TRANSITION TO A LOW-EMISSIONS ECONOMY IN POLAND

The World Bank
Poverty Reduction and
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Europe and Central Asia Region

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ESMAP
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THE WORLD BANK
POVERTY REDUCTION AND ECONOMIC MANAGEMENT UNIT

EUROPE AND CENTRAL ASIA REGION

FEBRUARY 2011

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ACRONYMS AND ABBREVIATIONS

BAU	Business-as-usual
CCS	Carbon capture and storage
CDM	Clean Development Mechanism
CES	Constant elasticity of substitution
CGE	Computable General Equilibrium
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DSGE	Dynamic Stochastic General Equilibrium
EAs	Emission Allowances
EC	European Commission
EE	Energy efficiency
EERP	European Economic Recovery Package
EIA	US Energy Information Administration
EITE sectors	Energy-intensive and trade-exposed sectors
EOR	Enhanced Oil Recovery
EU	European Union
EU10	Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia
EUROSTAT	the statistical office of the European Union
ETS	Emissions Trading Scheme of the European Union (also, the sectors included in the trading scheme)
GDP	Gross domestic product
GHGs	Greenhouse gases
GTAP	Global Trade Analysis Project database
GUS	Główny Urząd Statystyczny, or Poland’s Central Statistical Office
GW	Gigawatt (1000 MW)
GWh	Gigawatt hour
HEV	Hicksian equivalent variation
HVAC	Heating, ventilation, and air conditioning
IBS	Instytut Badan Strukturalnych, or Institute for Structural Research, Warsaw, Poland
IGCC	Integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
KASHUE-KOBiZE	National Administration of the Emissions Trading Scheme-National Center for Emission Balancing and Management
KLEMS	EU database on capital (K), labor (L), energy (E), materials (M) and service inputs (S) productivity
LULUCF	Land use, land-use change and forestry
MAC	Marginal abatement cost
MacroAC	Macroeconomic abatement cost
MacroMAC	Macroeconomic marginal abatement cost
MicroMAC	Microeconomic marginal abatement cost
MEMO model	Macroeconomic Mitigation Options model
MIND module	Microeconomic Investment Decisions module
$MtCO_2e$	Millions of metric tons of CO_2 equivalent
MWh	Megawatt hours
NPV	Net present value
Non-ETS	Sectors not covered by the ETS system
OECD	Organization for Economic Co-operation and Development
PIT	Personal income tax
PL	Poland (abbreviation used in figures)
PPS	Purchasing power standard
ppm	Parts per million
R&D	Research and development
ROCA model	Regional Options of Carbon Abatement model
Solar PV	Solar photovoltaic power
TREMOVE	EU traffic and emissions motor vehicle model (approximate)
tCO_2e	Metric tons of CO_2 equivalent
toe	Tons of oil equivalent
UNFCCC	United Nations Framework Convention on Climate Change
VA	Value-added
VAT	Value-added tax

CONTENTS

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EXECUTIVE SUMMARY

After 500 years, [global average temperature] is projected to increase by 6.2°C over the 1900 global climate. While we have only the foggiest idea of what this would imply in terms of ecological, economic, and social outcomes, it would make most thoughtful people – even economists – nervous to induce such a large environmental change. Given the potential for unintended and potentially disastrous consequences, it would be sensible to consider alternative approaches to global warming policies.

*William Nordhaus, 1997**

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* Nordhaus, W. (1997), "Discounting in economics and climate change," Climatic Change (37, 315–328).

This study on Poland is part of the World Bank's series of low-carbon growth studies. It poses the question of how Poland, an EU member state, an industrialized 'Annex I' country for the purposes of international climate discussions,[1] and an OECD member, can transition to a low emissions economy as successfully as it underwent transition to a market economy in the early 1990s. With a broad consensus that global coordinated action is needed to prevent dangerous climate change (estimated to cost about 1 percent of global GDP) and with EU policies on climate change already in place, Poland faces immediate policy challenges. Could the country commit to more ambitious overall greenhouse gas mitigation targets for the longer term—to 2030 and beyond? What technological options are available, and how expensive are they compared with existing technologies? Would there be high costs in lost growth and employment? Over a shorter horizon, to 2020, what are the implications for Poland of implementing EU policies on climate change? The report addresses these questions while advancing the approach of the Bank's low carbon studies by integrating 'bottom-up' engineering analysis with 'top-down' economy-wide modeling. [2]

The main findings of the report are:

- Poland can cut its greenhouse gas emissions by almost a third by 2030 by applying existing technologies, at an average cost of €10 to 15 per ton of carbon dioxide equivalent[3] abated.
- Costs to the economy will peak in 2020; but by 2030, the shift towards low emissions will augment growth. Overall, this abatement will lower GDP by an average one percent through 2030 from where it otherwise would have been.
- The economic cost in output and employment of Poland's required abatement by 2020 under EU rules is higher than for the average EU country; and the restrictions on emissions trading between sectors aggravate that cost.
- The energy sector currently generates near half of Poland's emissions; but the transport sector—with precipitous growth and the need for behavioral change in addition to the adoption of new technologies—may end up posing the tougher policy challenge.

Global concern

There is a broad consensus that an international coordinated response to the threat of climate change is needed. Evidence that the world is warming and that human activity is primarily to blame has continued to accumulate in recent years, as has the understanding that a lack of action will impose very high costs, especially on poorer countries. Under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), richer countries, including Poland, committed to reduce greenhouse gas emissions by about 5.2 percent during 2008-12 compared to 1990; and the climate summits in Copenhagen and Cancun were to make progress on post-2012 emission targets and their allocation. While Europe will not be among the worst harmed, the European Union has taken a proactive stance within the international community's ongoing negotiations by setting a unilateral target of a 20 percent reduction in emissions by 2020. Thus, EU members such as Poland already face specific obligations for climate action. However, Poland faces a particular challenge in CO_2 (carbon dioxide) mitigation because of its heavy reliance on abundant domestic coal.

Poland's greenhouse gas emissions

Poland is not among the largest emitters of greenhouse gases globally, but its economy is among the least emissions-efficient in the EU. Poland's global share in greenhouse gas (GHG) emissions is just 1 percent; and its per capita emissions are similar to the EU overall. With its 10 tons of CO_2e per capita in 2007, Poland is exactly at the level of the EU average, but given its lower income level, the Polish economy comes out as among the least emissions-efficient. Poland's transition to a market economy since 1989 had a co-benefit of sharply reduced CO_2e emissions; however, the link between growth and emissions has re-emerged in recent years. A critical difference in the make-up of Poland's emissions is the dominance of the power sector and its extraordinary dependence on coal. Over 90 percent of electricity in Poland is generated from coal and lignite, the highest share in the EU, and which makes Poland an outlier in both Europe and globally (see Executive Summary Figure 1). Outside the energy sector, Poland's transport sector has experienced very high rates of emission growth, and energy efficiency, although considerably improved over the past 20 years, has not yet reached Western European standards. Despite dramatic advances during 1988 to 2000, per unit of GDP, Poland's economy is still more than twice as energy intensive as the EU average (see Executive Summary Figure 2).

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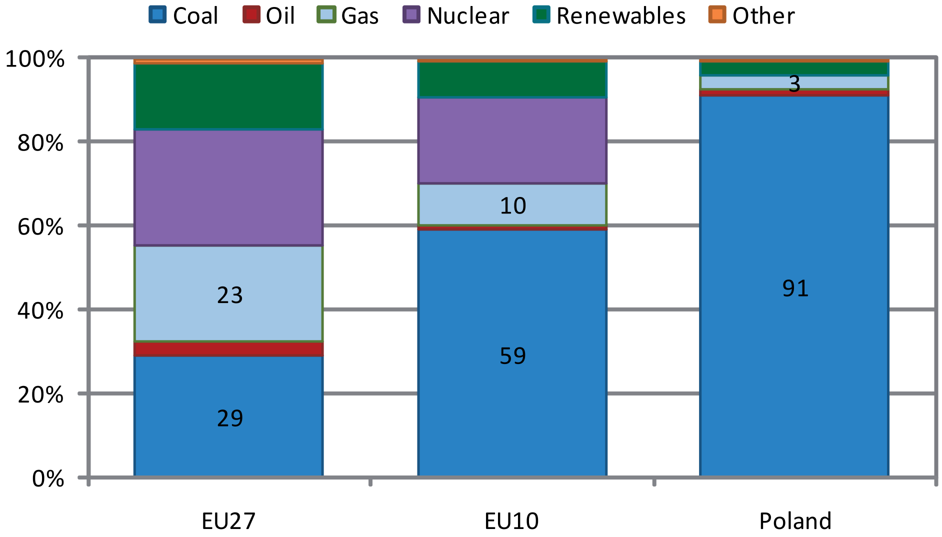
[1] 'Annex I' countries are 37 industrialized countries and economies in transition which signed the Kyoto Protocol of the United Nations Framework Convention on Climate Change and face modest but binding targets on emissions reduction.

[2] The words 'carbon' and 'emissions' are used interchangeably in this report as a shorthand for greenhouse gas emissions, usually measured in carbon dioxide equivalent (CO_2e) units.

[3] Carbon dioxide equivalent is a common metric based on the differing warming influences of each greenhouse gas. See footnote 12 in the main text for details.

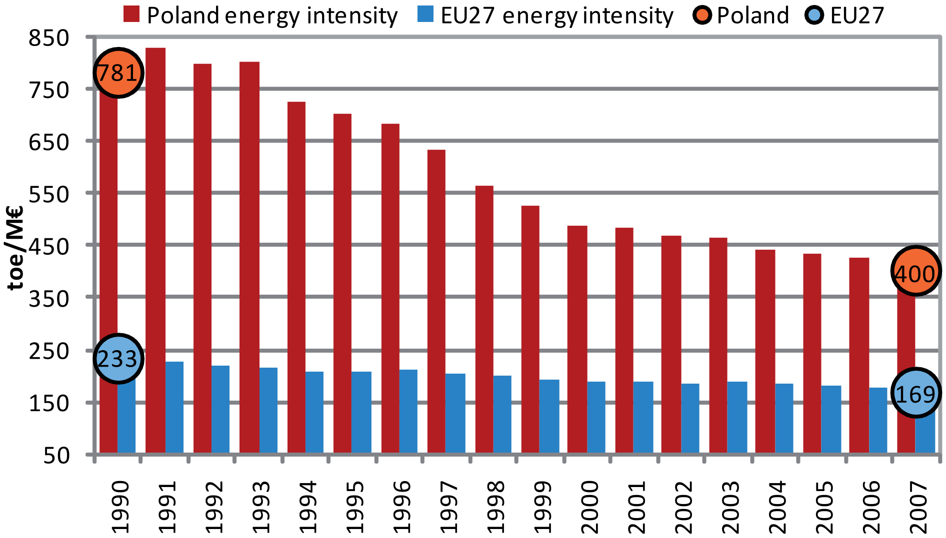
Executive Summary Figure 1. Electricity generation by fuel, 2007



Note: See Figure 10 in main text. Energy consumption is gross inland consumption of energy. The EU10 consists of Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. The EU27 is all 27 EU member states.

Source: European Commission, World Bank staff calculations.

Executive Summary Figure 2. Energy intensity in the EU and Poland



Note: See Figure 11 in main text. Energy intensity is the ratio of gross inland consumption of energy (in toe, tons of oil equivalent) to GDP (in millions of euros at 2000 prices).

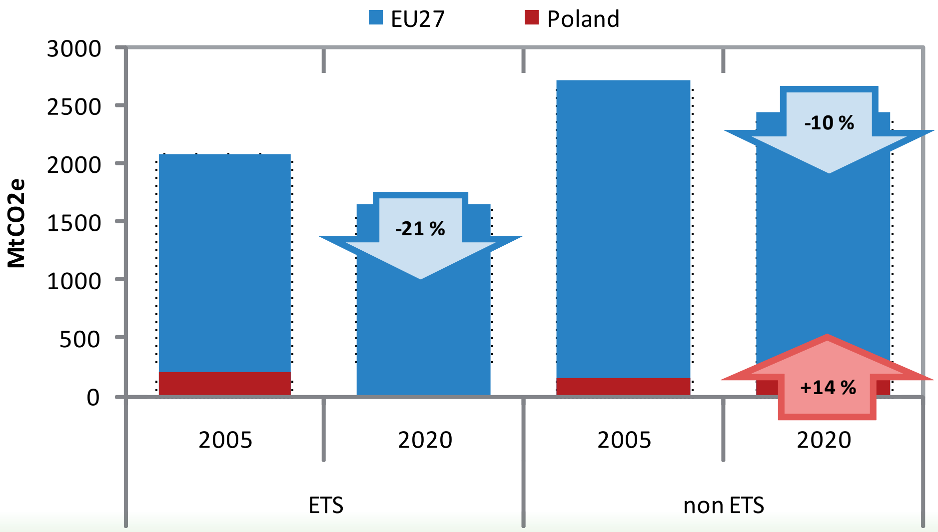
Source: European Commission, World Bank staff calculations.

Emissions abatement targets and policy challenges for Poland

The international agreement on climate change that is expected to eventually supersede the Kyoto Protocol and, more immediately, compliance with EU policies on climate change, pose policy challenges for Poland. Poland has been an active participant in international negotiations on climate change, in particular as a signatory to the Kyoto Protocol and as host to the 14th Conference of Parties of the UNFCCC in December 2008. The contraction of GHG emissions that accompanied economic restructuring in the 1990s caused Poland to outperform against its Kyoto commitments, and the country continues to exceed its Kyoto targets by a large margin. The most demanding of commitments on emissions, however, comes from EU policies on climate change mitigation. The EU climate change and energy package, or the '20-20-20' targets, requires comprehensive further action by EU members to achieve a 20 percent reduction in greenhouse gas emissions by 2020, renewable energy as 20 percent of energy consumption, and a 20 percent improvement in energy efficiency.

The 20-20-20 package requires Poland's energy-intensive sectors to contribute to the EU-wide target of a 21 percent reduction (compared with 2005) while allowing Poland's other sectors' emissions to increase by 14 percent. The EU package segments sectors into two groups as well as setting multiple targets. Large installations in energy-intensive sectors are covered by the EU-wide Emissions Trading Scheme (the ETS sectors), a regional carbon market. Energy, heavy industry, and fuels are ETS sectors. In Poland, approximately 60 percent of CO_2 emissions in 2005 were generated in the ETS sectors (compared with about 40 percent in the EU as a whole). For the non-ETS sectors, the package requires a reduction in emissions by 10 percent compared to 2005 in the EU27. That EU-wide target was translated into a national target for Poland of an increase in its non-ETS emissions by 14 percent (see Executive Summary Figure 3). These sectors (including transport and energy end-use in buildings and households) will require national policies to restrain emissions growth.[4] The EU Scheme's auctions of emission allowances will raise significant revenue for the Polish government in the future, estimated at roughly one percent of GDP; this revenue will be inversely related to the share of allowances that the government decides to allocate for free to support the competiveness of affected industries. More importantly, this segmented approach raises the cost of mitigation because of diverging marginal abatement costs across emission sources and sectors.

Executive Summary Figure 3. EU-wide and Poland's 2020 targets, ETS and non-ETS sectors



Source: UNFCCC, European Commission, World Bank staff calculations.

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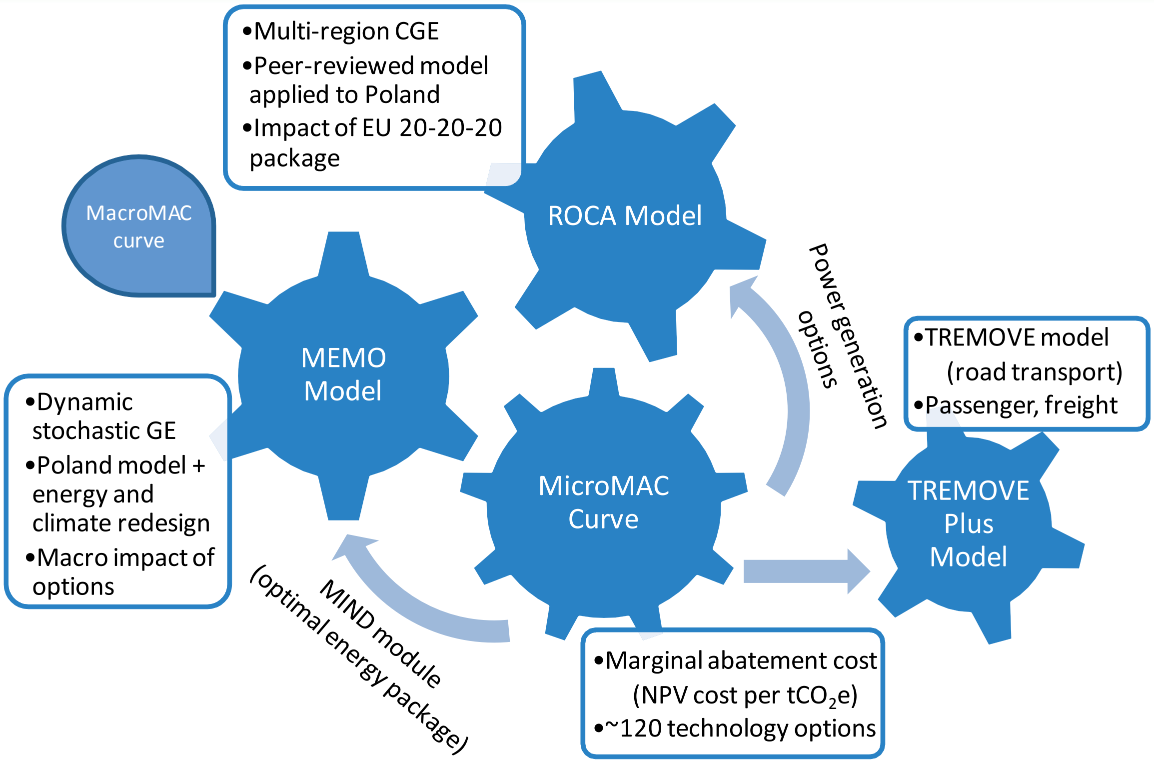
[4] Under EU regulations, energy-intensive industries are referred to as 'ETS' sectors since they must acquire emissions permits through the EU Emissions Trading Scheme carbon market, while 'non-ETS' sectors refers to the other, less energy-intensive, sectors.

A suite of models to assess emissions abatement

Three (and a half) complementary and interlinked models for Poland were developed to quantify the economic impact of CO_2 mitigation, taking advantage of available data and leveraging existing models. The most familiar of these models is likely the widely-used Marginal Abatement Cost (MAC) curve which provides a simple first-order ranking of technical options for GHG mitigation by sector based on the net present value of costs and savings per metric ton of CO_2 equivalent avoided. Then, two different economy-wide models were developed, a dynamic stochastic general equilibrium (DSGE) model and a computable general equilibrium (CGE) model, both of which are standard tools for economic impact assessment. The Macroeconomic Mitigation Options (MEMO) model, a DSGE model of Poland revised to include energy and emissions, assesses the macroeconomic impact of the options costed in the microeconomic MAC curve. It is linked to the MAC curve via a Microeconomic Investment Decisions (MIND) module which grouped the technology levers into seven packages, including an optimized package of options for the energy sector. The Regional Options of Carbon Abatement (ROCA) model, a country-level CGE model for energy and GHG mitigation policy assessment adapted to Poland, analyzes implementation of the EU 20-20-20 policy in the context of global policy scenarios, with an emphasis on spillover and feedback effects from international markets. The last "half" model is a detailed sectoral approach for road transport, the sector with the fastest growing emissions and central to Poland's commitments under EU 20-20-20 (as a non-ETS sector). It makes use of the EU transport and environmental model, TREMOVE, updated with the latest information and policy intentions, here denoted as the TREMOVE Plus model. All three (and a half) used very similar "business-as-usual" reference scenarios (within the limitations of data) against which to measure policy changes. Executive Summary Figure 4 summarizes the modeling approach.

Executive Summary Figure 4. Model suite for low-emissions growth assessment for Poland



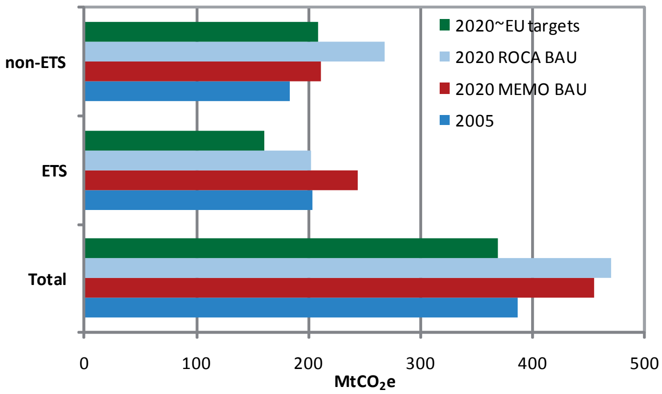
Note: See text for explanation and Figure 20 in main text for more details.
Source: World Bank staff.

Poland's growth path before a low-emissions strategy

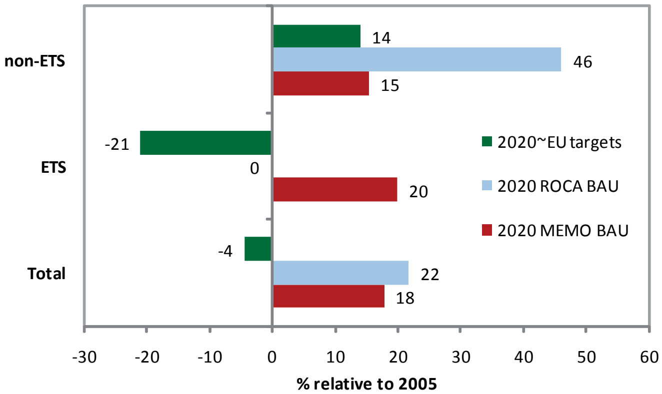
A business-as-usual scenario is fundamental to the calculation of costs of emissions abatement. If Poland were to take no action (the "business-as-usual scenario"), the models developed in this report suggest that overall emissions in 2020 will stand roughly 20 percent above 2005, while 2030 levels will be 30 to 40 percent higher. It is difficult to project the path of an economy over a 15 or 25 year period, and it is not surprising that sectoral details will differ significantly across models constructed via alternative methodologies and using separate datasets. The Microeconomic Marginal Abatement Cost (MicroMAC) curve model constructs a relatively simply reference scenario, which matches official projections for growth and energy demand and presumes a rising level of efficiency. While more or less matching overall emissions projections, the Macroeconomic Mitigation Options (MEMO) model forecasts in great detail that the Polish economy will shift relatively quickly towards less emissions- intensive sectors (mainly services), propelled by convergence towards EU averages. The Regional Options for Carbon Abatement (ROCA) model generates similar aggregate emissions levels for business-as-usual, but with a very different development path for sectors, with less sectoral transformation, guided by recent EU projections for its members. The detailed sectoral approach of the TREMOVE Plus model of road transport provides a scenario of rapid emissions growth for road transport, a major component of non-ETS emissions. The comparison of reference scenarios generated by the suite of models draws attention to the fact that, since each of the models illuminates important aspects of the economics of GHG mitigation, policymakers will need to be ready to consider multiple model results, rather than a single answer.

The projected pattern of emissions across sectors varies, however, with important implications for where policymakers will need to focus their attention. The projections for 2030 are somewhat divergent: the MEMO business-as-usual (BAU) scenario for 2030 emissions is 9 percentage points higher than the projection made in the MicroMAC curve model. By comparison, the overall projections of emissions for 2020 are similar across models. However, the MEMO projections indicate a heavier burden for ETS sectors to comply with EU targets, while according to ROCA projections, the major challenge will be faced by the non-ETS sectors. While the MEMO scenario projects ETS sectors to expand by 20 percent relative to 2005 by 2020, the ROCA scenario predicts constant emissions during the period. The MEMO projections seem to indicate Poland will have little problem in fulfilling the country-specific target for the non-ETS sectors under the EU 20-20-20 package (since the projected 15 percent increase under business-as-usual is very close to the 14 percent increase ceiling). In contrast, the ROCA projections warn of a significant challenge for non-ETS sectors, with emissions increasing by 46 percent between 2005 and 2020 (see Executive Summary Figure 5 and Executive Summary Figure 6). Over a period of decades, assumptions about efficiency improvements within sectors and shifts towards less emissions-intensive sectors as part of normal development have a large impact: policymakers need to think carefully about country-specific sectoral development in far more detail than these economy-wide models can manage.

