fossil energy is a CES function of coal and oil and gas.

The labor side of the production function is also decomposed, first in two labor bundles by education (unskilled: from no education to lower secondary; skilled: from higher secondary to tertiary). The second CES function allows the imperfect substitution between workers by age (young workers are aged up to 35; old workers are 36 and above). Finally, the analysis also considers the imperfect substitution of workers by gender.

At the macroeconomic level, wages are set by skill following a curve that allows a trade-off

Figure A3.1 The Production Function and Energy Demand



14. For a detailed description of the other blocks of the model see Marouani and Robalino (2012), "Assessing Interactions among education, social insurance and labor market policies in Morocco," *Applied Economics*, volume 44, No 24, pp. 3149-3167

between wages and unemployment. Sectoral wages are linked to macroeconomic wages by exogenous wage differentials that reflect differences in productivity. Defined for each sector and skill are eight exogenous wage differentials based on skill, age, and gender.

The model has four closures: a macro closure, a government closure, an external balance closure, and a labor market closure. The macro closure is savings-driven (marginal propensity of households to save is exogenous). The government closure consists in fixing government spending as a constant share of GDP and tax rates and leaving the budget balance endogenous. An alternative could also be to fix the government budget balance and leave government spending endogenous. The foreign balance closure consists in fixing the exchange rate and leaving the current account balance endogenous. Finally, the labor market closure consists in a joint determination of unemployment and average formal wage through the wage curve.

The model dynamics are sequential. Capital accumulation is sectoral. Each year the stock of capital of each sector corresponds to the sum of the stock of last year plus new investment and minus depreciation. Sectoral investment is modeled as a function of the sectoral stocks of capital, sectoral rates of return to capital, and capital acquisition costs.

The Data

The Social Accounting Matrix (SAM) was built using 2011 data from the Global Trade Analysis Project (GTAP) global database. The correspondence between the GTAP and LFS classifications, given the study's focus on energy issues, explains the decision to aggregate the SAM in 15 sectors (administration, agriculture, coal, business, communication, construction, electricity, finance, manufacturing, mining, real estate, trade, transport, and water).

Employment data are from the Labor Force Survey (LFS) of 2011, and wage data from EUROSTAT (EU-SILC 065) because the LFS has information only on wage deciles. Because the classification is not similar, it was necessary to make some hypotheses, for example that wages in coal and other mining activities are the same.