Executive Summary Figure 5. GHG emissions in Poland, 2005 and 2020 scenarios

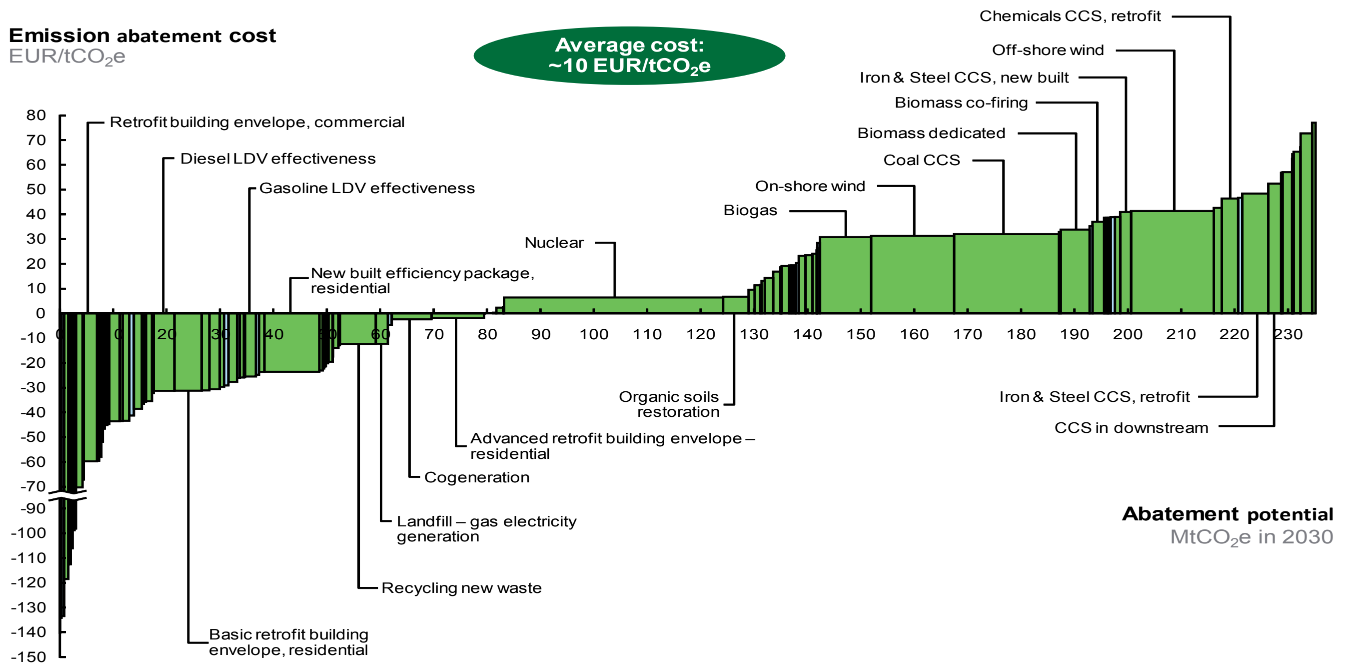


Executive Summary Figure 6. Changes in GHG emissions in Poland, 2020 scenarios vs. 2005



Note: The MEMO ETS and non-ETS projections are corrected for small energy installation. The ROCA model produces CO_2 emissions so equivalent GHG emissions were estimated. Poland's EU ETS target is assumed to be the same (as a percentage change) as the EU-wide target.
Source: IBS technical paper, Loch Alpine technical paper, World Bank staff calculations.

Executive Summary Figure 7. Microeconomic marginal abatement cost (MicroMAC) curve for Poland, 2030



Note: Each column is one of the 120 abatement measures. The height of the columns is the cost in € per abated tCO$_2$e. The width is the amount emissions can be reduced against business-as-usual levels projected for 2030. Some measures are shown with net benefits (negative costs). The scenario assumes that 6 GW of nuclear power will be installed by 2030, providing about 15% of electricity.
Source: McKinsey technical paper.

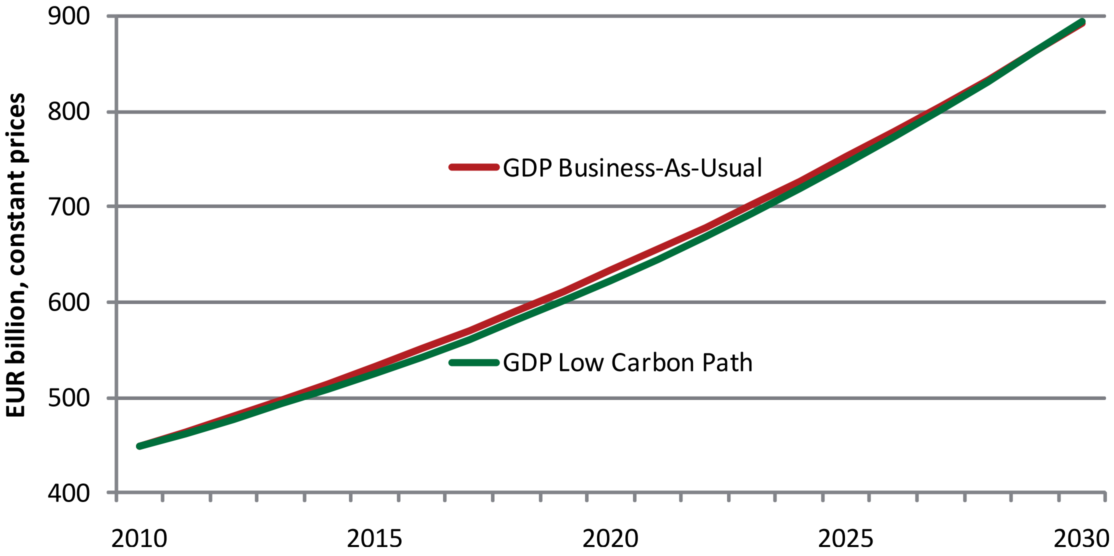
Poland's abatement options

Poland can reduce emissions by 30 percent by 2030 compared to 2005 at an average cost of €10 to 15 per metric ton of CO$_2$ equivalent, according to the Marginal Abatement Cost (MicroMAC) curve, a bottom-up engineering approach. This approach creates a ranking by net cost of about 120 emission reduction options based on existing technologies and presents the measures via a well-known visual summary tool—the MAC curve. When measured against the level of emissions that would otherwise occur in 2030, the reduction is even more significant—47 percent (see Executive Summary Figure 7). Te curve identifies that the majority of Poland's abatement potential is associated with the switch to low-emissions energy supply (via energy sector investments) and with energy efficiency improvements. In order to implement all the low-emissions levers, additional investment of about 0.9 percent of annual GDP will be needed through 2030. Moreover, mitigation measures will take some time to deliver lower emissions, and despite the all-out effort required if this abatement package were to be implemented, Poland will just meet its 2020 EU targets (with overall emissions reduction projected for 2020 at about 3 percent below 2005 levels). Note that despite the presentation of some abatement measures with negative net costs in the MicroMAC curve in Executive Summary Figure 7, costs will not be less than zero after implementation barriers are considered; the overall cost of implementing the MAC curve levers will rise by at least 50 percent after this recalculation.
The macroeconomic impact of the abatement package

Implementation of the full abatement package will reduce incomes modestly, costing an average one percent of GDP each year through 2030. This assessment comes from the Macroeconomic Mitigation Options (MEMO) model, a large scale DSGE model of Poland which incorporates each option identified in the bottom-up engineering approach of the MicroMAC curve. The innovative linking of this economy-wide model to the bottom-up engineering approach of the MicroMAC curve allows analysis of the varying macroeconomic implications of GHG abatement measures, across four public financing options. For the comprehensive abatement package, the MEMO model simulations find that GHG emissions will be reduced by 24 percent by 2020 and by 47 percent by 2030, with an economic impact that is generally negative but appears affordable. At a more disaggregated level, the model finds that it is the switch to low-emissions energy supply and fuel efficiency measures (mostly in transport) that provide the bulk of abatement. Finally, the MicroMAC curve can be transposed into a Macroeconomic Marginal Abatement Cost (MacroMAC) curve to examine in detail the impact on growth associated with the implementation of specific abatement measures.

The impact of the entire package on GDP is consistently negative over the twenty-year period of the model, but the losses approach zero by 2030. GDP will be reduced by an average one percent each year through 2030 (see Executive Summary Figure 8), and the growth rate of GDP would be about 0.3 percentage points lower during the first five years of the move towards low carbon (as compared with GDP in the business-as-usual scenario). Losses to real GDP peak in 2020 at near two percent and then gradually diminish, leaving annual GDP slightly above the business-as-usual level by 2030 (see Executive Summary Figure 9). The level of real GDP in 2020 would be from 1.8 to 3.1 percent lower than in the BAU scenario, but by 2030 it would recover to 0.7 lower to 0.7 higher than the BAU level. This U-shaped pattern of the impact on GDP is driven by the need for upfront investments, with benefits materializing in future years, and in particular, the long lead times required by the power sector. Employment would also suffer, with losses of about one percent of jobs each year, or about 140,000 jobs on average. The overall employment loss ranges from 2.6 to 0.2 percent reduction compared to the BAU scenario. Not surprisingly, the fall in GDP is driven by recession in emission-intensive sectors, which bear the heaviest burden of abatement. Value-added in energy-intensive sectors is projected to shrink by more than 9 percent by 2030, with sectoral employment falling by more than 5 percent.

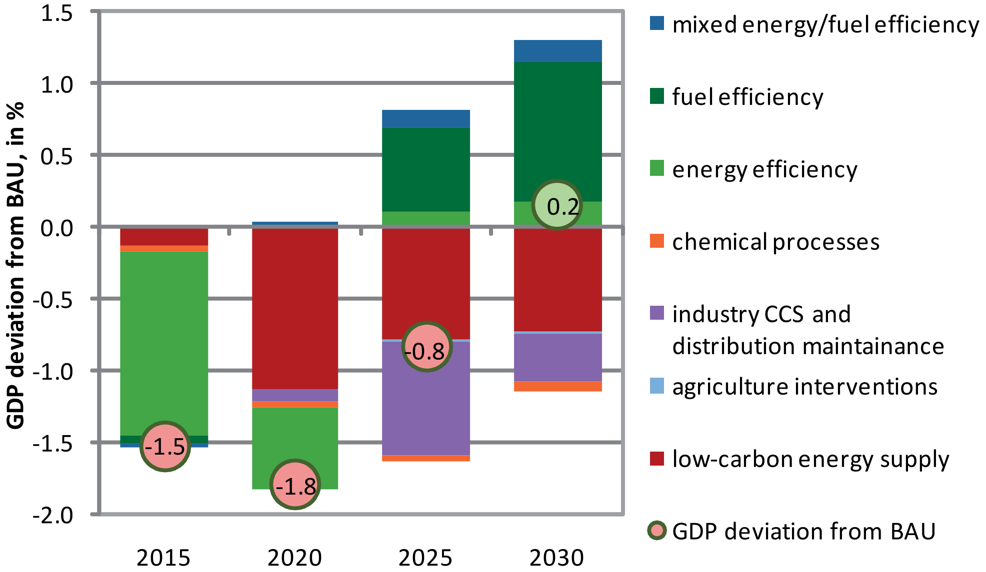
Executive Summary Figure 8. Impact of low-emissions package on projected GDP



Source: IBS technical paper, World Bank staff calculations.

The technological micro-packages—groups of related mitigation options—with the largest abatement potential do not necessarily impose the biggest macroeconomic cost. The switch to low-emissions energy supply provides about 40 percent of abatement through 2030 and also imposes the largest cost on GDP (of about one percent each year). Fuel efficiency measures, on the other hand, while contributing 30 percent of overall abatement, begin to enhance GDP significantly by 2025 and provide a net boost to growth overall. Energy efficiency measures are most important in the early years, contributing 20 percent of mitigation in 2015, while costing over one percent in GDP losses in 2015 but switching to mildly growth-enhancing by 2025 (see Executive Summary Figure 9). In contrast, industry CCS (carbon capture and storage) contributes only marginally to emissions abatement while costing about one-half percent per year in lower GDP after 2020, leaving it the second most expensive micro-package in terms of growth.

Executive Summary Figure 9. Decomposition of GDP impact of low-emissions package



Note: See Figure 34 in main text. Change in real GDP is measured against business-as-usual scenario. Categories are micro-packages (mitigation options grouped by economic characteristics). Low-emissions energy supply measures are energy sector investments such as gas-fired power plants, onshore wind power generation, and IGCC coal plants. Fuel efficiency measures are mostly in the transport sector. Energy efficiency measures are mostly in buildings. Mixed energy/fuel efficiency measures are mostly in building and also have fuel impact.
Source: IBS technical paper, World Bank staff calculations.

Onshore wind and small hydropower plants are superior to many energy efficiency measures by the metric of GDP growth. Nuclear power offers the biggest abatement potential but remains a drain on growth even with a twenty-year horizon—still myopic for plants with 60-year lifespans.[5] These insights come from use of a macroeconomic version of the MAC curve allows detailed examination of the impact on growth associated with the implementation of specific abatement measures (see Executive Summary Figure 10). The Macroeconomic Marginal Abatement Cost curve (or MacroMAC curve) presents the marginal abatement impact in terms of GDP of each abatement option, making it easy to see which measures are 'cheaper'. The area under the MacroMAC curve defines the overall impact of the entire abatement package on real GDP, an interpretation similar to that of the bottom-up MicroMAC curve (in which the area under the curve equals the financial cost of the abatement package). This curve is also generated for 2020, revealing that the impact on GDP of abatement options shifts over time and becomes more positive, flattening the MacroMAC curve as investments are completed and operations begin.

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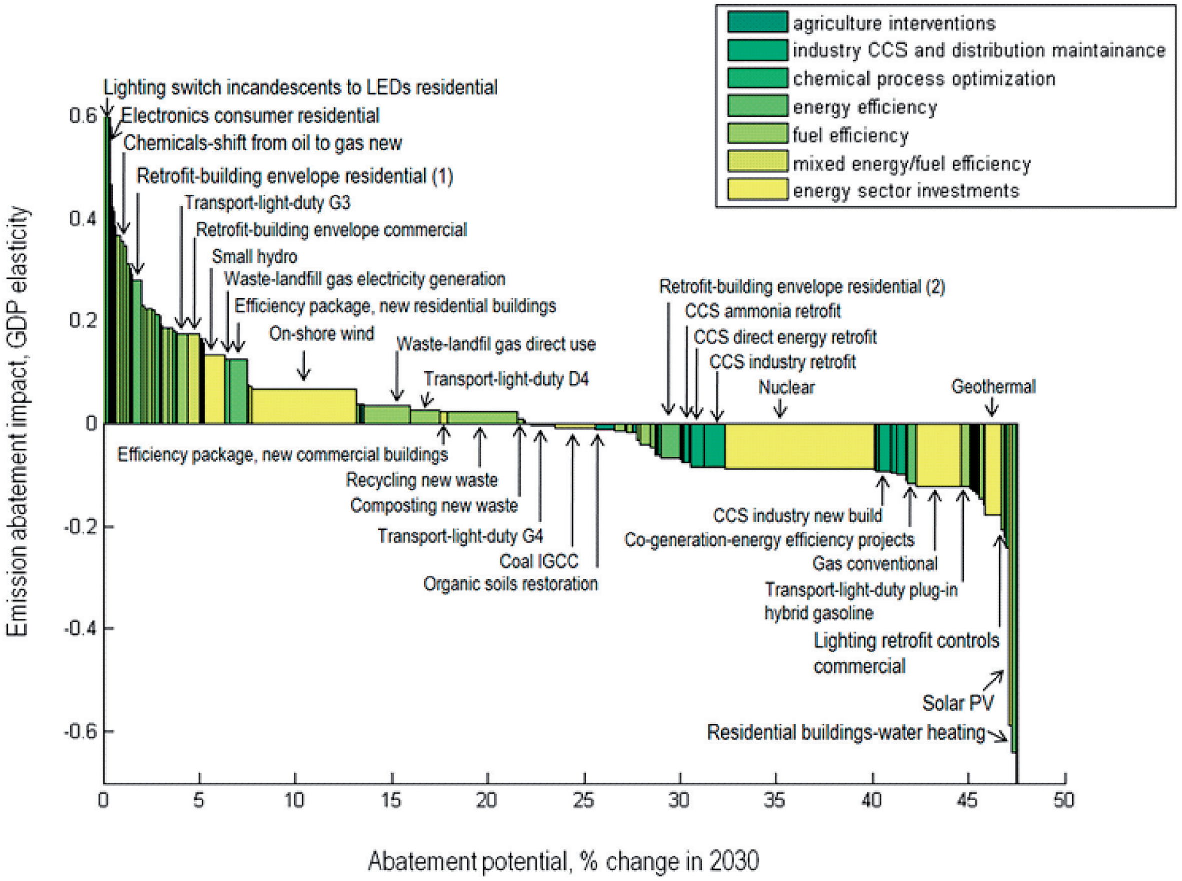
[5] Following from the engineering analysis—the MicroMAC curve, the MEMO model also assumes that 6 GW of nuclear power can be installed by 2030, constituting 19 percent of electricity supply.

Executive Summary Figure 10. Macroeconomic marginal abatement cost (MacroMAC) curve, 2030



Note: A positive value on the vertical axis means that an abatement measure increases GDP. Each column is one of the 120 abatement measures. The height of the columns is the marginal abatement impact in percent of GDP (for each percent of GHG abatement) compared to business-as-usual in 2030. The width is the percent emissions can be reduced (including the assumption that 6 GW of nuclear power will be installed by 2030, providing 19% of electricity). The area of any rectangle equals the GDP impact (loss or gain) of emissions abatement via any specific lever.
Source: IBS technical paper, MEMO model simulations.

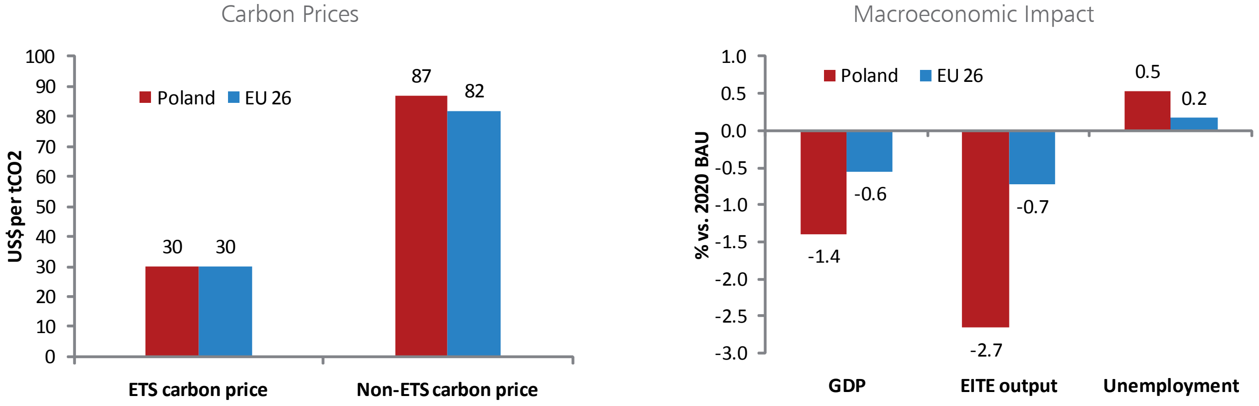
Implementing EU climate policy

In complying with the requirements of the EU's 20-20-20 package, Poland bears a higher economic burden than the rest of the EU *en bloc* because of the predominance of coal in power generation and the expected strong growth in sectors such as transport. The Regional Options of Carbon Abatement (ROCA) model, a country-level CGE model for GHG mitigation policy assessment adapted to Poland, considers key aspects of EU climate policy[6]. The model considers several variations on climate policy design that meet the same emission reduction targets and some alternative model assumptions that further illuminate the impact on Poland's economy in 2020 through the analysis of 11 simulations. The market segmentation created by the EU's division of economic sectors according to energy intensity greatly elevates the marginal cost of abatement for less energy-intensive industries. Removing that segmentation reduces overall compliance costs for Poland. Similarly, allowing emission reductions in the least-cost location dramatically reduces compliance costs and the need for adjustment, as most abatement is off-shored. Then, an additional aspect of EU policy is incorporated into the ROCA model—overlapping regulation in the form of an EU target for renewable energy sources—to determine conditions in which it may be (counter-intuitively) welfare-improving. The model considers various policy choices under the control of

[6] This analysis considers the key elements of the EU climate and energy package as of late 2010, but with some simplifications (such as formulation of the target for renewable energy) and omissions (such as the possibility of banking of allowances from the second ETS trading period to the third).

the Polish government. First, alternative revenue recycling via wage subsidies is analyzed, which generates a weak 'double dividend' (reducing emissions while easing distortions in the labor market) and lower unemployment. Then, the loosening of restrictions on the scope of nuclear power is found to cut compliance costs for Poland by about one-third (although installation of so much nuclear capacity is unlikely to be feasible by 2020). Lastly, the granting of free emission allowances to energy-intensive and trade-exposed sectors, which might be vulnerable to 'carbon leakage' (the off-shoring of high-emissions production), preserves sector output but generates overall losses in GDP.

Executive Summary Figure 11. EU 20-20-20 package: carbon prices and macroeconomic impact



Note: EU 26 is rest of the EU excluding Poland. The carbon price in non-ETS sectors is a shadow price. EITE is energy- and trade-exposed sectors. Unemployment is the change in the rate in percentage points.
Source: Loch Alpine technical paper; ROCA model simulations.

The findings of the main scenario of the ROCA model illustrate that Poland bears a higher economic burden than the rest of the EU *en bloc* because of its relatively high abatement targets for non-ETS sectors with strong baseline emissions growth. Setting a non-zero price of carbon generates a negative shock to emissions-intensive sectors. Since power generation in Poland is predominantly coal-based, it will be hard hit. CO_2 reduction from the sector takes place through rising electricity prices (by about 20 percent, much more than in the rest of the EU), a decline in output by about 10 percent, the expansion of CO_2-free renewable power production, and, to a more limited extent, fuel shifting to gas (since nuclear power is assumed restricted to BAU levels). The higher costs of production for those sectors in which (fossil fuel) energy inputs represent a significant share of direct and indirect costs leads to a loss in competitiveness, depressing production. In the new equilibrium, real wages are lower, and unemployment rises (although by only half a percentage point). The effects on real GDP are modest but more than twice as high for Poland as for the rest of the EU (with a loss of 1.4 percent of GDP) (see Executive Summary Figure 11).

Energy-intensive and trade-exposed industries are not devastated by emissions abatement, but market segmentation drives the marginal cost of abatement in non-ETS sectors to almost three times the level in ETS sectors. Even for energy-intensive and trade-exposed industries (a subset of ETS sectors) worried about loss of competitiveness, the contraction is still moderate in size (although they are harmed more than the average, with 2.7 percent loss in output in 2020 compared to GDP losses of 1.4 percent). At the same time, marginal abatement costs in the non-ETS sectors for both Poland and the rest of the EU are much higher than the ETS value (at a shadow price of US$87 per tCO_2 for Poland, and US$82 for other EU), revealing less potential for cheap emission abatement in the non-ETS sectors. The differences between ETS and non-ETS prices drive the direct excess costs of EU emission market segmentation, which are alleviated to some degree through limited low-cost offsets from developing countries (via the Clean Development Mechanism of the Kyoto Protocol).

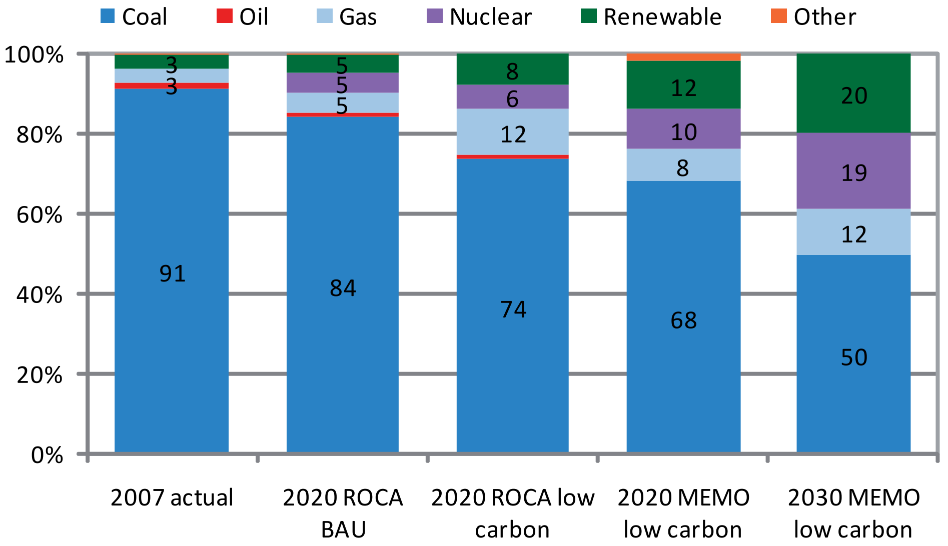
Insights for fiscal policy

The choice of tax instruments to finance possible public subsidies for low-emissions measures and the choice of how to spend potential revenues from emissions taxes change the impact on GDP, sectoral output, and employment. While the economywide models are designed to focus on real sector developments over long horizons, they also offer insights on fiscal issues. The MEMO model assumes fiscal neutrality so that the impact of mitigation options on fiscal expenditures or revenues must be financed by offsetting changes in spending or taxes. However, the choice of which taxes to increase or which expenditures to cut affects the results. For example, the restructuring of public spending away from less productive categories such as social transfers is supportive of job creation (because households react to shrinking transfers by working more). As a result, employment and GDP perform better, but household welfare is diminished. In one of the ROCA model scenarios, analysis of revenue recycling via wage subsidies reveals a weak double dividend in which unemployment is reduced. When revenues from an emissions tax are used to subsidize labor costs, the downward pressure on wages from taxing emissions is more than offset such that real wages increase and unemployment falls. That is, using carbon tax or allowance revenues for wage subsidies is superior to subsidizing affected industries.

Energy, energy efficiency, and transport

The switch to low-emissions energy supply, end-user energy efficiency measures, and transport policy will be the central pillars of Poland's low emissions growth strategy, starting with the power sector in which aging infrastructure ready for replacement provides a timely opportunity for a shift in direction. The power sector, as the dominant source of today's emissions, necessarily must be addressed, but the sector's large investment costs raise financing challenges while long lead times guarantee that its structure will shift only slowly (see Executive Summary Figure 12). The combination of technologies chosen or new investments will depend not only on capital costs, operational savings, and emissions abatement potential, but also energy security, domestic sourcing, and a raft of other issues. It is not surprising that the models applied here forecast the structure of the power sector to shift only slowly. The ROCA model's results argue that a strong shift towards nuclear power is the option most likely to reduce emissions without harming the economy (although it proposes the optimum level of nuclear power above that deemed feasibly installed by 2020). The MEMO model, which takes the most sophisticated approach to selecting the structure of the sector, uses an optimization model to determine the cheapest feasible energy-mix package within multiple constraints. However, even if a full low-emissions package is implemented, coal will likely remain the fuel for half of Poland's electricity in 2030. The additional fact that the average age of Poland's existing energy infrastructure is relatively high means that natural retirement of plants provides an opportunity for the country's energy sector agenda to largely coincide with the low-emissions agenda.

Executive Summary Figure 12. Current and projected electricity mix in Poland, 2020 and 2030



Note: 'Coal' includes conventional coal, IGCC coal, new-built coal with CCS, and new-built coal with CCS with enhanced oil recovery (EOR); 'Gas' is conventional gas, new-built gas with CCS, and new-built gas with CCS and EOR; 'Renewable' is onshore wind, small hydro, geothermal, and dedicated Biomass.
Source: Loch Alpine technical paper, ROCA model simulations, IBS technical paper, MEMO model simulations, World Bank staff calculations.

With lower capital costs and earlier returns, end-user energy efficiency measures[7] hold out the promise of relatively low cost abatement that works directly to delink emissions from growth, the essence of a low-emissions economy. Energy efficiency measures play a central role in the MicroMAC curve analysis because of their substantial potential, apparent low price, and impact on growth. While it is logical that abatement measures cannot in reality have negative net costs, ascertaining the details of the relevant implementation barriers for these measures is a challenge. Exploiting the energy efficiency agenda will not be easy, but it likely does have some opportunities that are 'win-win,' with benefits realized relatively quickly and relatively low upfront costs. Initial analysis of the macroeconomic impact of energy efficiency measures in the MEMO model found that although most energy efficiency measures individually have little potential, if they could be grouped together for implementation, they could be an important emissions abatement tool. Deeper detailed analysis of energy efficiency options in Poland is needed to be able to provide more specific recommendations on how to overcome implementation obstacles that are preventing households and businesses from realizing the financial savings embedded in many of these measures.

The transport sector may prove the most challenging to hold emissions growth within the EU target since most technological solutions are already in place, leaving policymakers with only behavioral solutions that are much more complicated to implement. While the energy sector, as the dominant source of today's emissions, necessarily receives much attention and analysis in any study of low-emissions policies, and while energy efficiency, with well-known potential for 'no-regrets' actions, is rightfully high on policymakers' agendas, Poland also needs to consider how to address the sector with the fastest growing emissions—transport. Road transport GHG emissions in Poland are converging from a low historic base towards EU averages. While contributing about 10 percent of overall emissions, road transport constitutes about 30 percent of non-ETS emissions. The objective of sustainability and greening of the transport sector is not new for the EU, but the EU 20-20-20 climate package is now the centerpiece. A business-as-usual scenario through 2030 was developed for passenger and freight road transport in Poland, using the TREMOVE Plus model (see Executive Summary Figure 12). This forecast incorporated key characteristics of Poland's transport sector, in particular, a high number of imported used cars, low motorization rates and low mileage, and a highly competitive freight sector that has been shifting to newer and bigger trucks. Emissions from road transport are expected to almost double between 2005 and 2030. Because steady technological improvements are

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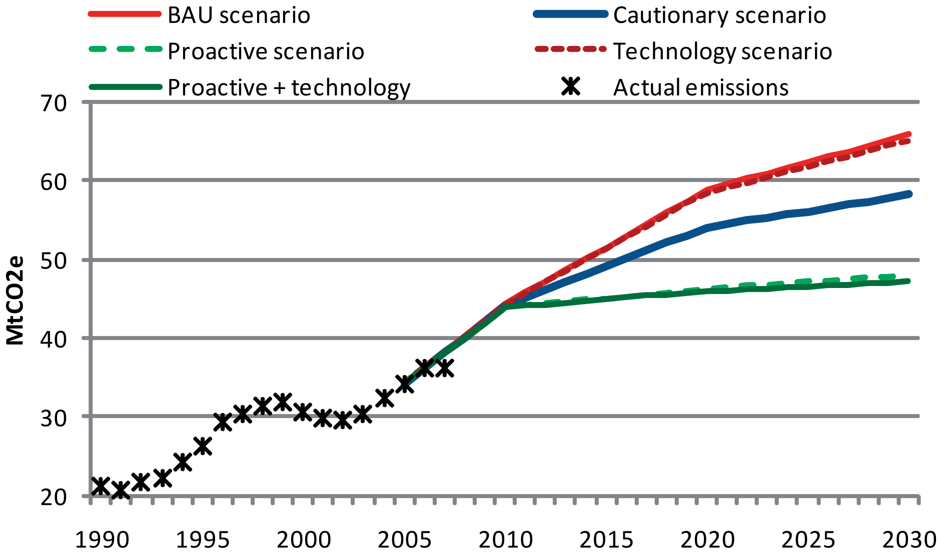
[7] End-user energy efficiency measures include dozens of measures in commercial and residential buildings, such as improved insulation, more efficient lighting, and more efficient appliances, as well as energy-saving measures in industry (such as co-generation).

already incorporated into the BAU projections, the two low-emissions scenarios developed by the TREMOVE Plus model include only modest technological improvements and concentrate on other emissions-reducing policy measures. The results of the scenarios present a more worrying vision than previously established for the road transport sector in Poland, with abatement unlikely to hold emissions growth below 35 percent through 2020. With most technological solutions already in place, more difficult behavioral change will be needed,[8] but even proactive abatement policies are unlikely to hold emissions growth within the EU target for these sectors.

Executive Summary Figure 13. TREMOVE Plus CO_2e emissions projections for road transport by scenario, $MtCO_2e$



Note: Precautionary scenario contains policy measures such as road pricing, fuel tax increases, and eco-driving. Proactive scenario contains same measures but with greater effort. Technology scenario contains policy measures for modest technological improvement in trucks (medium and heavy duty vehicles). See Figure 71 in the main text.
Source: Transport technical paper, World Bank 2010.

Additional issues and further work

While this report provides some complex assessments and new analytic tools for policymakers, its analysis, rather than exhausting the central issues related to a transition to low-emissions growth, has identified a number of additional economic issues for further work. There are a number of extensions and revisions of the economywide models, in particular the MEMO model, to improve integration and harmonization with the engineering approaches and with other macroeconomic models. Supplementary analysis by extending the time horizon, including R&D and technological progress, and considering the distributional and geographical impact of low-emissions scenarios would all be of value. The sectoral analysis could also be usefully enhanced with more detailed work on energy efficiency and on agriculture, land use, and forestry. A number of aspects of EU policy should be modeled, including subsidies and energy sector derogations. Last is the overlooked but important issue of possible new business opportunities for early movers on emissions abatement. For this additional work, it should be emphasized that the idea is not to meld the three and a half models used here into one. The preservation of alternative models, which produce differing results, has important advantages, among which is the ability to highlight continually for model users the criticality of model assumptions and simplifications.

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[8] Such as shifting away from private cars towards public and non-motorized transport.

Conclusions

This report provides a detailed assessment of many aspects of a low emissions growth strategy for Poland, developing insights via a suite of models that should provide ongoing assistance to policymakers in Poland. Policymakers may find reassuring the report's main message that Poland's transition to a low-emissions economy, while not free or simple, is affordable. However, capturing the full package of technologically feasible and economically sensible abatement measures requires coordinated and early action by the government. With an ambitious approach, Poland can aim to reduce its GHG emissions by about one-third by 2030 (relative to 1990) with little cost to incomes and employment. Similarly, meeting the EU targets for 2020 appear generally feasible for Poland at modest cost, albeit likely more challenging for less energy-intensive sectors such as transport than for sectors that can access the efficiencies of EU-wide carbon trading. Poland has already weathered one economic transition and emerged with a strong and flexible economy. This next transition—to a low emissions economy—while requiring an evolution in lifestyles and priorities over the next 20 years, may well turn out to be much easier.

INTRODUCTION

Against the backdrop of agreement that global coordinated action is needed to prevent dangerous climate change,[9] individual countries are thinking through the implications of climate action for their economies and people. Some countries are already observing the impact of global warming on local weather and water supply. Others wish to position themselves as leaders in the ongoing international negotiations. With the expectation that a global price for carbon[10] will eventually be established, some countries may wish to push to the front on emerging clean technology industries and avoid 'stranded assets'—expensive long-lived infrastructure such as dirty coal-burning generators. Some simply want to inform policymaking on a key issue. Given that Poland ratified the Kyoto Protocol and hosted the December 2008 round of international climate negotiations,[11] 'carbon' mitigation is not a new issue for Poland. But with its obligations as a member of the European Union making that commitment more concrete, it is an opportune time to assess more thoroughly the complex economic impact of emissions mitigation by Poland, in particular the expected tradeoffs between reducing greenhouse gases[12] (GHGs) and sustaining economic growth and employment.

There is a broad consensus that the world is warming and that human activity is primarily to blame. Average global temperatures and sea levels are rising while the extent of Arctic sea ice, mountain glaciers, and snow cover is declining. The Intergovernmental Panel on Climate Change (IPCC) has concluded that warming of the Earth's climate system is unequivocal and that anthropogenic (human-made) greenhouse gas emissions, generated mostly by the burning of fossil fuels and deforestation and changes in land use, are to blame. The level of carbon dioxide (the most important GHG) in the atmosphere is already the highest concentration in the last 650,000 years (at 379 parts per million (ppm) in 2005 as compared with 280 ppm in the preindustrial era). Via the 'greenhouse effect', these high and rising levels of GHGs are projected to raise average global temperatures over the next 100 years by 1 to 6°C. [13] (See Box 1).

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[9] Climate change is defined as changes in the mean or variability of weather (generally, temperature, precipitation and wind) over a multi-year period, generally 20 or 30 years (following usage by the Intergovernmental Panel on Climate Change).

[10] Note that throughout this report, the words 'carbon' and 'emissions' are used interchangeably as a shorthand for greenhouse gas emissions, usually measured in carbon dioxide equivalent (CO_2e) units.

[11] Poland is a signatory to the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and has ratified the 1997 Kyoto Protocol.

[12] Greenhouse gases trap heat within the atmosphere, creating the greenhouse effect (warming of the atmosphere which would otherwise have a temperature of -19°C). In this report, GHGs refer to the anthropogenic greenhouse gases covered by the UNFCCC: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O); and the F-gases (or halocarbons) covered by the Kyoto Protocol: hydrofluorocarbons, perfluorocarbons, and sulphurhexafluoride.

[13] IPCC (2007), Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and A. Reisinger (eds.)]. Intergovernmental Panel on Climate Change, Geneva, Switzerland, 104 pp.

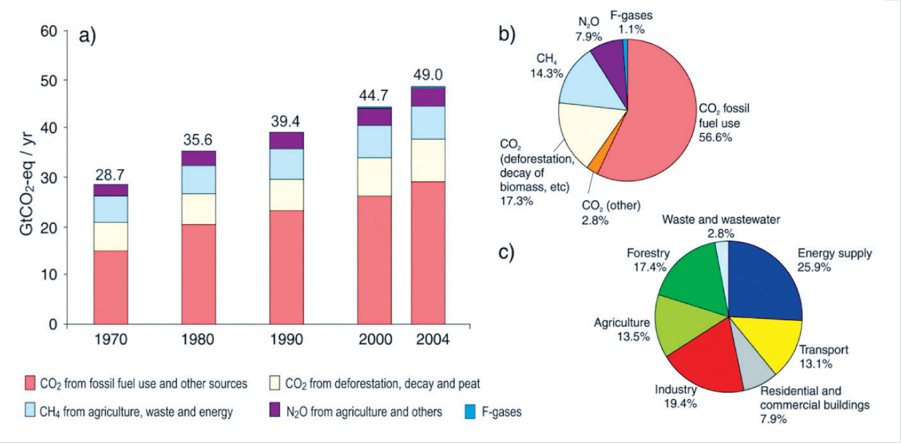
Box 1. The Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report

The Intergovernmental Panel on Climate Change (IPCC), established by the United Nations in 1988, assesses scientific information and environmental and economic consequences of climate change, in support of the United Nations Framework Convention on Climate Change (UNFCCC). This box summarizes key conclusions of their 2007 Assessment Report, which today appears conservative in its conclusions. According to its most recent Report, representing a consensus view among more than 2000 scientists worldwide on climate change, warming of the climate system is unequivocal, based on evidence from increases in global average air and ocean temperatures (especially over the last 50 years), widespread melting of snow, Arctic ice, and mountain glaciers (over the last 30 years or so), and rising global average sea level (over the last 50 years or so).

This global warming is being driven by rising atmospheric concentrations of greenhouse gases, in particular carbon dioxide. Human activities result in emissions of four long-lived GHGs: carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O) and halocarbons (a group of gases containing fluorine, chlorine and bromine that can destroy stratospheric ozone). Atmospheric concentrations of GHGs increase when emissions are larger than removal processes. The IPCC report notes that "global atmospheric concentrations of CO_2, CH4 and N2O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values". From a pre-industrial level of 280 ppm, CO_2 concentrations were at 390 ppm in mid-2010. [1]

There is little doubt that human activity is the cause of higher GHG levels and, therefore, of climate change. "Global increases in CO_2 concentrations are primarily due to fossil fuel use, with land-use change providing another significant but smaller contribution. It is very likely [with a confidence level greater than 90 percent] that the observed increase in CH4 concentration is predominantly due to agriculture and fossil fuel use. The increase in N2O concentration is primarily due to agriculture."[2] Overall, human-made emissions rose 70 percent between 1970 and 2004 (see Figure 1), driven primarily by the energy supply sector.

Figure 1. Global annual emissions of greenhouse gases



Note: (a) Global annual emissions of anthropogenic GHGs from 1970 to 2004 (b) Share of different anthropogenic GHGs in total emissions in 2004 (c) Share of different sectors in total anthropogenic GHG emissions in 2004 (Forestry includes deforestation.) $GtCO_2$-eq is gigatonnes (billions of metric tons) of carbon dioxide equivalent, a common metric based on the differing warming influences of each GHG.
Source: IPCC (2007), p. 5.

In the absence of additional climate mitigation policies, global GHG emissions are projected to increase by 25 to 90 percent between 2000 and 2030. Using a range of scenarios, world temperatures are projected to rise by between 1.1 and 6.4°C compared with 1980-99 (with a confidence level greater than 66 percent) while sea levels will rise by 18 to 59 cm during the 21st century (but with a high degree of uncertainty). Further, with a confidence level greater than 90 percent, there will be more frequent warm spells, heat waves and heavy rainfall; and with confidence level greater than 66 percent, there will be an increase in droughts, tropical cyclones and extreme high tides. Abrupt or irreversible impacts are possible, such as partial melting of polar ice sheets (which would cause meters of sea level rise); changes in ocean circulation such as the Gulf Stream; and, if global average temperature increase exceeds about 3.5°C, extinction of 40 to 70 percent of terrestrial species and widespread coral mortality in marine ecosystems.

Source: IPCC (2007).

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[1] Data from US National Aeronautics and Space Administration's Jet Propulsion Laboratory.

[2] IPCC (2007), p. 5

Unfettered climate change will impose enormous costs unevenly distributed across countries, with developing countries faring the worst. As the World Bank's World Development Report 2010 has stressed, the projected rise in temperatures will create "a vastly different world from today, with more extreme weather events, most ecosystems stressed and changing, many species doomed to extinction, and whole island nations threatened by inundation".[14] A 2°C warming above preindustrial levels will cause more frequent and stronger extreme weather events, including heat waves, drought, flooding, and hurricanes; increased water stress in many world regions and especially in Africa and Asia; declining food production in many tropical regions as cereals become no longer cultivable in low latitudes; coastal erosion and aquifer salinization; and damaged ecosystems and biodiversity loss, including widespread dying off of coral reefs and shifting ranges for pests and diseases. These consequences will fall disproportionately on developing countries, with estimates of a 4 to 5 percent permanent reduction in annual income per capita in Africa and South Asia and a global average GDP loss of about 1 percent.[15]

While other parts of the globe will face the greatest harm, the countries of Central and Eastern Europe and Central Asia[16] face considerable threats from climate change. Rising temperatures and shifting precipitation patterns will aggravate winter floods and summer droughts and heat waves. Precipitation intensity is expected to increase across the region while water availability is projected to decrease everywhere but Russia. The rapid melting of the region's glaciers will reduce summer water availability, with severe impacts in irrigation-dependent Central Asia. Changes in sea level will affect the four major basins—the Baltic Sea, the East Adriatic and Turkey's Mediterranean coast, the Black Sea, and the Caspian—as well as the Russian Arctic Ocean, threatening low-lying areas such as, for example, Poland's heavily populated coast. Increased temperatures and changing hydrology are expected to generate substantial tree loss and degradation, the northward migration of pests, and the return of malaria to Europe.[17]

The international community has been negotiating a coordinated response to the threat of climate change for some time. Under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), industrialized countries and economies in transition (or 'Annex 1' countries under the UNFCCC) committed in 1997 to reduce greenhouse gas emissions by about 5.2 percent during 2008-12 compared to 1990. The UNFCCC climate summits in Copenhagen in December 2009 (Conference of the Parties or COP-15) and in Cancun in December 2010 (COP-16) aimed to make progress on post-2012 emission targets and their allocation. A 2 to 2.5°C increase in global temperatures above preindustrial levels by 2050 has been accepted as a target because it is considered achievable while also likely to prevent some of the most catastrophic potential effects of climate change, such as major increases in global sea level and disruption of agriculture and natural ecosystems. The stabilization of greenhouse gases at 450 ppm CO_2e (or carbon dioxide-equivalent),[18] which would provide a 40 to 50 percent chance of limiting the temperature rise to 2°C, requires emissions to be reduced by at least 50 to 85 percent in 2050 compared to 2000 levels and global emissions need to peak prior to 2020, according to the IPCC. Intermediate targets for 2020 have also been suggested, including an indicative range of 25 to 40 percent reductions compared to 1990 for developed and transition countries.[19]

The European Union has taken a proactive stance through its 'climate and energy package,' setting ambitious mitigation targets for its members for 2020 in advance of an international agreement. Following the European Council's decision for unilateral emissions reductions of 20 percent by 2020 at its March 2007 summit, the package of measures referred to as the '20-20-20 targets' was approved by the European Parliament in December 2008 and became law in June 2009.[20] By 2020, EU emissions are to be cut by 20 percent (or 30 percent if a global deal is reached); energy efficiency is to be increased by 20 percent; and 20 percent of energy used is to come from renewables.[21] Higher emission sectors are included in an EU-wide cap-and-trade system (the Emissions Trading Scheme) while other sectors face national targets only. Thus, EU members such as Poland already face specific obligations for climate action.

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[14] World Bank (2009), World Development Report 2010: Development and Climate Change, p. 1.

[15] World Bank (2009), p. 5.

[16] Central and Eastern Europe and Central Asia includes: Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kosovo, Kyrgyzstan, Latvia, Lithuania FYR Macedonia, Moldova, Montenegro, Poland, Romania, Serbia, Slovakia, Slovenia, Tajikistan, Turkey, Turkmenistan, Ukraine, and Uzbekistan.

[17] Fay, Marianne, Rachel I. Block, and Jane Ebinger, eds. (2010), Adapting to Climate Change in Eastern Europe and Central Asia (World Bank).

[18] GHGs differ in their warming influence (radiative forcing) on the global climate system due to their different radiative properties and lifetimes in the atmosphere. These warming influences may be expressed through a common metric based on the radiative forcing of CO_2. CO_2-equivalent emission is the amount of CO_2 emission that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of GHGs.

[19] IPCC (2007).

[20] European Union (2008), The Climate Action and Renewable Energy Package: Europe's Climate Change Opportunity.

[21] Renewable energy (or renewables) is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished).

Poland faces a particular challenge in CO_2 mitigation because of its reliance on abundant domestic coal. 85 percent of Poland's GHG emissions come from the energy sector, and more than 90 percent of electricity comes from coal-fired power plants (which emit the highest levels of CO_2 per unit of electricity of any power generation technology, and roughly two to three times as much as equivalent gas-fired plants). Despite progress over the last two decades, Poland's economy remains twice as energy intensive as the EU average. Also, while emissions overall have fallen by near 30 percent since Poland's transition to a market economy began, those from the transport sector have grown by almost three-quarters (although they still constitute just over 10 percent of total emissions). There is understandable concern in Poland that a move towards a lower carbon economy will boost electricity prices, already amongst the highest in the region, which in turn will undermine welfare and profitability, with devastating effect on employment at home and competitiveness abroad. How costly will it be for Poland to move to a lower carbon path? What combination of energy efficiency, shifts in fuel for power generation, and other measures is most desirable? How steep is the tradeoff between carbon abatement and growth?

Through the Low Carbon Growth Country Studies Program, the World Bank has been supporting selected countries' work on lower carbon development paths. In 2007, the donor community asked the Bank to build on its experience in developing country-specific marginal abatement cost curves which aggregate the incremental costs of GHG mitigation measures relative to a business-as-usual scenario and the associated financing needs. The Bank was asked to assist in preparation of low carbon country case studies for Brazil, China, India, Indonesia, Mexico, and South Africa. These studies aim to integrate carbon abatement targets with objectives for economic growth and poverty alleviation. The Bank has been careful to ensure that these studies are client led, to help ensure the transition to implementation. As a result, each study has taken a different approach, appropriate to the client country and building on experience. This report on Poland draws on that ongoing experience but aims to go further in addressing the macroeconomic impact of a low emissions growth strategy by integrating 'bottom-up' engineering analysis with 'top-down' economy-wide modeling.

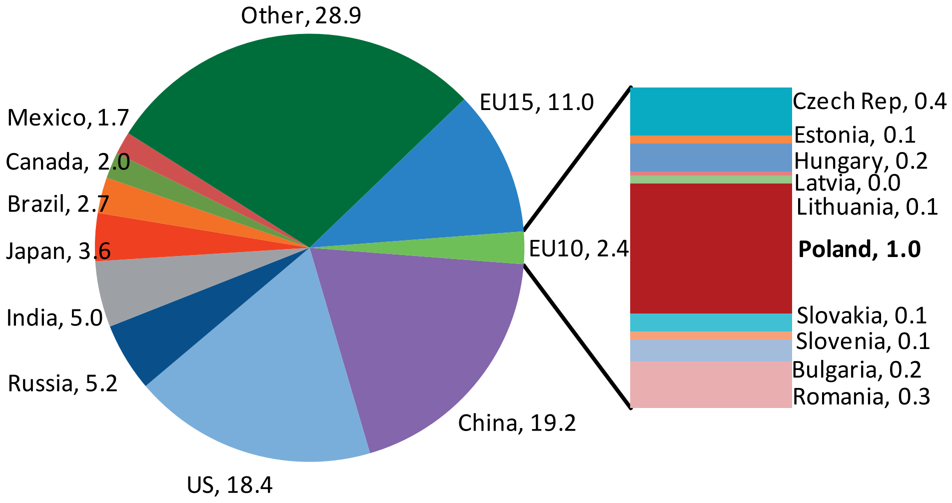
The rest of the report is organized along the following lines. The next section provides background on Poland's greenhouse gas emissions. Then section C sets out Poland's existing carbon abatement targets and key policy challenges related to GHG mitigation. The next section summarizes the innovative methodological approach used by the report. Section E discusses the methods and implications of constructing business-as-usual or reference scenarios. Section F provides the major findings from the first model, the engineering approach, on the costs of measures aimed at GHG mitigation for Poland. Section G explains how these findings are expanded and revised by incorporation into the first macroeconomic model. Section H provides an analysis of the economic impact through 2020 of mitigation measures within the constraints of EU policy arrangements. Section I examines the energy sector and how Section F's findings are enhanced by optimization of the structure of the energy sector. Section J takes a first look at the challenges of energy efficiency. Section K provides additional analysis of the transport sector. The last section provides some notes on additional issues and further work.

POLAND'S GREENHOUSE GAS EMISSIONS

Poland is not among the largest emitters of greenhouse gases globally, but its economy is among the least carbon-efficient in the EU. Poland's global share in GHG emissions is just 1 percent; and its per capita emissions are about the average for the EU. Poland cut its emissions considerably as a side effect of the restructuring of transition to a market economy, but the link between growth and emissions has re-emerged in recent years. A critical difference in the make-up of Poland's emissions is the dominance of the power sector and its extraordinary dependence on coal. Apart from energy sector, Poland's transport sector has experienced very high rates of emission growth, and energy efficiency, although improving, remains below EU averages.

Poland contributes marginally to the global carbon footprint, with a share in global GHG emissions equal to about 1 percent. The EU as a whole is responsible for about 13 percent of global emissions, while China and the US, the largest emitters, are responsible for almost 40 percent of global emissions between them. (Figure 2). On a per capita basis, Poland emits about 10 metric tons of CO_2e (tC02e) each year, which is the average across the EU (with most countries at between 7 and 15 tC02e per capita). On average, Europeans emit less than half the greenhouse gases of North American or Australian citizens. Nonetheless, this level remains well above the global average of 7 tC02e as well as the benchmark of 2, the average global per capita emissions consistent with a 2°C rise in temperature.[22]

Figure 2. World's largest greenhouse gas emitters, 2005, in percent



Source: World Resources Institute, World Bank staff calculations.

Despite unremarkable overall emissions levels, Poland's economy remains among the least carbon-efficient in the EU. In 2007, around 1.3 metric tons of CO_2e were required to produce €1 million in GDP, while the EU average was less than 0.5 tC02e. This high emissions-intensity of the economy is due partly to high amounts of CO_2 generated by the energy consumed but also to the high energy intensity of production in Poland. While in the EU on average, consumption of energy equal to one ton of oil equivalent[23] generates 2.5 metric tons of CO_2, in Poland the same ratio is around 3.4 (Figure 3), despite the downward trend of carbon intensity in Poland over the last two decades. At the same time, energy used per million euros of GDP, at 400 tons of oil equivalent, greatly exceeds the EU-wide average of 169 (Figure 11) and stands at about the world average (Figure 4). Among transition economies, Poland's performance appears better: its carbon intensity on a per capita basis is situated in about the middle of the countries of Eastern and Central Europe and Central Asia (see Figure 5).

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[22] The Contraction and Convergence model developed by the Global Commons Institute estimates that to contain global warming to 2°C increase, which is typically associated in climate models with a CO_2e concentration of 400-500 ppm, emissions per capita must come down to 2 $tC0_2e$ per capita by 2050. The Institute has advocated for an egalitarian sharing of emissions abatement costs under which every country brings emissions per capita to the same level.

[23] Toe (ton of oil equivalent) is the amount of energy released by burning one ton of crude oil, approximately 42 GJ or 11.63 MWh (according to the IEA and OECD).

Figure 3. CO_2 intensity of energy use in Poland and EU27

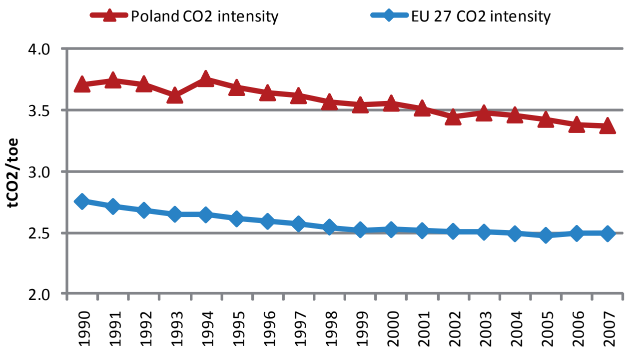
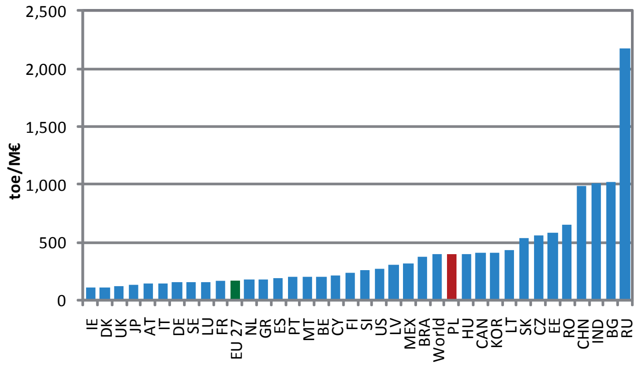
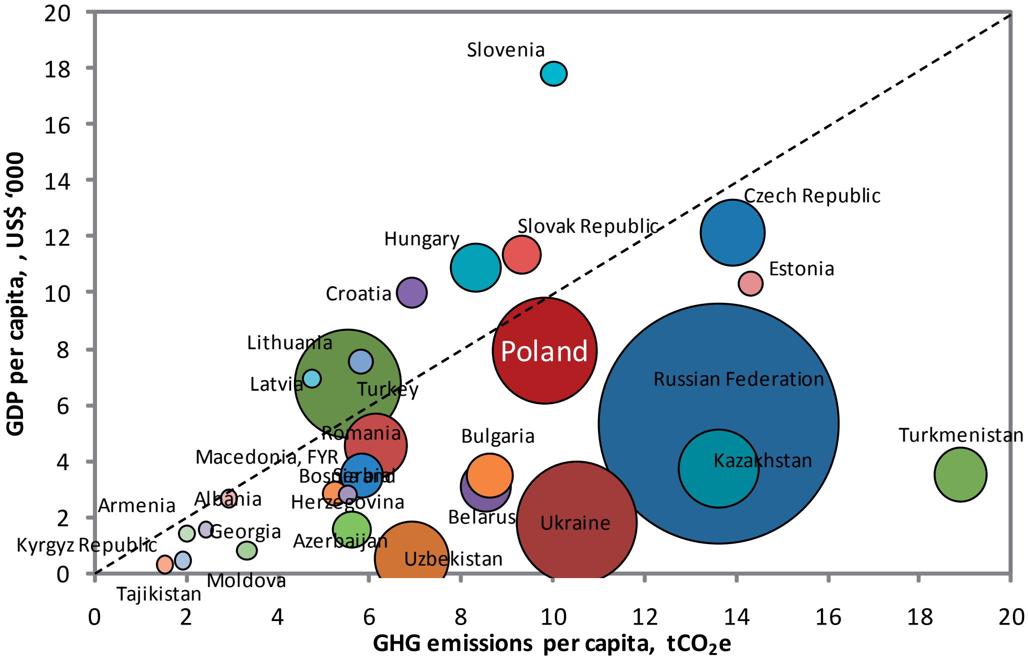


Figure 4. Energy intensity across countries, 2007 (toe/M€)



Note: CO_2 intensity is measure in metric tons of CO_2 per tons of oil equivalent consumed. Energy intensity is the ratio of gross inland consumption of energy (in toe, tons of oil equivalent) to GDP (in million euros at 2000 prices).
Source: European Commission, World Bank staff calculations.

Figure 5. Carbon intensity in Central and Eastern Europe and Central Asia, 2005



Note: Size of circle indicates total CO_2e emissions for each country.
Source: World Bank staff calculations.

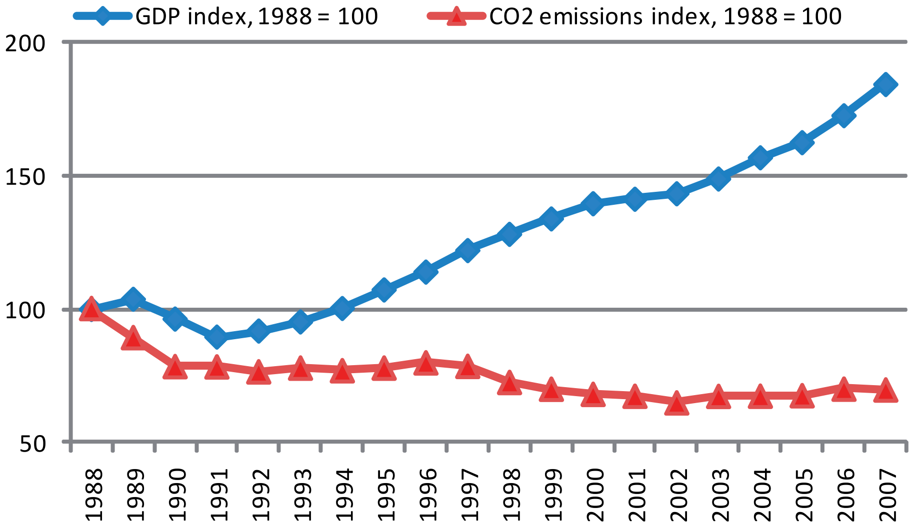
Poland's transition to a market economy had a co-benefit of sharply reduced carbon emissions. From 564 million metric tons of CO_2e in 1988, greenhouse gas emissions collapsed along with output through 1990 (declining 20 percent), as inefficient, often highly energy-intensive plants shut down during the early years of transition. The period of 1996 to 2002 witnessed another 17 percent decline in emissions but while GDP expanded. Overall, although Poland's GDP near doubled during 1988 to 2008, its GHG emissions were reduced by about 30 percent. Nevertheless, during the last half decade or so, a more traditional positive correlation between GDP growth and GHG emissions has re-established itself. (See Table 1 and Figure 6).[24]

Table 1. Poland's greenhouse gas emissions, 1988, 2000, and 200

Emissions, in $MtCO_2e$	1988	2000	2008
GHG emissions (without LULUCF)	564.0	390.2	395.6
Net emissions/removals by LULUCF	-28.7	-24.5	-39.2
GHG net emissions with LULUCF	535.3	365.7	356.4
GHG emissions (without LULUCF)	1988 to 2000	2000 to 2008	1988 to 2008
Changes in emissions, %	-30.8	1.4	-29.9
Average annual growth rates, %	-3.0	0.2	-1.8

Notes: LULUCF is land use, land use change, and forestry.
Source: Fourth National Communication under the UNFCCC.

Figure 6. Economic growth and GHG emissions in Poland, 1988-2008



Source: World Resources Institute, UNFCCC, Central Statistical Office, World Bank staff calculations.

Poland's types and sources of greenhouse gas emissions resemble those for the rest of the EU except for the electricity sector. The breakdown of Poland's greenhouse gas emissions by type of gas show that its emissions are predominantly CO_2 (with a more than 80 percent share), with the EU overall at about the same level. Compared with the rest of the world, emissions from agriculture are less important in the EU and in Poland. One point of departure from the EU and even from the EU10[25] is Poland's greater emissions from the electricity and heat sector (Figure 7 and Figure 8).

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[24] Net emissions removals by land use, land use change, and forestry (LULUCF) are shown in Table 1. Because they are not a central issue for Poland and because consistent cross-country measurement of LULUCF remains under discussion, the remainder of this report considers emissions without LULUCF.

[25] The EU10 consists of Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia.

Figure 7. GHG emissions by gas, 2007

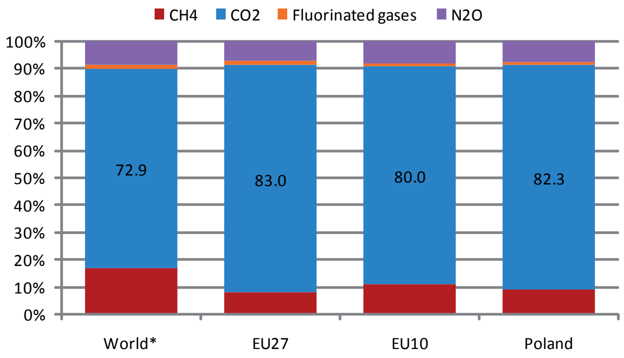
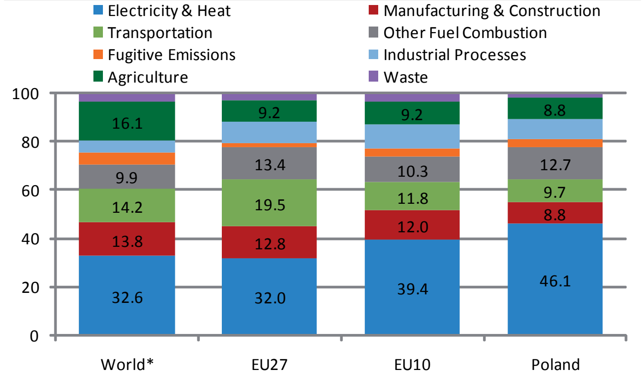


Figure 8. GHG emissions by sector, 2007



*Note: *world data from 2005.*
Source: World Resources Institute, European Commission, World Bank staff calculations.

Poland's energy mix is dominated by coal to such an extent that it is an outlier in both Europe and globally. In contrast to the EU overall or even to the EU10, in Poland solid fuels (coal and lignite) constitute 57 percent of gross inland energy consumption (Figure 9). The share of natural gas (13 percent) and renewable energy (5 percent) are significantly below the EU15 and EU10. Also, Poland is one of 11 countries in the EU and one of 3 countries in the EU10 with no energy generated by nuclear power plants. Poland's dependence on domestically available coal is one of the highest in the world. Over 90 percent of electricity in Poland is generated from coal and lignite (Figure 10), which is the highest share in the EU.

Figure 9. Energy consumption by fuel, 2007

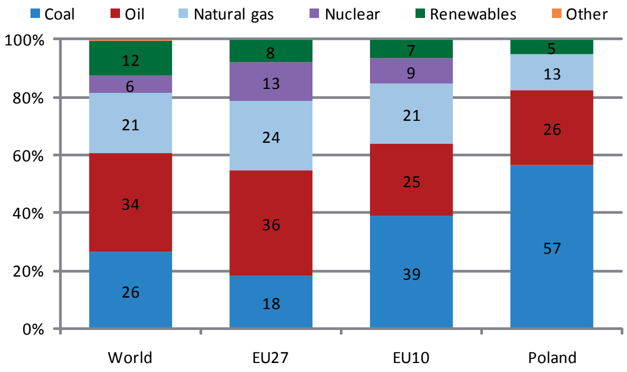
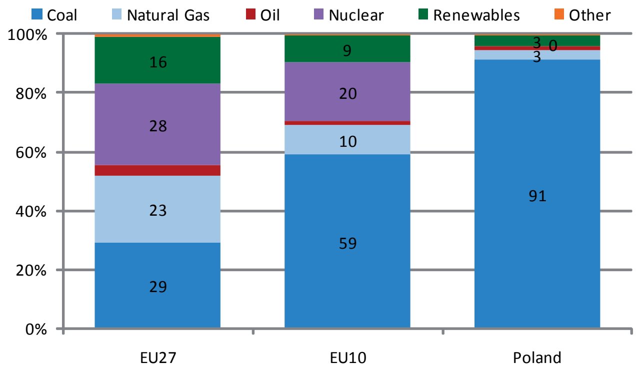


Figure 10. Electricity generation by fuel, 2007



Note: Energy consumption is gross inland consumption of energy.
Source: European Commission, World Bank staff calculations.

Poland has made considerable advances in energy efficiency in the past 20 years; yet further efforts are required to bring it to Western European standards. Per unit of GDP, Poland's economy is still more than twice as energy intensive as the EU average.[26] Advances in energy efficiency, which were dramatic during 1988 to 2000, have slowed during the most recent decade (see Figure 11). Consumption of energy per € of GDP has fallen by half during 1990 to 2007, from 781 tons of oil equivalent required for every hundred million euros of output to 400. From a level of energy intensity 3.4 times higher than the EU average, Poland as of 2007 stands 2.4 times above the EU.

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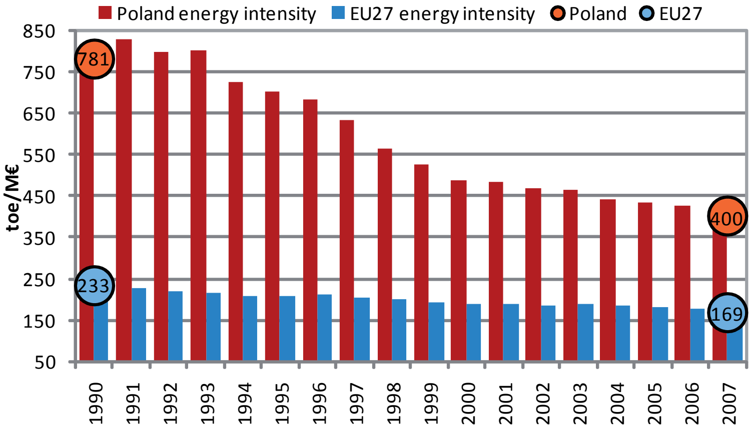
[26] Alternative statistics, using GDP adjusted for purchasing power parity, as reported by the IEA, suggest a smaller gap between Poland's and Western European energy intensity of about 30 percent.

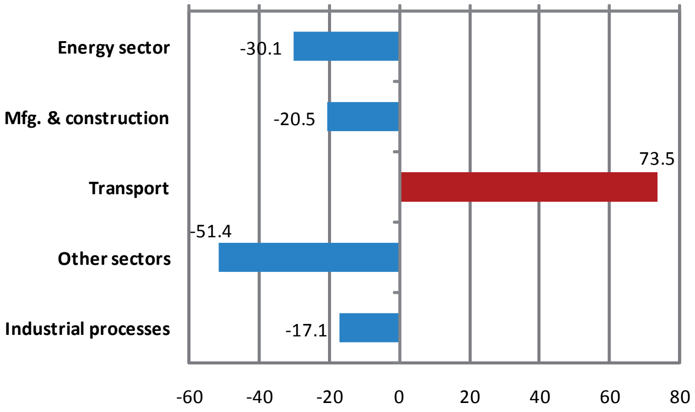
Figure 11. Energy intensity in EU27 and Poland, in toe/M€



Note: Energy intensity is the ratio of gross inland consumption of energy (in toe, tons of oil equivalent) to GDP (in millions of euros at 2000 prices).
Source: European Commission, World Bank staff calculations.

While the energy sector currently dominates Poland's emissions profile, emissions from the transport sector have been growing at a high rate. Energy sector emissions have fallen by one-third since 1988, although the sector still produces near half of the country's greenhouse gases. Transport, on the other hand, while constituting about 10 percent of overall GHG emissions has grown by almost three-quarters since transition. Moreover, Poland still has relatively low rates of motorization, which argues that the growth of road transport will likely be high going forward. Further complicating the picture is the very high share of used vehicles, which tend to be much more fuel inefficient and polluting (see Figure 12).

Figure 12. Change in GHG emissions by key sector, 1988 to 2006, in percent



Note: Industrial processes emissions consist of by-product or fugitive emissions of greenhouse gases, excluding emissions from fuel combustion.
Source: UNFCCC, Greenhouse Gas Inventory, 2006.

The level and structure of Poland's greenhouse emissions will be important as the next sections lay out the challenges of moving towards a lower carbon growth path. Poland's overall carbon intensity of GDP, the sectoral composition of emissions, its dependence on coal, and its progress to date will all be important factors in assessing the economic costs of abatement. The combination of large energy and carbon efficiency gaps in Poland and huge investment requirements in energy, infrastructure, and housing suggests there is a substantial scope for climate-smart policy choices that would likely yield benefits regardless of climate developments.

b.

CARBON ABATEMENT TARGETS AND POLICY CHALLENGES FOR POLAND

The international agreement on climate change that will eventually supersede the Kyoto Protocol and, more immediately, compliance with EU policies on climate change, pose policy challenges for Poland. Poland's greenhouse gas emission levels and its achievements to date seem to argue that further movement towards a low emissions economy might simply be a matter of accelerating existing momentum. On the other hand, Poland's heavy dependence on coal would seem to make such a transition highly challenging. While Poland has been actively involved in global discussions on climate change policy and has easily met the Kyoto Protocol's requirements for emissions reduction, the country now faces a complex set of regulations under the EU's climate and energy package and will likely face ambitious mitigation targets as part of an eventual global agreement.

Poland has been an active participant in international negotiations on climate change. Poland participated in the Earth Summit in Rio de Janeiro in 1992 and adopted the United Nations Framework Convention on Climate Change. In mid-1998, Poland ratified the Kyoto Protocol (Box 2) and committed to a modest reduction of GHG by 2012 (see Box 2). The country hosted the 14th Conference of the Parties (COP-UNFCCC) to review the Convention's progress and discuss its successor at Poznan, Poland in December 2008; and with Indonesia (the chair of the preceding COP in December 2007), and Denmark (the chair for December 2009), Poland formed a 'troika' of countries aiming at a new treaty agreement to replace the Kyoto Protocol which lapses in 201

Box 2. The Kyoto Protocol of the UNFCCC

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change. While the UNFCCC encouraged industrialized countries to reduce GHG emissions, the Kyoto Protocol set binding targets for Annex 1 Parties--37 industrialized countries, including all members of the European Union--by an average of 5 percent against 1990 levels over the five-year period 2008-2012. Some countries with economies in transition negotiated a pre-transition base year: Bulgaria (1988), Hungary (average of 1985 to 1987), Poland (1988), Romania (1989) and Slovenia (1986). The Protocol was adopted in Kyoto, Japan, in December 1997 and entered into force in 2005. Among industrialized countries, only the United States failed to ratify the Protocol. Countries must meet their targets primarily through national measures, but the Protocol offers three alternative (or flexibility) mechanisms:

- International emissions trading ("the carbon market"). Annex 1 countries that have emissions permitted but not "used" are allowed to sell excess capacity to other Annex 1 countries. Because carbon dioxide is the principal greenhouse gas, the market is called the "carbon market." At present, the European Union Emissions Trading Scheme (EU ETS), established in 2005, is the largest in operation.
- Clean development mechanism (CDM). Annex 1 countries can meet part of their caps using credits generated by CDM emission reduction projects in developing countries.
- Joint implementation (JI). Annex 1 countries can invest in JI emission reduction projects in any other Annex 1 country as an alternative to reducing emissions domestically.

Source: UNFCCC website.

As noted earlier, Poland's transition to a market economy had a co-benefit of sharply reduced carbon emissions, causing it to outperform against its Kyoto commitments. The country continues to exceed its Kyoto targets by a large margin, with its 2007 level of emissions 29 percent below the base year (against a target of 6 percent).[27] For the EU overall, it has been the large shifts in energy intensity by transition countries who joined the EU in 2004 and 2006 that have allowed the EU as a whole to meet its aggregated Kyoto commitments. The 15 members of the European Union from before 2004 have reduced greenhouse emissions by 4 percent by 2007 compared to the base year, while the EU10 have 35 percent lower emissions. Together, the 27 members of the EU have cut emissions by about 12 percent (exceeding their combined Kyoto target of 8 percent).[28]

Energy security and climate action have been included as key priorities in recent government strategy documents. The Poland 2030 Report was prepared by the Board of Strategic Advisers to the Prime Minister and presented in May 2009.[29] One of its ten key development priorities is a harmonization of climate change and energy challenges to ensure adequate energy supplies while meeting environmental targets, including climate protection. Among Poland's objectives for 2030 are to achieve economic growth without additional demand for primary energy and to reduce the energy intensity of Polish economy to the EU-15 level. The Government's

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[27] Poland can sell its surplus emission reductions to deficit countries under the Kyoto Protocol, which sets specific rules and arrangements (Box 2). The first transaction was with Spain in November 2009, followed by two transactions with Japan and one with Ireland. By end-May 2010, the total value of transactions amounted to over €80 million.

[28] But note that Kyoto commitments are for the EU15 and separately for another 10 member states.

[29] Board of Strategic Advisers to the Prime Minister, (2009), Poland 2030: Development Challenges, .

commitment to low-emissions growth was confirmed in the Energy Policy of Poland until 2030, adopted by the Council of Ministers in November 2009.[30] In line with the above, the primary aims of Polish energy policy are to:

- improve energy efficiency;
- enhance the security of fuel and energy supplies;
- diversify electricity generation by introducing nuclear energy;
- develop the use of renewable energy sources, including biofuels;
- develop competitive fuel and energy markets; and,
- reduce the environmental impact of the power industry.

As an EU member state, Poland is subject to EU policies on climate change mitigation. In particular, Poland must comply with the climate and energy package referred to as "the 20-20-20 targets", which was approved in December 2008 (see Annex 1 for more details). This package requires comprehensive action by EU members on overall emissions reduction across all sectors in the economy. With the EU aiming to lead the global action against climate change, it has set ambitious targets for 2020 for itself: a 20 percent reduction in greenhouse gas emissions compared to 1990 levels (a 14 percent reduction compared to 2005); a 20 percent renewable energy target as a percent of gross final energy consumption, including a 10 percent share of biofuels in the transport fuel market; and a 20 percent reduction in primary energy use compared to projected levels under a business-as-usual scenario, to be achieved through energy efficiency improvements.

Table 2. Breakdown of EU 20-20-20 regulations by sector groups

ETS **s**(that must use the EU Emissions Trading Scheme for CO_2 permits)		Non-ETS (with national targets)
Power	Non-power	Transport, construction, services, smaller industrial and energy installations, agriculture, and waste.
Power stations and other large fuel combustion installations	Oil refineries, coke ovens, iron and steel, cement, glass, lime, bricks, ceramics, and pulp, paper and board, petrochemicals, ammonia, aluminum, acid production, and aviation (possibly covered from 2011 or 2012).	

Source: World Bank staff based on EU publications.

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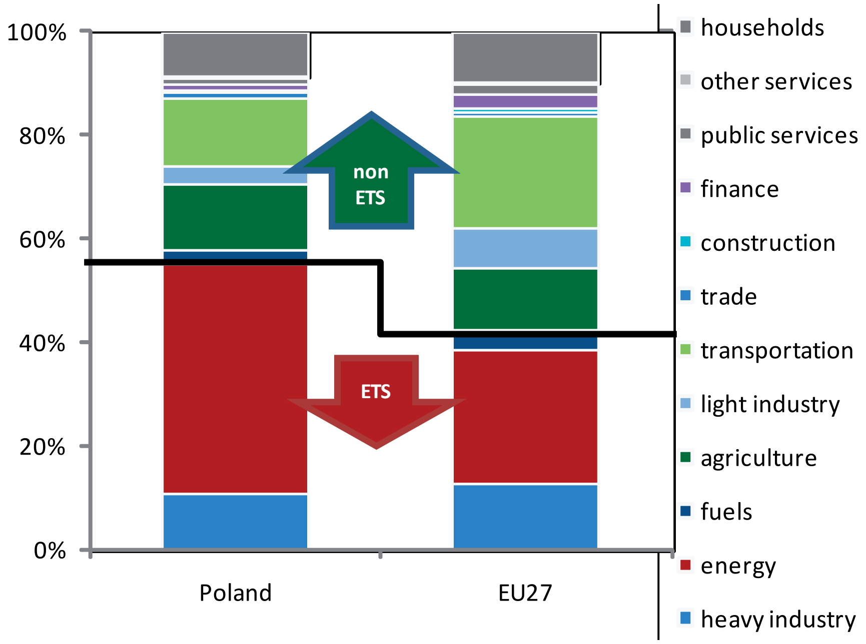
[30] Ministry of Economy (2009), Energy Policy of Poland until 2030, Appendix to Resolution no. 202/2009 of the Council of Ministers, Government of Poland (10 November).

Figure 13. GHG emissions in Poland and EU, by ETS and non-ETS sectors, %, 2005



Note: The breakdown is approximate, based on sector data available in the national accounts. Because the EU regulations apply by installation, the ETS share for Poland is overestimated as it includes small energy installations, for example. Accordingly, the non-ETS share is underestimated. Based on the 2005 data reported by KASHUE-KOBiZE, ETS emissions in 2005 were about 17 MtCO$_2$e lower than the results from the breakdown by sector (203 instead of 220 MtCO$_2$e).
Source: World Bank staff calculation based on EU KLEMS database (on productivity by industry for EU member states with a breakdown into contributions from capital (K), labor (L), energy (E), materials (M) and service inputs (S)).

The 20-20-20 package segments sectors into two groups as well as setting multiple targets. The targets for overall reduction and for renewable energy have been translated into legally binding commitments, while the third target (on energy efficiency) has been left as indicative only. Large installations in energy-intensive sectors are covered by the EU-wide Emissions Trading Scheme (EU-ETS), a cap-and-trade arrangement (see Table 2). These sectors—energy, heavy industry, and fuels—are referred to as 'ETS' sectors, while everything else is categorized as 'non-ETS' sectors. In Poland, approximately 60 percent of CO$_2$ emissions in 2005 were generated in the ETS sectors (compared with about 40 percent in the EU as a whole) (see Figure 13). For the non-ETS sectors, the package requires a reduction in emissions by 10 percent compared to 2005 in the EU27. That EU-wide target was translated into a national target for Poland of an increase in its non-ETS emissions by 14 percent (see Figure 14). Poland also committed to a 15 percent share of renewable energy in gross final energy consumption by 2020 (up from 7.5 percent in 2006), including a 10 percent share of biofuels in the transport fuel market (overall fuel consumption).[31]

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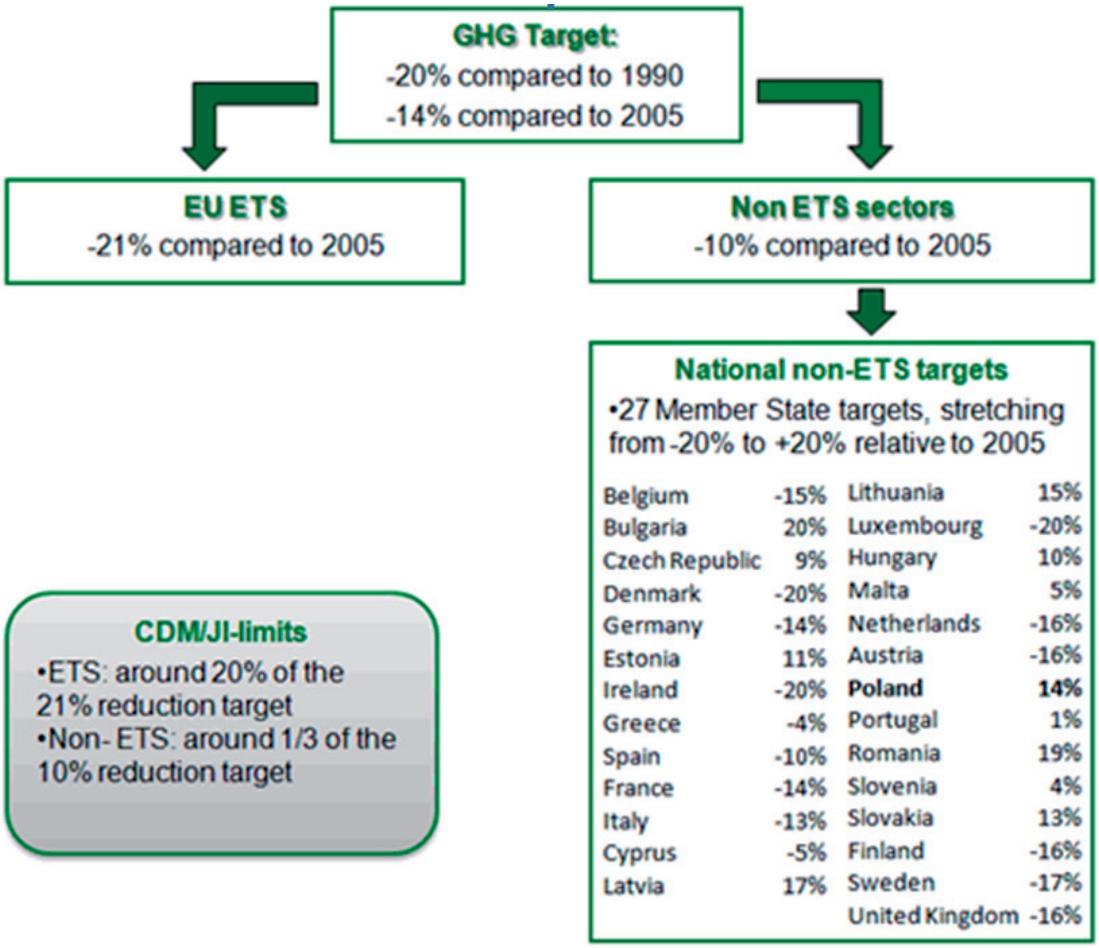
[31] The third "20" of the 20-20-20 package—a 20 percent reduction of primary energy consumption compared to the business-as-usual level for 2020 (that is, an increase in energy efficiency by 20 percent)—is not legally binding.

Figure 14. GHG emission targets in the EU 20-20-20 package



Belgium	-15%	Lithuania	15%
Bulgaria	20%	Luxembourg	-20%
Czech Republic	9%	Hungary	10%
Denmark	-20%	Malta	5%
Germany	-14%	Netherlands	-16%
Estonia	11%	Austria	-16%
Ireland	-20%	**Poland**	**14%**
Greece	-4%	Portugal	1%
Spain	-10%	Romania	19%
France	-14%	Slovenia	4%
Italy	-13%	Slovakia	13%
Cyprus	-5%	Finland	-16%
Latvia	17%	Sweden	-17%
		United Kingdom	-16%

Notes: Emission crediting from projects undertaken in other countries was set up under the Kyoto Protocol (see Box 2). CDM is Clean Development Mechanism; JI is Joint Implementation.
Source: EU regulations; World Bank staff calculations.

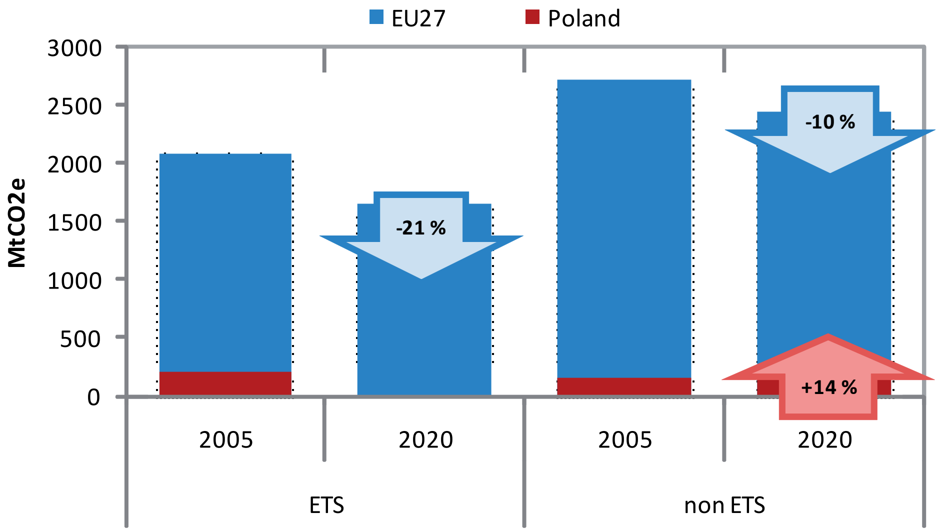
The EU targets are more ambitious than Kyoto targets and, therefore, likely to require more efforts, sectoral adjustments, and resources from EU members to achieve. In contrast to Kyoto, there are no overall country targets. The national targets are only for non-ETS sectors, while the reduction target for ETS sectors is EU-wide. In the most important ETS sector—power—auctions will be phased in gradually from 2013, and full auctioning of ETS permits is to be in place by 2020. Aviation may be included into the EU-ETS as early as 2011. Other industrial ETS sectors will step up to full auctioning by 2020, while sectors particularly vulnerable to competition from producers in countries without comparable carbon constraints (carbon leakage[32]) will have until 2027 to be phased in. In addition, auctions will be open. Thus, any EU operator will be able to buy allowances in any member state. The EU ETS phasing-in process is presented in detail in Annex 1.

The EU 20-20-20 package contains both an EU-wide cap-and-trade approach and possible national carbon taxes. The EU Emissions Trading Scheme for energy-intensive large installations is a cap-and-trade mechanism—policymakers set quantities and the market determines the price. The abatement target for the ETS sectors is EU-wide, and emissions in the EU in 2020 will have to be 21 percent lower than in 2005 (Figure 15). For smaller installations and those in less energy-intensive sectors, each member state may specify additional domestic abatement policies to comply with their country-specific targets, and many may consider introducing carbon taxes in

[32] Carbon leakage occurs when emissions reductions are offset by increases in other countries. For example, if the emissions policy of the first country raises local costs, a trading advantage may be created for the other country with lower standards, and production may move offshore.

these sectors—that is, setting prices instead of quantities. As discussed in Annex 2, policymakers can choose between controlling price and controlling quantity, taking into consideration aspects such as transparency, operating (or transaction) costs, public acceptability, dynamic efficiency, revenue and distributional issues, and international harmonization.

Figure 15. EU-wide and Poland's 2020 targets, ETS and non-ETS sectors, $MtCO_2e$ and % vs. 2005



Source: UNFCCC, European Commission, World Bank staff calculations.

Poland is likely to receive significant fiscal revenues in the future from ETS auctions. Revenues from the ETS will add to member states' revenues in proportion to the emissions traded through their national systems. The allocation of the revenues will be a national policy choice; however, countries are encouraged by the EU to use at least half of them on 'green' initiatives. The EU also encourages that part of the revenues go towards helping developing countries adapt to climate change. Future fiscal revenues from ETS auctions in Poland, as elsewhere, will be inversely related to the number of allowances allocated for free. The potential derogations for the modernization of electricity generation[33] and granting emission allowances for free will proportionally decrease revenues from auctions. A very rough estimate of total potential allocation over 2013-2020 is 1.8 billion metric tons of CO_2. Assuming, for example, that 50 percent of allowances in the EU will be distributed for free during 2013-2020, the remaining 900 million will be auctioned. At a price of €15, which is close to the market price of carbon as of late May/June 2010, total revenues during 2013-20 would reach more than €13 billion; if the price were higher, e.g., €25, revenues would exceed €22 billion. According to some preliminary estimates for 2013 applying EU regulations[34], Poland may have 155 $MtCO_2$ of allowances available for auctions (see Table 20 in Annex 1), which would be worth over €2 billion at a carbon price of €15 per metric ton, or near €4 billion at a price of €25. These amounts are equivalent to 0.8 and 1.3 percent of projected GDP in 2013, but any derogations or free allocations would reduce the auction receipts available for the budget.

There are costs, however, in this dual and segmented approach. In principle, the initial allocation of the EU-wide emission cap between ETS and non-ETS sectors at the EU level and the subsequent split of the non-ETS budget across Member States need not have adverse implications for cost-effectiveness as long as comprehensive emissions trading across all segments of the economy is assured. However, current EU legislation does not foresee such trading. Diverging marginal abatement costs across emission sources are a likely consequence of this segmentation, causing emission abatement in the EU overall to become much more expensive compared to a comprehensive EU-wide cap-and-trade system and causing substantial burden shifting between ETS and non-ETS segments (Box 3). While EU legislation does allow for some flexibility, with limited abatement beyond EU borders through crediting from emission-saving

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[33] A derogation is a provision in EU legislation that permits greater flexibility in the application of the law to take into account special circumstances. In this case, under EU rules, transitional free allocations will be available for any new power plants for which construction began by end-2008, as part of support for modernization of electricity generation.

[34] E. Smol (2010), Metodyka wraz z Przykładowym Obliczeniem „Limitu" Krajowej Emisji Gazów Cieplarnianych dla Polski na lata 2013-2020 (Dyrektywa EU ETS i Decyzja NON-ETS) [Methodology and calculation of the country's GHG emissions limit for Poland 2013-2020] , KASHUE-KOBiZE.

projects undertaken in third countries via Joint Implementation (JI) or the Clean Development Mechanism (CDM), only part of EU member reductions can be covered through extra-EU abatement, in order to comply with principles of additionality and supplementarity.[35] Although the rules on access to CDM credits are complex, in summary, non-ETS sectors are allowed to purchase about one-third of their emission reduction requirement from outside the EU, and ETS sectors can offset up to one-fifth of their ETS requirement (Figure 14 and Annex 1).

Another potential source of excess costs can be traced back to the use of multiple instruments in EU climate policy. Setting overall emissions targets, binding goals for renewable energy production, and proposals for energy efficiency improvements is liable to generate excess costs due to overlapping and counterproductive regulation. If a target for energy efficiency becomes binding in addition to those for renewable energy and overall emissions, the outcome will move even further from the cost-effective solution generated by comprehensive emission trading and likely create additional costs. In an economically efficient setting, the relative contribution of renewables and energy efficiency should be determined by markets.

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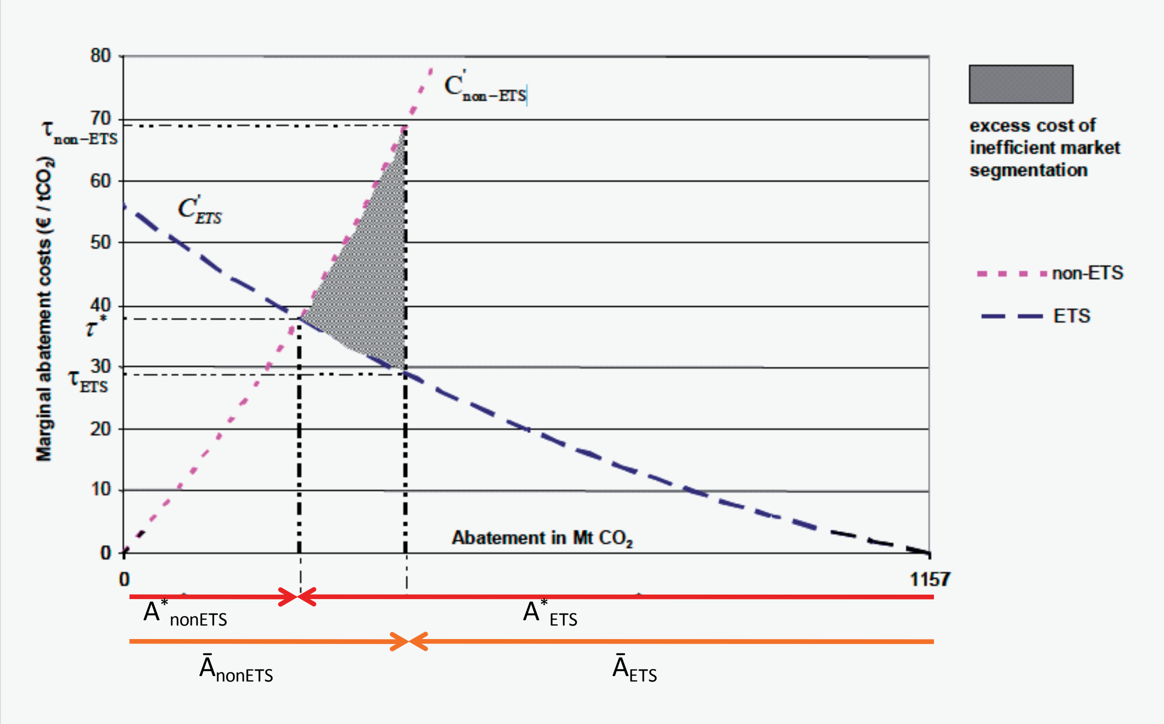
[35] These are two important principles of the flexibility mechanisms under the Kyoto Protocol, in particular the CDM: that there is additionality of any emissions-reducing project (to avoid giving credits to projects that would have happened anyway) and that supplementarity holds, i.e., that internal abatement of emissions should take precedent before external participation in flexible mechanisms.

Box 3. Excess costs of emission market segmentation

Figure 16 illustrates the pitfall of EU emission market segmentation, based on (estimated) aggregate marginal abatement cost curves for the ETS and non-ETS sectors in the year 2020. Total emission abatement in 2020 equals the difference between EU-wide baseline emissions and the targeted emission ceiling (86 percent of the 2005 EU emission level or a 14 percent reduction). Comprehensive emissions trading leads to a uniform EU-wide emission price τ^* at the intersection of marginal abatement cost curves C'_{ETS} and C'_{nonETS}. The efficient allocation of abatement burden between ETS and non-ETS sectors (A^*_{ETS} and A^*_{nonETS}) will be endogenously determined through the uniform emission price τ^*. If instead ETS and non-ETS markets are not linked through emissions trading, then the administrative partitioning of abatement requirements between ETS and non-ETS sectors by setting emissions ceilings for each segment must exactly equal the efficient split to achieve cost-effectiveness. However, to do so, the EU planning authority would require perfect information on the future effective abatement requirement as well as the future marginal abatement cost curves for ETS and non-ETS sectors. If the estimated marginal abatement cost curves in Figure 16 are reasonably accurate, in particular that the slope of the curve for non-ETS sectors is much steeper, then the prescribed EU partitioning (requiring about 60 percent of total abatement from ETS sectors and about 40 percent from non-ETS sectors) is rather inefficient, shown by $\bar{A}_{ETS}$ and $\bar{A}_{nonETS}$. The deadweight loss with differential emission pricing (with the marginal cost of abatement from non-ETS sectors, τ_{nonETS}, far above that for ETS sectors, τ_{ETS}) is shown by the shaded area. Furthermore, a policy with at least twenty-eight CO_2 prices (one for ETS, one for the non-ETS sector in each EU Member State) will further boost excess costs.

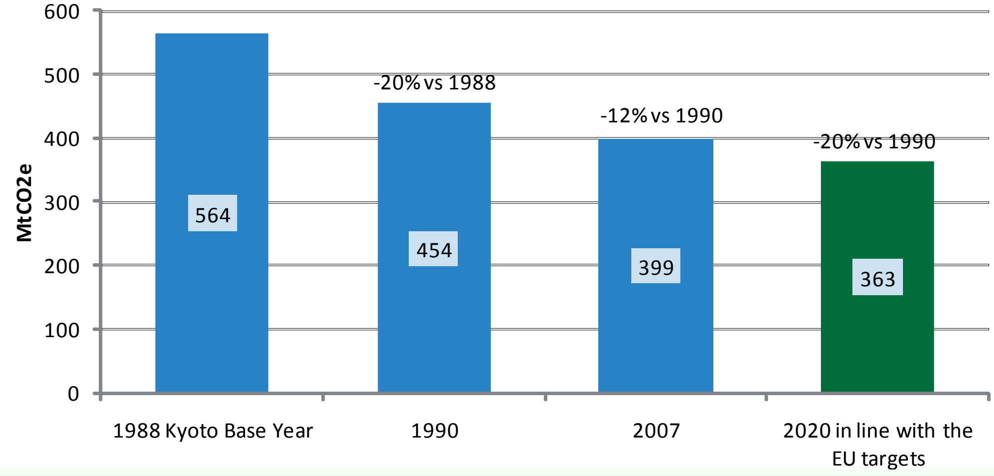
Figure 16. Deadweight loss in emission markets



Source: Böhringer, C., A. Löschel, U. Moslener, and T.F. Rutherford (2009), EU Climate Policy Up to 2020: An Economic Impact Assessment, Energy Economics 31, 295–305.

At first glance, it seems Poland is not far from meeting the EU's 2020 overall targets of 20 percent reduction compared to 1990. Because there is no overall national reduction target for Poland, measuring the distance to the 2020 target is hypothetical. It assumes that Poland has to reduce its emissions in line with the 20 percent EU-wide target relative to 1990. In 2007, Poland's GHG emissions were already 12 percent below the 1990 level (Figure 17). To achieve the 20 percent 2020 reduction target, Poland would need to reduce its emissions by an additional 35 $MtCO_2e$, which is 9 percent below the 2007 level. However, given that Poland's impressive achievements during the 1990s were driven by economy-wide restructuring, it is a more complicated question going forward as to whether ongoing efficiency gains and sectoral evolution will outweigh the rising demand for energy generated by economic growth.

Figure 17. Poland's historical GHG emissions and EU-wide 2020 target



Source: UNFCCC, European Commission, World Bank staff calculations

Poland's target for renewable energy appears more challenging. According to the renewable energy sources directive, while the EU overall has committed to raise the share of renewables in final energy demand from 8.7 percent in 2005 to 20 percent in 2020, Poland has to double its share from 7.5 percent in 2006 to 15 percent in 2020. Compared to other EU members, this target does not look overambitious (Figure 18). Yet, progress in recent years in Poland has been relatively slow, with the renewable energy source share in final energy consumption growing from 2.3 percent in 1992 to 6.5 percent by 2000, but only to 7.5 percent in 2006. In addition, Poland's renewables are not diversified. Biomass dominates, while sources like hydro, wind, solar, and geothermal energy have not been developed (Figure 19).

Figure 18. Share of renewable energy sources in final energy consumption

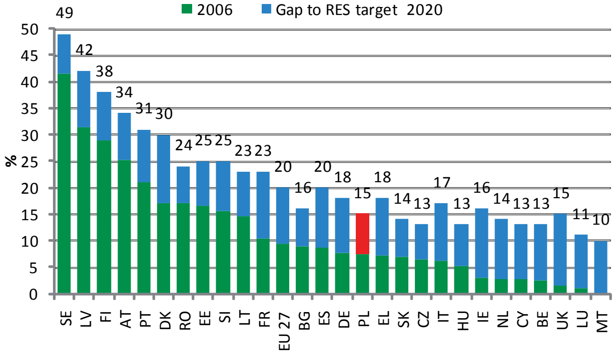
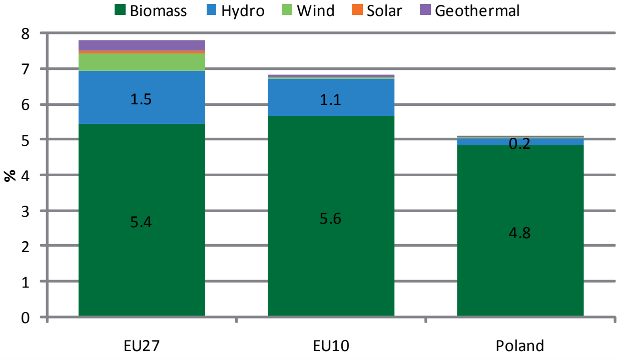


Figure 19. Share of renewable energy sources in gross inland energy consumption, 2007



Note: Gross inland energy consumption is energy consumption by the energy sector itself, distribution and transformation losses, and final energy consumption by end users (final energy consumption).
Source: European Commission, World Bank staff calculations.

Energy efficiency is often seen as the easy place to start in considering GHG mitigation, but exploiting the energy efficiency agenda is not easy. It is often seen as a 'win-win' option, with benefits realized relatively quickly and lower upfront costs. Yet much of energy efficiency potential remains untapped because of the many obstacles to investments in energy efficiency: inadequate domestic energy prices and lack of payment discipline, insufficient information on suitable technologies, too few contractors and service companies, and financing constraints. Effective energy efficiency interventions combine market-based approaches (which send correct price signals) with regulations (which support changes in practices and behaviors of economic agents). The two components operate coherently only in tandem—regulations will not bring results without adequate energy pricing policy.

A transition towards a low-emissions economy may also present opportunities to Poland. As more regions and countries adopt abatement targets, the demand for products and processes with lower greenhouse gas emissions will accelerate. Innovation will be critical in this growing market for clean technology—the expertise and equipment related to new developments in areas such as renewable energy (in particular, wind power, solar power, biomass, hydropower, and biofuels), electric motors and low emission transportation, energy efficient lighting and appliances, and green buildings. The energy sector, the dominant source of today's emissions, is also the focus of much clean technology—clean energy. Given the well-established fact that the private sector acting alone will tend to underinvest in research and development (R&D), governments who are moving early towards abatement, such as Poland's, need to consider whether active support to clean technology R&D is an important complementary policy measure.

This description of Poland's mitigation targets and some of the complexities facing policymakers helps set the stage for a more comprehensive assessment of Poland's possible transition to a low emissions growth path. Three aspects, in particular, stand out and will be the focus of the next sections of this report:

- The negotiation of a base year for Kyoto obligations that preceded Poland's transition to a market economy further eased the already modest targets for 2012. Selection of base years affects the strictness of agreed targets (often defined as a percent reduction), but even more critical to understanding how much adjustment will be needed to hit a policy target for GHG mitigation, how is the economy likely to develop in the absence of the climate change target, under 'business-as-usual'?
- Despite slow progress in UNFCCC negotiations, it has been relevant for some time for Polish policymakers to consider in detail, how challenging would more ambitious overall mitigation targets be for Poland?
- As the EU 20-20-20 package progresses in implementation, with its complex set of overlapping regulations, what impacts will compliance have on Poland's economy?

C.

A SUITE OF MODELS TO ASSESS EMISSIONS ABATEMENT

To address the issues set out in the last section, engineering and sectoral analyses are integrated into macroeconomic modeling via a suite of models, to allow improved analysis of the feasibility of emissions mitigation, including its impact on growth, sectoral output and employment. With the objective of assessing the macroeconomic and fiscal implications of greenhouse gas mitigation policies for Poland, a suite of innovative analytic tools were developed to analyze abatement prospects not only from the usual bottom-up engineering perspective but also with economy-wide models that explicitly link to the technological options assessed in the engineering approach. This work builds on existing analyses of low carbon growth undertaken for other countries, in particular, the other six low carbon growth country studies supported by the World Bank (Brazil, China, Mexico, India, Indonesia, and South Africa).[36] First, a bottom-up engineering model with an intensive analysis of the power sector helped identify cost-effective abatement measures. Then a large scale, multi-sector dynamic stochastic general equilibrium model translated the engineering model's technical options into economic impacts. A multi-sector, multi-country computable general equilibrium model which incorporated a hybrid bottom-up and top-down representation of the power sector analyzed the economic impact on Poland of EU climate policy implementation. Lastly, an alternative engineering approach to the transport sector was developed to examine this key sector in more detail. Together, this suite of models yields a series of insights on how Poland might best move towards a lower carbon future.

Other low carbon growth country studies have generally depended on detailed bottom-up sectoral work, often supplemented by separate top-down macroeconomic modeling; thus, it seemed that the next methodological step would be full integration of approaches into a single model. Sectoral work can provide country-specific recommendations for action at the sector or subsector level while macroeconomic modeling ensures the basic consistency of projected sectoral growth rates, energy demand, and other key variables. The recent World Bank study on Mexico took this approach, with in-depth sectoral and subsectoral studies (of electric power, oil and gas, energy end-use, transport, and agriculture and forestry) and relatively simple macroeconomic modeling focused on energy demand.[37] The report by the UK Committee on Climate Change (2008) is a good example of applying these two complementary approaches with more sophisticated macroeconomic modeling.[38] When this study began, its objective was to develop a model that integrated bottom-up analysis with top-down analysis. However, it became clear that the more comprehensive a model, the more complex it needs to be, and the more likely it will become a 'black box' intelligible only to its designers. Given the long horizon of this modeling—10 and 20 years—degrees of uncertainty are amplified. Thus, this study moved towards the more robust approach of developing a suite of models shaped to the policy scenarios and sectoral questions to be assessed and the availability of data. By taking this diversified approach, it is hoped policymakers will focus not just on bottom line conclusions but also keep an eye on the assumptions and structures that generated those results. In other words, modeling should be for insights, not for numbers.

Three (and a half) complementary and interlinked models for Poland were developed to quantify the economic impact of CO_2 mitigation, taking advantage of available data and leveraging existing models. The most familiar of these models is likely the widely-used microeconomic Marginal Abatement Cost (MAC) curve which provides a simple first-order ranking of technical options for GHG mitigation by sector based on the net present value of costs and savings per metric ton of CO_2 equivalent avoided. Then, two different economy-wide models were developed, a dynamic stochastic general equilibrium model and a computable general equilibrium model, both of which are standard tools for economic impact assessment.[39] The Macroeconomic Mitigation Options (MEMO) model, a DSGE model of Poland revised to include energy and emissions, assesses the macroeconomic impact of the options costed in the MicroMAC curve. It is linked to the MicroMAC curve via a Microeconomic Investment Decisions (MIND) module which grouped the technology levers into seven packages, including an optimized package of options for the energy sector. The Regional Options of Carbon Abatement (ROCA) model, a country-level CGE model for energy and GHG mitigation policy assessment adapted to Poland, analyzes implementation of the EU 20-20-20 policy in the context of global policy scenarios, with an emphasis on spillover and feedback effects from

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[36] See the documents on the ESMAP (Energy Sector Management Assistance Program) website at http://www.esmap.org/esmap/node/69.

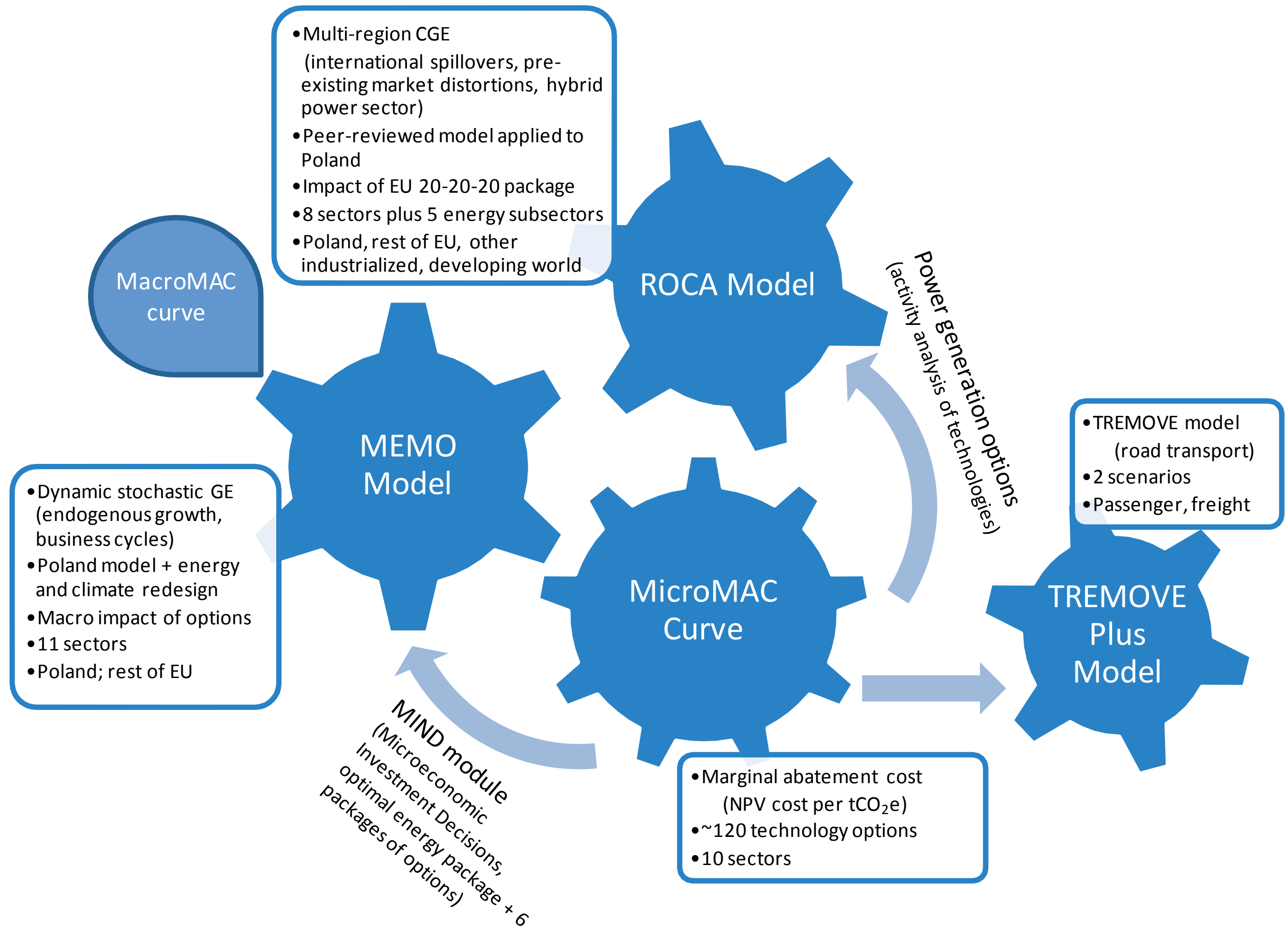
[37] Johnson, Todd M., Feng Liu, Claudio Alatorre, and Zayre Romo, eds., (2008), Mexico Low-Carbon Study, World Bank (December).

[38] Committee on Climate Change (2008), Building a Low-Carbon Economy - the UK's Contribution to Tackling Climate Change, The First Report of the Committee on Climate Change, UK, December.

[39] Among top-down models, there is often an exaggerated divide between econometric demand-driven Keynesian models and CGE models. Popular but unjustified arguments against the informational value of CGE models include that these models must be calibrated (and thus, lack empirical evidence) and can neither reflect disequilibria (such as unemployment or under-utilization of production capacities) nor transitional dynamics. In turn, econometric Keynesian models are often accused of a lack of micro-foundations. These claims ignore substantial developments during the last two decades to overcome such policy-relevant shortcomings. When it comes to providing a sound and flexible backbone tool for economy-wide climate policy analysis, a strong case can be made for applying CGE or DSGE models, which have become a standard tool for economic impact assessment.

international markets.[40] The last "half" model is a detailed sectoral approach for road transport, the sector with the fastest growing emissions and central to Poland's commitments under EU 20-20-20 (as a non-ETS sector). It makes use of the EU transport and environmental model, TREMOVE,[41] updated with the latest information and policy intentions, here denoted as the TREMOVE Plus model. All three (and a half) used very similar "business-as-usual" reference scenarios (within the limitations of data) against which to measure policy changes (discussed in detail in the next section). Figure 20 below summarizes the modeling approach, which is described in more detail in the rest of this section.

Figure 20. Model suite for low-emissions growth assessment for Poland



Source: World Bank staff.

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[40] The MEMO model allows financing for energy sector investments via the private or public sector and through a choice of policy closures: reduction in social transfers or public consumption, higher taxes such as VAT, or an indirect carbon tax. The ROCA model assumes public consumption remains constant and taxes adjust. The models' critical exogenous variables include carbon and fossil fuel prices into the future, which have an impact both on the energy mix and on final macroeconomic results. The two macro models reflect Poland as a small, open economy with access to external offsets (both CDM and JI as allowed under EU policy).

[41] TREMOVE is an EU transport and environmental policies assessment model. The acronym is derived from earlier EU transport models—approximately, traffic and emissions motor vehicle model.

The Microeconomic Marginal Abatement Cost (MicroMAC) curve represents a ranking by net cost of about 120 emission reduction 'levers'. The costs and abatement potential of more than 200 technical options or 'levers' for GHG abatement across the 10 largest sectors of the economy were analyzed, pared down to a set of 120 most relevant for Poland. They include measures such as a shift from coal to nuclear power and energy efficiency standards for new residential buildings. A business-as-usual case was constructed to serve as the baseline for future emissions reductions. Detailed bottom-up estimates for each intervention or lever were constructed. Possibilities and constraints in the power sector were studied with particular care. Levers that would require significant consumer lifestyle changes were not considered. Costs did not take into account transactions costs, taxes, subsidies, feed-in tariffs, and other governmental measures. A risk-free financing rate of 4 percent was used to generate net present values. Third, these levers were ranked according to their costs and presented in a summary graphic, a marginal abatement cost (MAC) curve. This visual presentation provides a wealth of information to policymakers and transforms the high-level objective of emissions abatement into detailed and specific sectoral choices. However, MicroMAC curves need to be read with a degree of caution--despite their apparent simplicity, they are heavily dependent on underlying assumptions, including the business-as-usual scenario, costs and abatement potential of each technology, and appropriate discount rates.

The Macroeconomic Mitigation Options (MEMO) model is a large scale DSGE model of Poland that includes energy and emissions. The earlier version of the model, without climate change features, is known in Poland among economists and macroeconomic policymakers, having been applied to issues such as the impact of joining the common currency area.[42] This dynamic stochastic model is large scale, with over 2000 variables (compared to the typical DSGE with fewer than 200 variables). The version redesigned for GHG abatement drew data from GUS (Poland's statistical office), EUROSTAT, and the EU KLEMS databases,[43] used 2006 as a base year, and has 11 sectors (agriculture and food; light industry; heavy industry; mining and fuels; energy; construction; commerce; transport; financial services; public services; and other services). It models an open economy, trading goods with the foreign sector (the rest of the EU). Special care was devoted to the real side of the economy. Labor markets feature imperfect competition where both seeking a job and finding employees is costly, wages are negotiated, and unemployment exists. The tax structure is detailed (corporate and personal income taxes, VAT and other taxes such as on property are included). Public expenditures include public consumption, investment, and transfers to households. Production includes a full input-output table for capital, labor, energy and materials. Emissions are generated as a byproduct, based on the amount of energy used and the energy intensity of the sector. (See Annex 3 for more details.)

The MEMO model ran simulations to calculate the macroeconomic impact of MAC curve mitigation options. The model was calibrated on the most recent available data for Poland, and only a small number of parameters are exogenous, based on outside empirical studies. The model is capable of mimicking the cyclical properties of the data with just four shocks. Four financing methods, or model closures, were considered (adjustment of public consumption, of social transfers, of VAT, or of personal income tax). The impact of abatement measures on a large variety of macroeconomic variables by sector, such as output, employment, emissions, household welfare, and fiscal revenues and expenditures, can be estimated by the model, which provides 5-year snapshots through 2030. This structure allows a dynamic assessment of the macroeconomic impact of the options costed in the MicroMAC curve, including a new visual presentation—a macroeconomic version of the MicroMAC curve. While this simplified graphic of results helps communicate the main findings of the MEMO model, and while this model remains both highly flexible and heavily detailed, it is a very large and complex model not easily accessible even to the professional economist.

A key innovation of the MEMO model is the design of a method to link to the MicroMAC curve, via a Microeconomic Investment Decisions (MIND) module. The MIND module transforms the MicroMAC curve levers so they can be analyzed in the MEMO model. Each lever is described by two 20-year time series (2010-2030), reflecting the expected capital and operating expenditures/ revenues from the given measure. Those numbers include technological assumptions, e.g., the scope of investments in the GHG abatement technologies and the resulting operating expenditures or savings. While derived from the engineering analysis, the dataset was supplemented and updated in accordance with macroeconomic data from EUROSTAT. In particular, for each lever from the MicroMAC package, new estimates were calculated of projected GHG abatement to be achieved if the lever is implemented. The MIND module was applied to find those abatement opportunities which are relatively cheap, offer considerable carbon abatement potential and are technically feasible via a multi-criterion optimization.

The MIND module creates seven packages of levers to be analyzed, including an optimized package of options for the energy sector. It assigns each lever from the MicroMAC package to one of seven categories: (1) agriculture interventions, (2) industry carbon

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42 IBS (2008) "Assessing Effects of Joining Common Currency Area with Large-Scale DSGE model: A Case of Poland", IBS Working Paper #3/2008, Institute for Structural Research, Warsaw, available at http://ibs.org.pl/publikacja/Effects_of_Joining_Common_Currency.

43 GUS is Główny Urząd Statystyczny, or Central Statistical Office, the national statistics office in Poland. EU KLEMS is the EU database on capital (K), labor (L), energy (E), materials (M) and service inputs (S) productivity.

capture and storage (CCS)[44] and distribution maintenance, (3) chemical processes, (4) energy efficiency, (5) fuel efficiency, (6) mixed energy/fuel efficiency, and (7) low-carbon energy supply (via energy sector investments). While the first six intervention groups were selected in the sectoral bottom-up analysis, the composition of levers in the last and most important sector (energy) was determined endogenously by the MIND module. The optimization was carried out by, first, computing the NPVs of new power plants of each type. Then, the government subsidy necessary to equalize its NPV with that of a traditional coal plant is calculated, within the constraint of the overall GHG reduction target in the energy sector (which according to the bottom-up sectoral data is about 50 percent relative to the BAU scenario). Finally, the cheapest feasible energy-mix package is determined, taking into account any technological constraints (such as the maximum availability of a given technology), energy production constraints (i.e., the BAU level of energy consumption), and the GHG reduction target (desired abatement). This optimal energy package is incorporated into the overall mitigation policy-options package that forms the basis for the MEMO model simulations.

The Regional Options of Carbon Abatement (ROCA) model is a country-level CGE model for energy and GHG mitigation policy assessment adapted to Poland. It starts from a static multi-sector, multi-region CGE model framework that has been used repeatedly for analysis of country and regional CO_2 mitigation, with open source code, use of a well-known algorithm, and extensive peer reviewing. Aggregating from the GTAP database (version 7),[45] the ROCA model of Poland contains 8 sectors (chemicals, aviation, other transport, non-metallic minerals, iron and steel, non-ferrous metals, paper-pulp-print, and other), emphasizing those that are more energy intensive, as well as 5 energy subsectors (coal, crude oil, natural gas, refined oil products, and electricity[46]). To capture key features of the economy, the model includes important market distortions (taxes, unemployment) and a simple government sector (one good). The energy sector gets innovative treatment, discussed below. As compared with the MEMO model, the ROCA model, since it is focused on implementation of the EU 20-20-20 package, produces results for 2020. As explained in Annex 4 , due to the limited availability of projections of non-CO_2 gases, the model tracks CO_2 only.[47]

The ROCA model is designed to analyze implementation of the EU 20-20-20 policy package in the context of global policy scenarios, with an emphasis on spillover and feedback effects from international markets. With this objective in mind, key determinants of economic adjustment to CO_2 emission constraints are incorporated, in particular:

- A hybrid bottom-up/top-down representation of power sector production possibilities with a detailed activity analysis representation of discrete power generation options while production technologies in other sectors are described in a conventional top-down aggregate manner through continuous functional forms trading off alternative input and output choices. This more complex formulation in the most important emissions sector prevents sudden abandonment of existing power generators when prices shift as well as allowing detailed analysis of power sector behavior.
- Global coverage of international trade and energy use across 4 countries/ regions (Poland, other EU, other industrialized, developing countries) to allow analysis of international spillovers and feedback from climate policies in each country, especially those large enough to influence international prices.
- The incorporation of initial energy/trade taxes and labor market rigidities to reflect the interaction of climate policy regulation with pre-existing market distortions. With this formulation, no-regrets options for abatement policies are possible, whereby direct or indirect benefits large enough to offset their implementation costs are generated.
- The appropriate representation of institutional settings and policy instruments for climate policy implementation, including the complex rules for the ETS and non-ETS sectors, and revenue recycling possibilities (e.g., lump-sum versus labor subsidies) from carbon pricing.

The ROCA model, as a modern CGE model, benefits from strong microeconomic foundations and the incorporation of market imperfections as well as more complex power production technologies. It can analyze complex and overlapping policies such as the EU climate package. However, it provides only an assessment for 2020 and only considers CO_2 emissions, and it is limited to 2004 as a base year because of data availability.

[44] Carbon capture and storage (or sequestration) encompasses a number of technologies that can be used to capture CO_2 from point sources, such as power plants and other industrial facilities; compress it; transport it mainly by pipeline to suitable locations; and inject it into deep subsurface geological formations for indefinite isolation from the atmosphere.

[45] The Global Trade Analysis Project (GTAP) database includes information on trade, production, consumption, and intermediate use of commodities and services, as well as GHG emissions and land use. It covers many sectors and all parts of the world. It is housed at Purdue University.

[46] Data limitations in the GTAP database prevented a decomposition that included district heating, which is important in Poland and largely fueled by coal.

[47] To allow comparisons with the MAC curve and MEMO models, it is assumed that the adjustment in non-CO_2 emissions will be proportional, so the percentage change in overall GHG emissions is assumed to be the same as the percentage change in CO_2 emissions. This is consistent with the approach used in the MEMO model, where changes in overall GHG emissions are explained through interventions associated with carbon emissions from the combustion of fossil fuels.

The last piece of modeling in this study is an alternative engineering approach to transport sector mitigation options with the TREMOVE Plus model. The EU transport and environmental model, TREMOVE (v. 2.9-2009), is an EU-wide policy assessment model, designed to study the effects of different transport and environmental policies on the emissions of the transport sector. Calibrated for 31 countries, the model is used to estimate the impact of policies such as road pricing, public transport pricing, emission standards, and others. To become TREMOVE Plus, the model was updated with new projections of transport activity and the latest disaggregated data on vehicle stocks from a wide range of sources including vehicle sales and car import data and from interviews with government officials. While the MicroMAC curve analysis assessed options in road transport, it did not produce separate business-as-usual projections for the sector. Working from a slightly different set of assumptions, the TREMOVE Plus model considers explicitly the characteristics of Poland's road transport sector and assesses the impact of existing policy commitments and possible mitigation options.

This quick overview of the models to be applied to Poland's potential for low emissions growth should be able to provide a sense of the scope of analysis to come. Each model has trade-offs and simplifications. The validity of the set of assumption that underpin each model will depend to a great extent on what question is posed for analysis. What will be important as simulations and results are reported is to link those findings to the underlying model design and the data that drives it. Model-based analysis can put decision-making on a more informed footing. Yet any model, no matter the complexity, remains a crude approximation of the real world, so numerical results will always need to be interpreted with caution. "Modeling for insights, not for numbers, is the real challenge."[48]

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[48] Loch Alpine technical paper, p. 37.

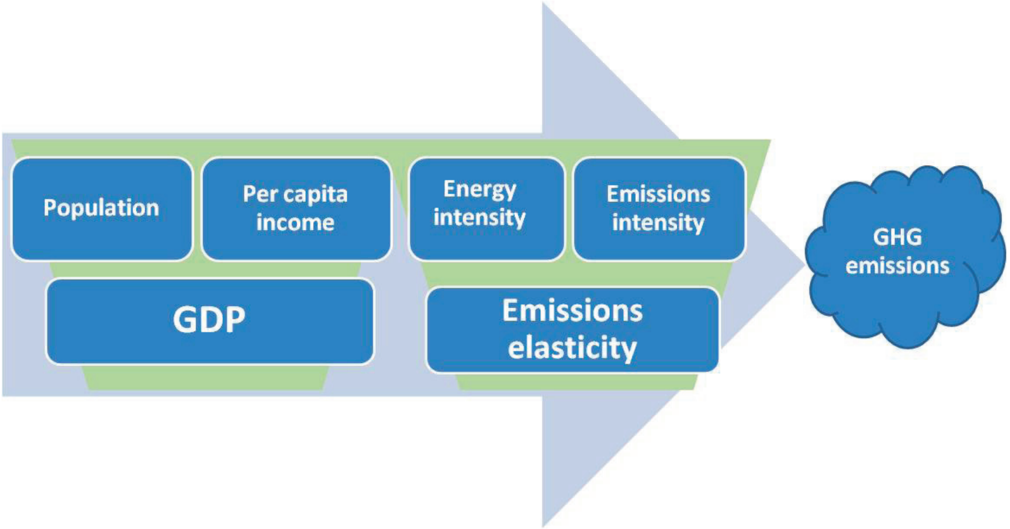
d.

BUSINESS-AS-USUAL SCENARIOS FOR POLAND

A business-as-usual scenario is fundamental to the calculation of costs of carbon abatement, but they can be generated by differing methodologies using separate datasets. It is difficult to project the path of an economy over a 15 or 25 year period, and it is not surprising that sectoral details will differ significantly across models. The Marginal Abatement Cost (MicroMAC) curve model constructs a relatively simply reference scenario, which matches official projections for growth and energy demand and presumes a rising level of efficiency. While more or less matching overall emissions projections, the Macroeconomic Mitigation Options (MEMO) model forecasts in great detail that the Polish economy will shift relatively quickly towards less carbon intensive sectors (mainly services). The Regional Options for Carbon Abatement (ROCA) model generates similar aggregate emissions levels for business-as-usual, but with a very different development path for sectors, with less sectoral transformation. The detailed sectoral approach of the TREMOVE Plus model of road transport provides a scenario of rapid emissions growth for road transport, a major component of non-ETS emissions. The comparison of reference scenarios generated by the suite of models draws attention to the fact that, since each of the models illuminates important aspects of the economics of GHG mitigation, policymakers will need to be ready to consider multiple model results, rather than a single answer.

The development path of the economy in the absence of new low emissions policy measures is the correct comparator for policymakers considering abatement actions. Mitigation targets are almost always defined against a base year. For example, Poland's non-ETS national target is defined as: emissions in 2020 will be no more than 14 percent above the level in 2005. But such a definition provides little indication of the degree of challenge involved in meeting the target. What matters is the size of the reduction compared to the expected level of emissions in the target year. This expected level is a matter for projections, determined by assumptions about the growth rate of emissions in the absence of additional policy--the business-as-usual (BAU) emission baseline. Central to these assumptions on future emissions are predictions of GDP growth and accompanying energy demands (Figure 21). Faster expected growth translates to faster rising emissions, and the higher is the future emission level in the absence of climate policy, the more stringent are the effective reduction targets and, thus, the costs of abatement.

Figure 21. Basic drivers of GHG emissions growth



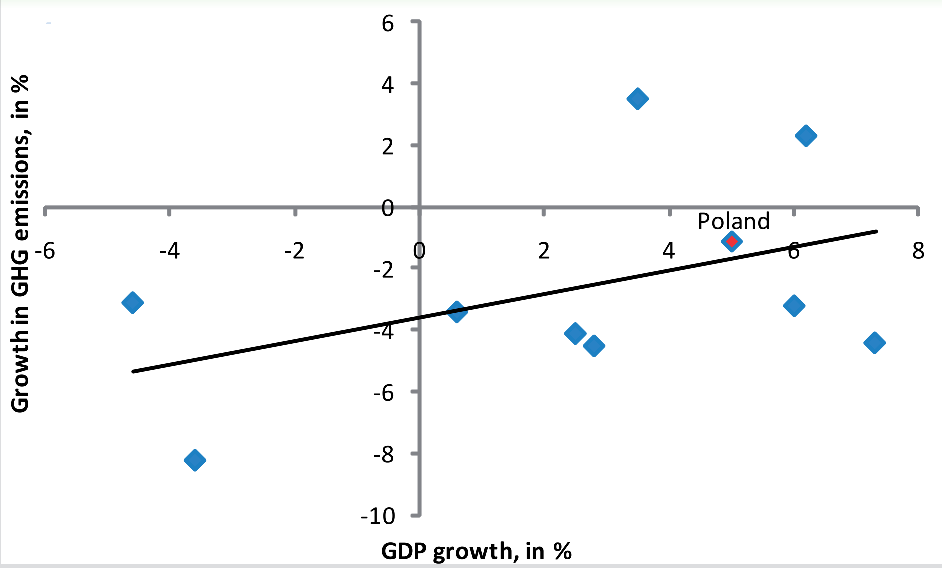
Note: All in growth rates, where energy intensity is change in toe per € GDP; emissions intensity is change in tCO_2e per toe; and emissions elasticity is growth of tCO_2e per € GDP. The figure makes clear that countries with higher population growth or higher income growth will face faster rising emissions. The emissions elasticity of GDP growth will need to be reduced by even more to offset GDP growth.
Source: derived from Kaya and Yokobori (1997).

The global financial crisis temporarily reduced GHG emissions but with little long-term impact. In the case of Poland, the effect of the global financial crisis on GHG emissions into the future is negligible. Poland was the only EU country that avoided recession in 2009, although real GDP growth slowed down from 5.1 percent in 2008 to 1.8 percent in 2009. In 2010, Poland's economy rebounded to a 3.8 percent growth rate and is expected to continue a gradual recovery in the years beyond (Box 4).

Box 4. Poland's growth projections and the global financial crisis

The BAU scenarios used in this report are based on pre-crisis growth trends. The global financial crisis triggered the worst economic recession since World War II, and post-crisis growth around the world could be dampened by continued uncertainty and scarce and more expensive capital. This could well lower global energy demand and GHG emissions going forward. For example, global energy consumption is likely to have declined in 2009 for the first time since 1981. In the EU, verified emissions in the ETS are estimated to have declined by 11.6 percent from 2008 to 2009. Finally, among the EU member states from Central and Eastern Europe, economic performance in 2008 mattered for GHG emissions. Estonia and Latvia, which already saw contractions in GDP in 2008 linked to the global financial crisis, experienced reductions in GHG emissions (Figure 22).

Figure 22. Growth in GHG emissions and GDP in 2008 in Central and Eastern Europe



In Poland, the impact of the global financial crisis on growth projections is likely to remain muted. First, Poland's economy has shown remarkable resilience to the global financial crisis. In 2010, Poland's economy performed well, after being the only member state of the European Union to avoid recession in 2009. Growth in Poland accelerated from 1.8 percent in 2009 to 3.8 percent in 2010. Second, the BAU scenario incorporates an annual growth rate of 3.5 percent for Poland going forward. This compares to average growth of 5.1 percent from 2003 to 2008, and to growth forecasts of around 4 percent growth over the medium-term from the IMF, OECD and the Government.

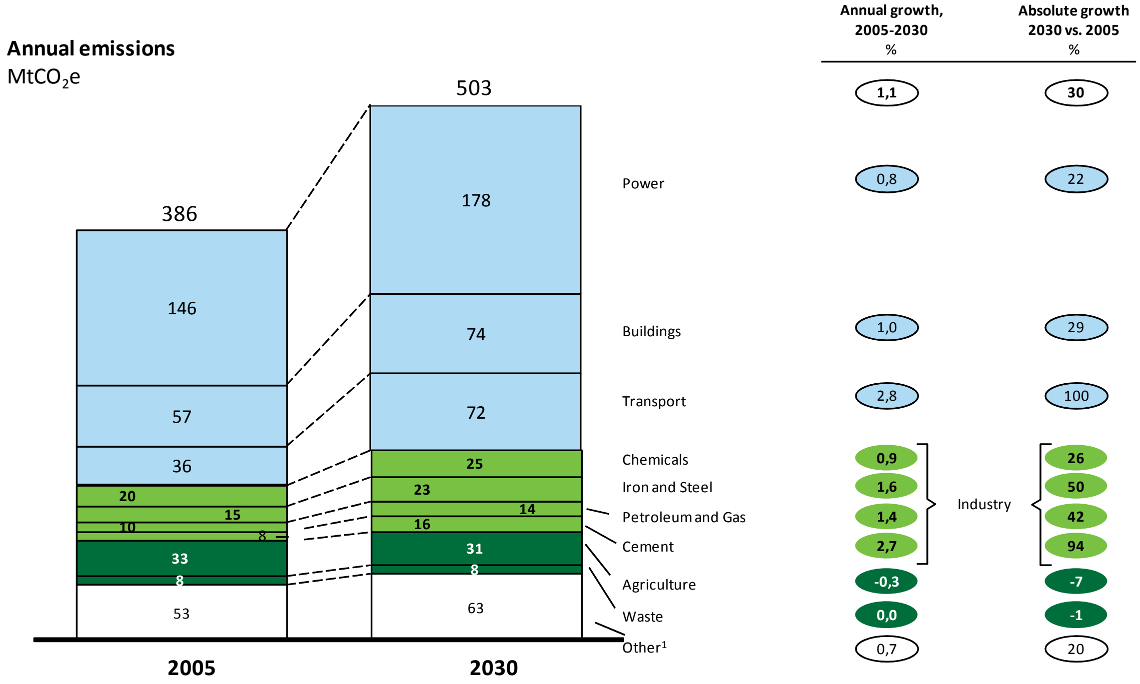
Overall, while the global financial crisis has slowed growth in 2009 and might have moderated growth prospects in the coming years, it is unlikely to have derailed the longer-term growth prospects which underlie the BAU scenarios.

Source: European Environment Agency; European Commission, communication IP/10/576), May 2010; World Bank staff calculations.

Because each model used in this report builds from a distinct dataset, there is no singular business-as-usual scenario. In the academic literature, BAU projections are often based on simple extrapolation of historical trends or the application of a single emissions elasticity to expected GDP growth, since rising incomes push up energy demand (usually the dominant driver of emissions) and, in turn, GHG emissions. A steady-state baseline, in which all physical quantities grow at an exogenous uniform rate while relative prices remain unchanged would have the virtue of providing a transparent reference path for the evaluation of policy interference. However, such a path would be unlikely to match official business-as-usual projections, limiting the interest of the model results to policymakers who need more realistic comparisions. Instead, each of the models used here produced its own business-as-usual scenario, using data that allowed for the level of detail needed for that model, but following the broad outlines of official growth projections. The MEMO model's BAU scenario is also closely matched to the simpler formulation of the MicroMAC curve, and the BAUs of the MEMO and ROCA models have been broadly harmonized through 2020, the end-point of the ROCA model. However, they do have points of difference, which help illuminate some of the underlying assumptions of the projections. Lastly, the TREMOVE Plus transport model takes a very different approach to projecting road transport emissions than the MicroMAC curve method, which demonstrates more starkly the importance for policymakers of understanding how models generate their numbers.

The MicroMAC curve business-as-usual baseline for emissions through 2030 was constructed from the bottom up. It was calculated based on future production levels for industry and future activity levels in transport and buildings and assuming natural improvements in technological efficiency as new capital replaces old. For example, the BAU baseline for power was calculated by estimating the required level of electricity production and the probable fuel mix in 2030, assuming no efforts were made to reduce emissions and only accounting for greater efficiency of new power plants. In transport, estimates were based on forecasted traffic growth in Poland, both in terms of increasing numbers of passenger cars and average distances travelled. This baseline scenario projects that Poland's GHG emissions will grow 30 percent above 2005 levels by 2030, to 503 $MtCO_2e$. This translates to an annual growth rate of 1.1 percent, compared with real GDP growth over the same period projected at 3.4 percent per annum (consistent with government projections). As a result, the carbon intensity of the economy continues to decline, driven by the ongoing expansion of the services sector and other (unidentified) efficiency improvements. In a 10-sector disaggregation, emissions from transport and cement are projected to rise fastest, about doubling by 2030. In transport, that growth is fuelled by expected increases in passenger cars per 1000 inhabitants, and in cement, by continuously strong growth in construction (Figure 23).

Figure 23. MicroMAC curve BAU scenario emissions growth

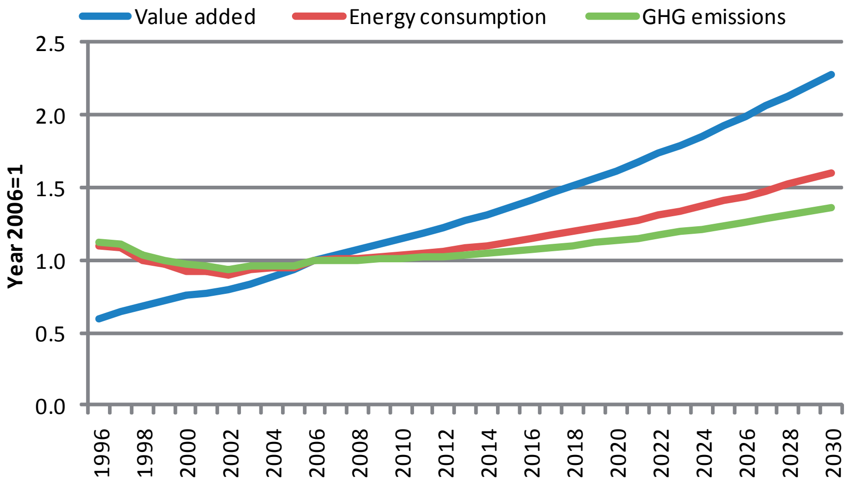


Notes: Industry, buildings, and transport sectors do not include indirect emissions from electricity consumption and well-to-tank emissions for fuel; these are accounted for in the power and P&G sectors respectively; buildings sector includes emissions from heat. Other includes: mining, light industry, food & beverage industry, glass production, colored metals, off-road transport, and other sectors.
Source: McKinsey technical background paper.

For the MEMO model, the BAU scenario through 2030 was estimated econometrically, based on continuation of the trends and convergence processes observed in the EU and Poland in the recent past. In forecasting the development of an economy over 25 years, convergence is a sensible assumption. The MEMO BAU estimation assumes that Poland will continue to converge towards the economic structure of the average EU country in line with the path experienced by EU members in the recent past. Using EUROSTAT data for 21 EU members, including Poland, during 1996-2006, panel regressions estimated the pace of convergence across 11 sectors for value-added share, energy intensity, and emission intensity. Long-term growth trends for the 21 countries were estimated based on the same data. Then projections of the key variables for the EU26 and Poland through 2030 were generated based on the growth trends for the EU adjusted by the convergence rates for each sector. Once the convergence process is completed, i.e., the country reaches the average EU level, it continues to grow at the average, trend rate. (See Annex 5 for more details on the estimation procedure).

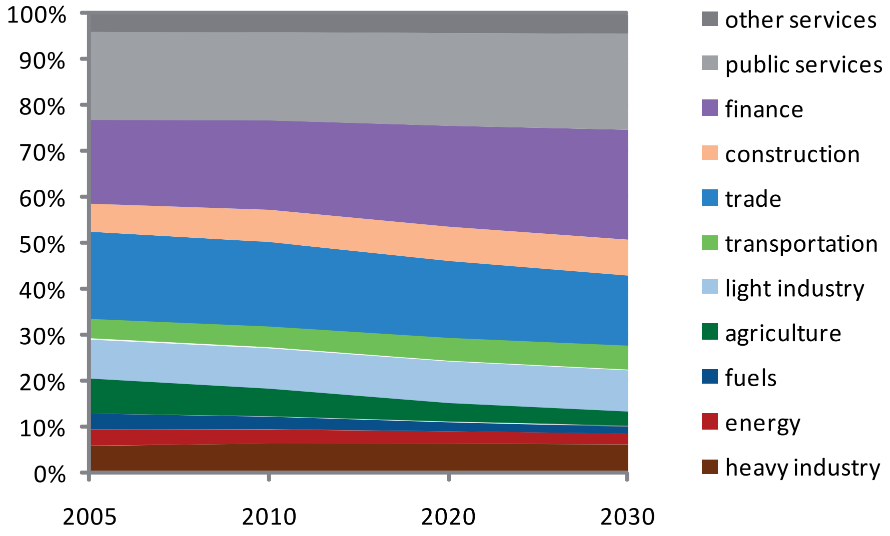
The convergence of Poland's economy towards EU averages in the MEMO BAU scenario builds in moderation of GHG emissions via the ongoing shift towards less emission-intensive sectors such as services and via improved efficiency in each sector. These developments generate a path for GHG emissions that lies below that for energy consumption which, in turn, lies below the path for growth of value-added (Figure 24). As the production structure in Poland converges to the European average over the next 20 years, services (especially financial services) are expected to expand their share in value added, while shares of fuels and agriculture are to diminish (Figure 25). At the same time, all sectors with the exception of households (which consume energy and produce emissions) effectively converge to EU levels of energy intensity (defined as energy per unit of GDP) within the next 10 years. Households, in turn, are gradually closing the gap to be just 1.3 times more intensively emitting in 2030 against 2.8 times in 1996. (See Annex 5 for details on energy intensity forecasts.) Lastly, in the majority of sectors, emission intensities (defined as emissions per unit of GDP) in Poland move closer to average EU values by 2030 without completing convergence. Overall emissions intensity improves by more than 40 percent, allowing projected greenhouse gas emissions to expand by just over 40 percent to 2030 while production rises by a factor of 1.5.

Figure 24. MEMO BAU projections for Poland



Source: IBS technical paper.

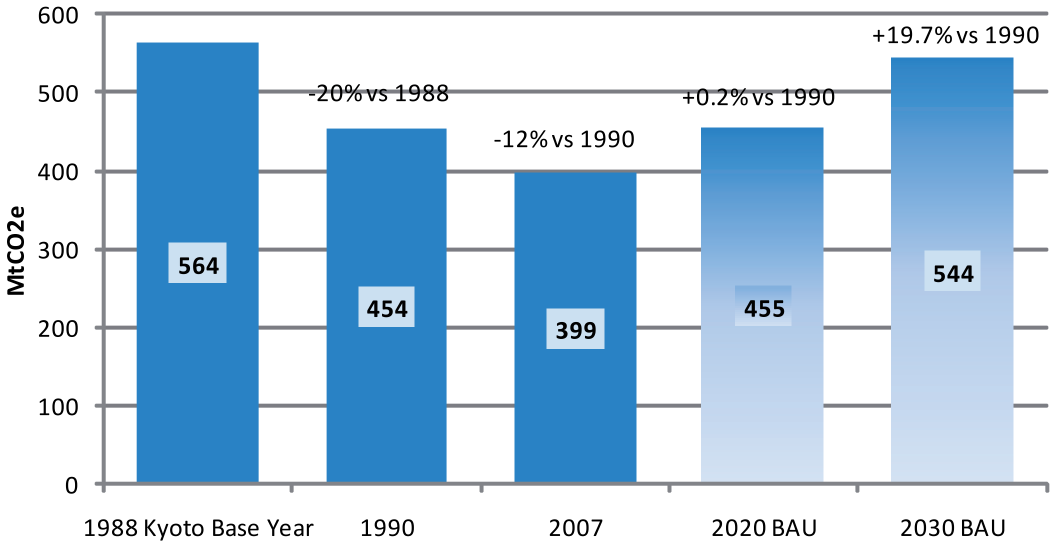
Figure 25. MEMO BAU value added by sector, 2005-2030, %



Source: IBS technical paper, World Bank staff calculations.

The MEMO model BAU scenario for Poland generates a U-shaped path for GHG emissions levels. After shrinking by 12 percent from 1990 to 2007, GHG emissions are projected by the MEMO model BAU scenario to recover to about the same level as in 1990 by 2020. With continued economic growth, however, emissions in 2030 are projected to be almost 20 percent higher than in 1990 (Figure 26).

Figure 26. GHG emissions and MEMO BAU scenario 2020/2030



Source: UNFCCC, IBS technical paper, World Bank staff calculations.

The ROCA model, with more emphasis on international interactions, derives a business-as-usual scenario in line with external projections from the US Energy Information Administration and the European Commission. For the ROCA model, the BAU scenario through 2020 (the time horizon of this model) is based on projected energy input demands across sectors, GDP levels, and the international price for crude oil, drawn from the EIA and complemented by more detailed forecasts from the EC on Poland and the rest of the EU,[49] as provided by the 2007 PRIMES projections.[50] The model adjusts sectoral productivities such that all sectors remain on the benchmark isocost line so that cost and expenditure functions are kept as close as possible to the initial static technologies and preferences underlying the base-year calibration (see more details in Annex 4).

As noted above, mitigation targets often look quite different when measured against the business-as-usual emissions levels: Poland's non-ETS sector target of no more than 14 percent growth compared to 2005 translates to cuts of 22 percent of emissions in 2020. Table 3 summarizes how EU 20-20-20 emission reduction obligations defined against 2005 levels translate into effective emission reduction requirements when compared to the ROCA BAU emissions levels for 2020. For simplicity, the EU-wide ETS reduction target of a 21 percent reduction in 2020 relative to 2005 is assumed to apply to each member state individually. The overall EU target of a 10 percent reduction in non-ETS emissions aggregates from Poland's commitment to increase emissions by no more than 14 percent by 2020 and the rest of the EU's promise to cut non-ETS emissions by 12.5 percent (see Section b for a description of ETS and non-ETS sectors and commitments). Because of the underlying growth in emissions through 2020, the effective reduction requirements in the non-ETS sectors for Poland become markedly higher.

Table 3. Nominal and effective emission reduction targets for 2020 for Poland and the EU, in %

	Nominal GHG reduction targets	Effective GHG reduction targets
	(relative to 2005)	(relative to ROCA BAU)
Poland (total)	-4.4	-22.7
ETS	-21.0	-23.7
Non-ETS	+14.0	-22.0
Other EU (total)	-16.6	-18.8
ETS	-21.0	-24.3
Non-ETS	-12.5	-13.5

Source: Loch Alpine technical paper and World Bank staff calculations.

The bottom-up activity-based transport model takes a very different, detailed sector approach to constructing a business-as-usual scenario for passenger and freight road transport in Poland. Like the MicroMAC curve, it was constructed based on future activity levels and considered forecasted traffic growth, in particular, expected high growth in passenger cars and distances travelled. However, the TREMOVE Plus transport model built a BAU scenario for road transport in far greater detail than the MicroMAC curve did, allowing for more of the distinctive character of Poland's road transport sector. Starting from the EU's 2009 TREMOVE baseline scenario for Poland, data and assumptions were updated, generating a higher path of baseline road transport emissions through 2030, more closely matching Poland's official GHG inventory of emissions for 2000-07. Importantly, the BAU calculations consider explicitly which transport and environment policies should be included in the reference scenario, and in this aspect, the transport BAU is quite different from the other BAU scenarios. (See Section j for discussion). Total GHG emissions from road transport are forecast to increase 93 percent from 2005 levels by 2030 (or 210 percent compared with 1990). The modeling revealed that key characteristics of today's road transport have a significant influence on the path going forward, in particular: the preponderance of imported used cars and the advanced age of the passenger fleet; low motorization rates and very low mileage driven per car compared with the EU15; and a highly competitive road freight sector which has already marginalized rail freight and has been shifting to newer and bigger trucks.

Although different methods were applied to generate the business-as-usual scenarios for each economy-wide model, the resulting projections are generally similar, while their points of difference are illuminating. The ROCA model's BAU projections for emissions in 2020 are very close to the projection for Poland underlying the MicroMAC curve model, and the MEMO model's BAU 2020 forecast is not far (Figure 27). The change, relative to 1990, ranges from 0.2 to 3.6 percent growth in overall emissions. The projections for 2030 are more divergent: the MEMO BAU for 2030 emissions is 9 percentage points higher than the projection made in the MicroMAC curve model. Both models suggest a significant increase in Poland's GHG emissions by 2030--by 20 percent and 11 percent relative to 1990, respectively. As noted above, the higher is the future emission level in the absence of climate policy, the more stringent is any reduction target defined against a base year, and, thus, the costs of abatement.

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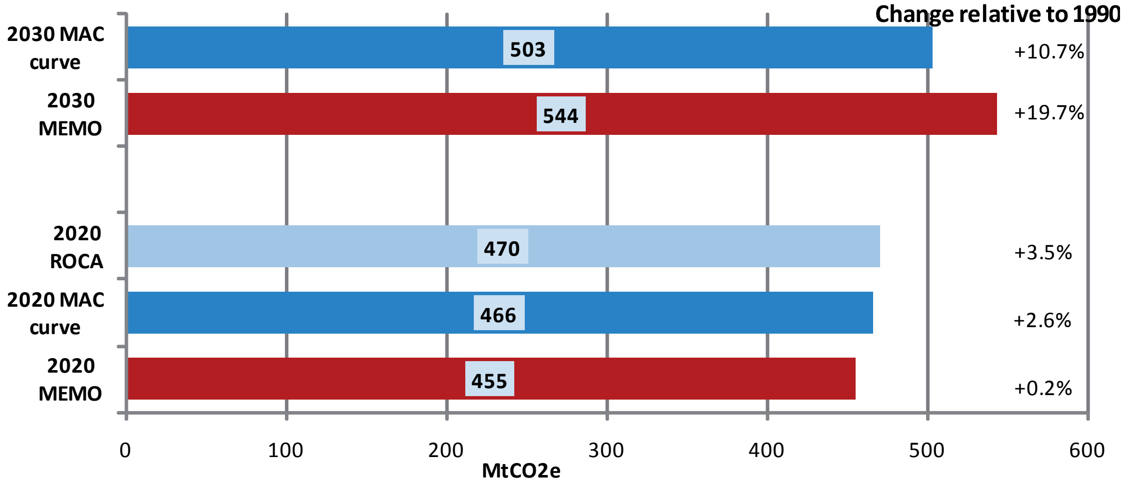
[49] EIA (2009); European Commission (2008).

[50] The PRIMES Energy System Model of the European Commission analyzes market-related mechanisms influencing energy demand and supply and technology penetration as well as energy policy, including all EU member states.

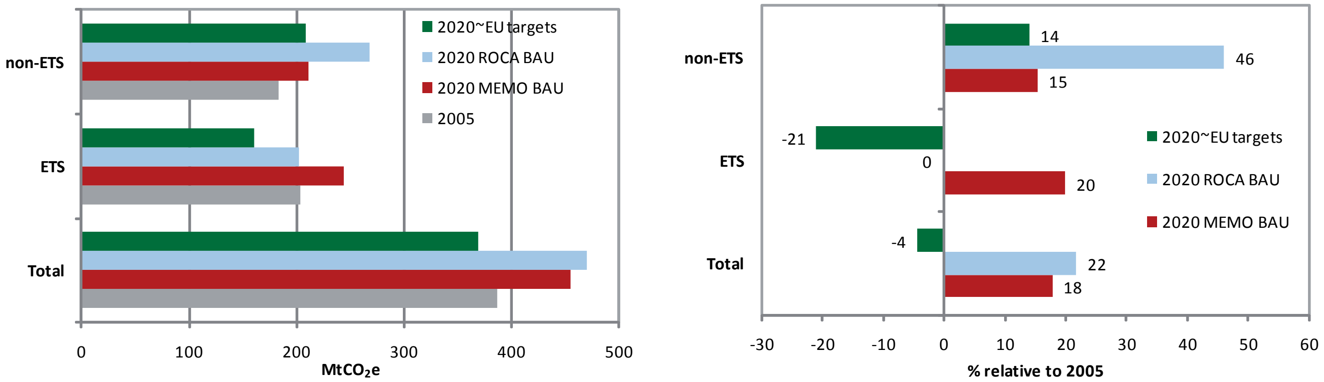
Figure 27. Comparing economy-wide BAU scenarios 2020/2030



Note: The ROCA model produces CO_2 emissions so equivalent GHG emissions were estimated.
Source: IBS technical paper, McKinsey technical paper, Loch Alpine technical paper, World Bank staff calculations.

The question of which sectors will find the shift towards low emissions more difficult is central to policymakers' concerns. Although the BAU scenarios for 2020 of overall GHG emissions in the MEMO and ROCA models do not differ significantly, the decomposition between ETS and non-ETS sectors suggests some important differences (Figure 28). The MEMO BAU projections indicate a heavier burden for ETS sectors, while according to ROCA BAU projections, the major challenge will be faced by the non-ETS sectors. While the MEMO BAU scenario projects ETS sectors to expand by 20 percent relative to 2005 by 2020, the ROCA BAU scenario predicts constant emissions during the period. The MEMO BAU projections seem to indicate Poland will have little problem in fulfilling the country-specific target for the non-ETS sectors under the EU 20-20-20 package (since the projected 15 percent increase under business-as-usual is very close to the 14 percent increase ceiling). In contrast, the ROCA BAU projections warn of a significant challenge for non-ETS sectors, with emissions increasing by 46 percent between 2005 and 2020. The TREMOVE Plus model's projections for emissions growth from road transport between 2005 and 2020—68 percent—also suggests that non-ETS sectors may pose the greater challenge.

Figure 28. GHG emissions in Poland, in $MtCO_2e$ and %, 2005 and 2020



Note: The MEMO ETS and non-ETS projections are corrected for small energy installations as explained in Figure 13's note. The ROCA model produces CO_2 emissions so equivalent GHG emissions were estimated. Poland's EU ETS target is assumed to be the same (as a percentage change) as the EU-wide target.

Source: IBS technical paper, Loch Alpine technical paper, World Bank staff calculations.

BAU projections are central to the costing of economic adjustment. The suite of models generate broadly consistent paths for the Polish economy through 2030, but some points of divergence will have important implications for the costs of transition to a low emissions growth path, discussed in the sections that follow which present the simulations of each of the models. It will be important to keep in mind some of the underlying assumptions driving the business-as-usual scenarios, and, thereby, the results on abatement costs. For example, the MEMO model's BAU scenario predicts that the emissions intensity of output will fall by more than 40 percent but note that, because of the mechanics of the model, there is no specification of required policies or behavioral shifts. The ROCA model BAU scenario projects less sectoral transformation, and if it turns out to be the more accurate forecast, Poland is more likely to face a sizeable challenge to contain the growth of carbon emissions in non-ETS sectors. The transport BAU confirms the probability of rapid and challenging non-ETS emissions growth, and, in addition, raises the question of how to determine which abatement measures or policy choices should be considered part of business-as-usual and which remain available as additional abatement levers. These contrasts within the model suite should be kept in mind as policymakers consider the simulation results of each of the models.

e.

THE MICROECONOMIC MARGINAL ABATEMENT COST (MICROMAC) CURVE AND POLAND'S ABATEMENT OPTIONS

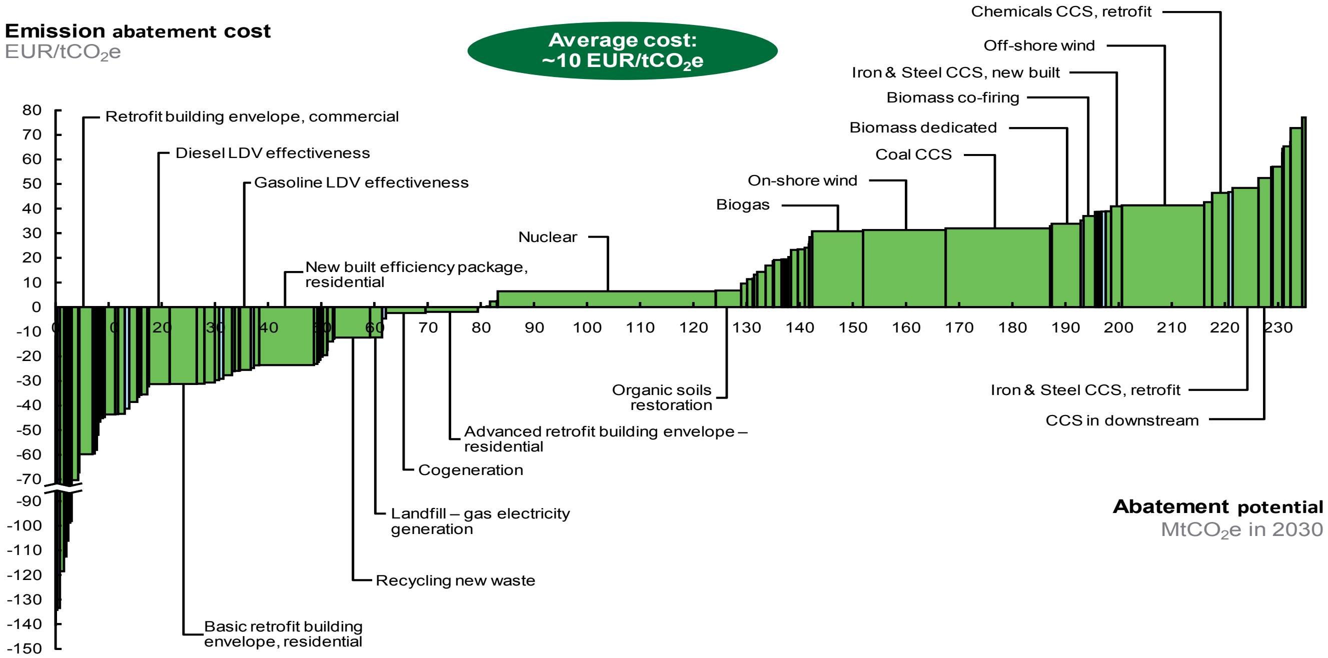
The Microeconomic Marginal Abatement Cost (MicroMAC) curve is a bottom-up engineering approach to assessing GHG abatement, with an intensive analysis of the power sector. Using detailed sectoral data, the MAC curve model creates a ranking by net cost of about 125 emission reduction levers and presents the measures via a well-known visual summary tool—the MicroMAC curve. The MicroMAC curve summarizes a large amount of policy-relevant information in an easily understandable format. It shows that Poland can significantly reduce emissions, with total abatement potential of a 31 percent reduction from 2005 levels, or 47 percent below the 2030 level in the MicroMAC curve business-as-usual scenario. However, capturing this full potential will require concerted, targeted actions by government, business, and consumers. According to the analysis of the MicroMAC curve, mitigation measures will take some time to deliver lower emissions, and Poland may have trouble meeting its 2020 EU targets. The MicroMAC curve also identifies that the majority of Poland's abatement potential is associated with the switch to low-carbon energy supply (via energy sector investments) and with energy efficiency improvements. Abatement measures do not have negative net costs after implementation barriers are considered, and the overall cost of implementing the MicroMAC curve levers will rise by at least 50 percent. In order to implement all the low-carbon levers, additional investment of about 0.9 percent of annual GDP will be needed during 2011-2030. Finally, the cost of abatement is sensitive to financing costs, fuel prices, and technology.

MicroMAC curves summarize a large amount of policy-relevant information in an easily understandable format. As discussed earlier (see Section c), this model analyzes about 125 technical options for Poland for GHG mitigation across the 10 largest sectors of the economy. First, a business-as-usual case was constructed to serve as the baseline for future emissions reductions, based on future production levels for industry and future activity levels in transport and buildings and assuming natural improvements in technological efficiency. Then, detailed bottom-up estimates of the costs and potential abatement volume for each intervention were constructed, with particular attention to the power sector. The options or 'levers' are ranked by the net present value of costs and savings per metric ton of CO_2 equivalent avoided. Finally, the levers were ordered according to their costs in a summary graphic, a marginal abatement cost (MAC) curve. This visual presentation provides a wealth of information to policymakers and transforms the high-level objective of emissions abatement into detailed and specific sectoral choices. The curve can be used to compare the size and cost of opportunities, assess the relative importance of sectors, and estimate the overall size of the emissions reduction opportunity.

A consistent approach across technical options required some simplification. Options include only available technologies or those expected to be available before 2030 (so, for example, carbon capture and storage is included but biodiesel from algae is not). Levers that cost more than €80 per tCO_2e were excluded since these are of less interest and tend to be early-stage and uncertain techniques. Also, levers that would require significant consumer lifestyle changes (such as switching to public transportation or lowering home temperatures) were not considered. Then, abatement cost is calculated as the sum of incremental capital expenditures in net present value terms and incremental operational expenditures or savings in NPV terms. Costs did not take into account transactions costs, taxes, subsidies, feed-in tariffs, and other governmental measures. A risk-free discount rate of 4 percent was used to generate net present values; and all costs are in 2005 real euros.

The MicroMAC curve shows that Poland can significantly reduce emissions but capturing the full potential would be a major challenge. The cost curve identifies potential abatement of 236 MtCo2e by 2030 at a unit price of €80 or less (Figure 29). The weighted average cost is about €10 per tCO_2e, ranging from minus €130 (net benefits) to almost €80. The width of each column on the curve represents the emissions reduction potential by 2030 compared to the BAU scenario. The height of each column represents the average cost of avoiding one tCO_2e by 2030 by replacing the underlying (reference) technology with a low-carbon technology. For example, in the power sector, a coal-fired power plant would be replaced by a gas or nuclear power plant. Altogether, the total abatement potential represents a 31 percent reduction from 2005 levels, or 47 percent below the 2030 level in the MicroMAC curve business-as-usual scenario. However, capturing this full potential will require concerted, targeted actions by government, business, and consumers. Significant gains will have to be made in the energy efficiency of buildings and transportation, and the share of low-carbon energy sources will have to rise to over 50 percent of total electricity supply by 2030 (from just 2 percent in 2005). If the total abatement potential is achieved, Poland will succeed in decreasing its GDP emissions intensity by almost 70 percent against current levels (see Section a andFigure 3).

Figure 29. Microeconomic Marginal Abatement Cost (MicroMAC) curve for Poland , 2030



Note: Each column is one of the 123 abatement measures (only the most significant ones are named). The height of the columns is the cost in € per abated tCO_2e. The width is the amount emissions can be reduced. Some measures are shown with net benefits (negative costs). The scenario assumes that 6 GW of nuclear power will be installed by 2030, providing about 15% of electricity.
Source: McKinsey technical paper.

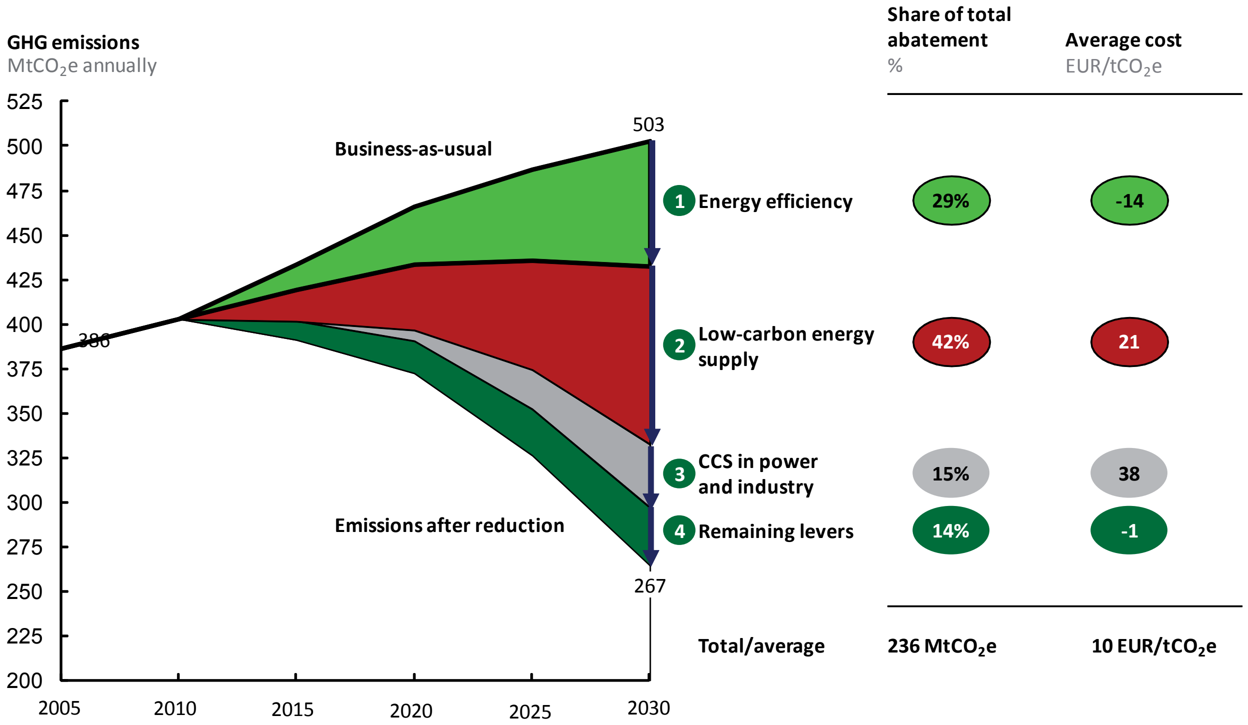
According to the analysis of the MicroMAC curve, mitigation measures will take some time to deliver lower emissions, and Poland may have some trouble meeting its 2020 EU targets. By 2020, emissions could be reduced by 20 percent against the BAU forecast, but this overall reduction translates to just 3 percent below 2005. By contrast, Poland needs to reduce overall emissions by more than 4 percent relative to 2005, assuming that emissions from ETS sectors will be reduced in line with EU-wide abatement (see Table 3 and note that the segmentation of sectors under EU rules creates multiple targets). The pace of abatement would pick up significantly only after 2020, when major projects in the power sector became operational, such as large-scale offshore wind generation, nuclear plants, or carbon capture and storage.

The majority of the abatement potential is associated with the switch to low-carbon energy supply and energy efficiency improvements. The levers can be usefully grouped into four categories: energy efficiency (including transport); low-carbon energy supply (via energy sector investments); carbon capture and storage (CCS) in power and industry; and other measures (in industry, waste management, and agriculture) (see Figure 30). About 70 percent of total abatement potential is related to the first two categories: efficiency improvements and low-carbon energy. Shifting from coal to low-carbon alternatives in the power sector such as wind, nuclear, biomass, or biogas, could abate 100 $MtCO_2e$ by 2030, or 42 percent of the total, at an average cost of €21 per tCO_2e. The coming years will be critical for the future fuel mix in Poland's power sector because a sizeable share of the current coal plants are set to retire. Their replacements will have lasting impact on GHG emissions, but choosing an optimal fuel mix is a complex undertaking. Thus, the MicroMAC curve analysis considered five scenarios with different costs and abatement, which are discussed further in Section h on energy. At the same time, the reduction of energy demand through more energy efficient buildings, vehicles, and industrial equipment could bring abatement of 68 $MtCO_2e$, or about 30 percent of total, at a negative cost of €14 per tCO_2e, according to the MicroMAC curve.

The most important opportunities in this category are in the buildings sector, where strict efficiency controls for new building and better insulating existing ones could abate almost 30 $MtCO_2e$ by 2030. More fuel-efficient vehicles could generate abatement of about 10 $MtCO_2e$ by 2030. Together these efficiency measures could help reduce growth in electricity demand from 1.5 percent per annum to about 0.9 percent.[51] Energy efficiency challenges are taken up in Section i.

Abatement measures do not have negative net costs after implementation barriers are considered, and the overall cost of implementing the MicroMAC curve levers will rise by at least 50 percent. Energy efficiency measures contribute substantially to the aggregate low average cost of the MicroMAC curve levers, but the idea of significant savings opportunities being ignored by households and firms does not make economic sense. Clearly, there must be some other hurdles preventing these savings-creating measures from being taken up at once. Three groups of barriers to these measures are: high upfront investment costs (for example, for an energy-efficient car), principal-agent problems (such as the owner, operator, occupant, and bill payer of a building being separate entities), and lack of information (about what savings are likely). A fourth, and potentially most difficult obstacle, is the costs of implementation across a high number of small entities (for example, with residential lighting). These barriers have not been costed, but if the simple assumption is made that unrecognized costs will inevitably shift negative costs into positive, then, at a minimum, the weighted average cost across the MicroMAC curve of €10 per tCO_2e will rise to €15 per tCO_2e (if all costs are set to zero or above).

Figure 30. MicroMAC curve: abatement potential for Poland in 2030 by groups of interventions



Note: Energy efficiency includes measures in buildings, transport except switch to biofuels, and a few in industry (such as cogeneration).
Source: McKinsey technical paper.

In order to implement all the low-carbon levers, additional investment of about 0.9 percent of annual GDP will be needed during 2011-2030. The total amount of investment needed is estimated at €92 billion. The annual amount would grow with time as more expensive abatement opportunities were implemented, offset by growing operational cost savings. Also, investment needs would be

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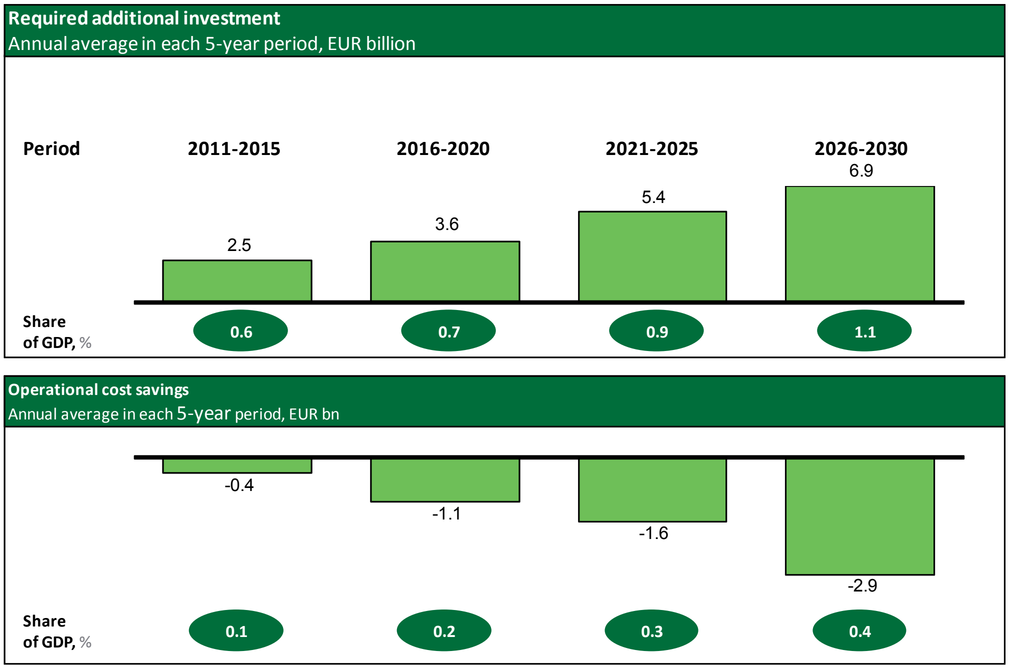
[51] About half of CCS potential is related to equipping coal power plants. The remaining 16 $MtCO_2e$ potential lies in industry, particularly in iron and steel and in chemicals. These estimates are based on assumptions about storage potential in Poland and the speed of technical progress. CCS's large-scale deployment before 2030 remains uncertain, but it could well have a major impact on emissions after 2030. The last category, other measures, generates half its abatement potential from reduction of nitrous oxide and methane in waste management and agriculture. Measures include recycling, methane capture and use, improving agronomic practices, and reflooding peat lands.

unevenly distributed across sectors. The capital costs would be relatively modest in industry, but considerable for power, buildings, or transport. In the latter two sectors, by 2030 they would be fully offset by substantial savings in operational costs. Across all sectors, businesses and households are expected to save about €30 billion on operational costs, or about 0.3 percent of GDP on average per annum.

Figure 31. MicroMAC curve: investment and operational cost savings, 2010-2030



Source: McKinsey technical paper.

The cost of abatement is sensitive to financing costs, fuel prices, and technology. Higher energy prices reduce the net costs of energy efficiency measures. If the price of oil were 50 percent higher than the assumption of $62 per barrel in 2030, the average overall cost of abatement would fall from €10 to €4 per tCO_2e. If technologies turned out to be more expensive in terms of capital investment, then abatement costs would rise in proportion. For example if the total capital to install 1 GW of nuclear capacity rises by €500 million, the abatement cost of the nuclear lever would rise by about €4 per tCO_2e. Perhaps most importantly, an interest rate higher than the risk-free rate of 4 percent used so far would directly increase the cost of capital-intensive technologies with relatively short lifetimes such as wind turbines and hybrid vehicles. Applying an interest rate of 8 percent, the overall average abatement cost would rise from €10 to €19 per tCO_2e.

MicroMAC curves communicate complex engineering information in a simple and accessible way; however, they need to be read with a degree of caution. Despite their apparent simplicity, they are heavily dependent on underlying assumptions, including the business-as-usual scenario, costs and abatement potential of each technology, and appropriate discount rates. For some levers, especially emerging technologies, uncertainty about volume and estimated costs can be significant. The adoption rate of new technologies depends strongly on energy prices as well as on cost and performance improvements, neither of which can be predicted with precision. The ease of capture or of implementation has been considered in a simple way, creating an additional dimension to the net present value of each measure that alerts policymakers to the importance of sequencing. Further, given the substantial impact the shift to a low emissions scenario will have on an economy, policymakers rightly have concerns about economic impact beyond discounted investment and operating costs. The next chapter presents a new methodology that allows just such an expanded assessment.

f.

THE MACROECONOMIC MITIGATION OPTIONS (MEMO) MODEL AND THE MACROECONOMIC IMPACT OF THE ABATEMENT PACKAGE

The Macroeconomic Mitigation Options (MEMO) model, a large scale DSGE model of Poland, can provide a dynamic assessment of the macroeconomic impact of GHG options, including a new visual presentation—a macroeconomic version of the MicroMAC curve. The innovative linking of this economy-wide model to the bottom-up engineering approach of MicroMAC curve model allows analysis of the varying macroeconomic and fiscal implications of GHG abatement measures, across four public financing options. For the comprehensive abatement package, the MEMO model simulations finds that GHG emissions will be reduced by 24 percent by 2020 and by 47 percent by 2030, with an economic impact that is generally negative but appears affordable. Not surprisingly, the fall in GDP is driven by recession in emission-intensive sectors, which bear the heaviest burden of abatement. At a more disaggregated level, the model finds that it is the switch to low-carbon energy and fuel efficiency measures that provide the bulk of abatement and that the technologies with the largest abatement potential do not necessarily impose the biggest macroeconomic cost. Finally, the MicroMAC curve can be transposed into a Macroeconomic Abatement Cost and Macroeconomic Marginal Abatement Cost curves to examine in detail the impact on growth associated with the implementation of specific abatement measures.

The MEMO model is a DSGE model of Poland redesigned to address climate and energy issues. This very large dynamic stochastic model has a detailed treatment of the real side of the economy and was calibrated on the most recent available data for Poland. It has 2 'countries' (Poland and the rest of the EU) to allow for trade, and 11 sectors with a full input-output table and emissions generated as a byproduct. Both public revenues and expenditures are disaggregated, and different financing methods (or model closures) were applied. Imperfect competition in labor markets allows for unemployment, and exogenous shocks generate cycles. The model provides 5-year snapshots through 2030 of the impact of abatement measures on a large variety of macroeconomic variables by sector, such as output, employment, emissions, household welfare, and fiscal revenues and expenditures.[52] (See Sections c and d and Annex 3 for more details.) The MEMO model's BAU scenario through 2030 was estimated econometrically, based on continuation of the trends and convergence processes observed in the EU and Poland in the recent past, as discussed in more detail in Section d. This approach builds in moderation of GHG emissions via the ongoing shift towards less emission-intensive sectors such as services and via improved efficiency in each sector. As a result, GHG emissions levels follow a U-shaped path, recovering to 1990 levels by 2020, then rising to 20 percent above 1990 levels by 2030.

The innovative linking of this economy-wide model to the MicroMAC curve engineering model is achieved by a Microeconomic Investment Decisions (MIND) module. The MIND module transforms the MicroMAC curve levers, incorporating additional data on the projected capital and operating expenditures, the potential efficiency and emissions gains, and required government subsidies to cover the additional costs of most options compared to the business-as-usual technology. The levers were combined into seven technological clusters or 'micro-packages' based on economic similarities to simplify analysis. While for the first six categories, potential emissions mitigation for individual levers follows the engineering analysis technological assumptions, the composition of levers in the last and most important sector (energy) was determined endogenously by the MIND module with the constraint that overall abatement by 2030 would reach 47 percent compared to the BAU level, matching the MicroMAC curve overall estimate. The MIND module was applied to find those abatement opportunities which are relatively cheap, offer considerable carbon abatement potential and are technically feasible via a multi-criterion optimization. (See Section h and Annex 3 for more details.) The micro-packages are:

- chemical processes, such as catalyst optimization;
- industry CCS and distribution maintenance;
- agriculture interventions, such as grassland management;
- energy efficiency, such as insulation for new residential buildings;
- fuel efficiency, such as hybrid passenger vehicles and other transport measures;
- mixed energy/fuel efficiency, such as retrofitting heating and air conditioning in commercial buildings; and,
- low-carbon energy supply investments, such as gas-powered generation plants and small hydropower facilities.

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[52] Household welfare is measured as discounted future consumption of goods and leisure.

Box 5. How do the bottom-up abatement opportunities work in the top-down model?

Low-carbon energy supply investments require a fuel switch towards lower carbon technologies, such as wind power. Such a measure means investing in an option with a lower NPV compared to a traditional coal-fired power plant, which is the business-as-usual or reference technology in the energy sector. In order to be implemented, that difference in value must be absorbed by someone. It is assumed in the MEMO model, for simplicity, that it is the public sector that covers the additional costs. During the two to five-year construction phase for the new generation plant, investment spending rises in the energy sector. Both the interest rate (the price of capital) and the prices of investment goods are pushed up, crowding out capital accumulation in other sectors. Domestic energy prices rise because of higher priced and expanded private investment in the energy sector, and this more costly energy is detrimental to overall growth. If the public costs are covered by higher taxes, an additional tax distortion is added to the economy. When construction is completed and operations begin, these effects are unwound: energy production becomes cheaper due to reduced fuel costs (since free wind costs less than coal), which leads to lower energy prices. The relative price of investment goods declines, to the benefit of the other sectors which increase their capital accumulation.

An energy efficiency measure such as switching to efficient commercial lighting will induce broadly similar effects on investment at the beginning of implementation, balanced by later savings on operational costs resulting from lower energy consumption. As noted above, it will be light rather than heavy industry that benefits early on. If the benefits during operation outweigh the initial costs, growth will be enhanced, together with changes in the structure of firms' intermediate consumption. The sectors that have implemented the efficiency measure then enjoy lower costs of production.

Starting from the basic assessment of net costs and investment demands in the MicroMAC curve analysis, the MEMO model determined the macroeconomic and fiscal implications of Poland's technological options for GHG mitigation. Each of 119 individual mitigation levers identified in the bottom-up analysis was incorporated in the model.[53] While all levers reduce emissions either by reducing energy intensity (energy used per unit of output) or emissions intensity (emissions per unit of energy), they vary in sectoral and fiscal impact. For example, an energy sector investment to move towards low-carbon supply such as construction of a wind power facility generates higher demand in the early years for the output of heavy industry (for the necessary capital goods), whereas an energy efficiency measure such as switching to efficient commercial lighting raises demand for light industry goods. Since most of the abatement measures require government support, they will have a direct impact on fiscal balances, as well as indirect effects. The government then needs to adjust other government spending or taxes (since the model assumes Ricardian equivalence[54]). For example, an increase in public subsidies to the energy sector might be used to spur nuclear plant construction and financed by an increase in the value-added tax. (See Box 5 for more details on how the levers were integrated and Box 6 for more on public financing options. An annotated list of all levers can be found in Annex 7.) The MEMO model reports the impact of each lever on output, emissions, employment, household wealth, and fiscal revenues and expenditures.

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[53] The remaining 4 levers included in the MAC curve were not significant and, lacking sufficient information, were dropped from the MEMO model analysis.

[54] Ricardian equivalence suggests that consumers internalize the government's budget constraint so that it does not matter whether a government finances its spending with debt or a tax increase since the effect on demand will be the same.

Box 6. Public financing options or 'closures' in the MEMO model

The MEMO model assumes that government must, in one way or another, pick up the tab for the excess costs of most of the mitigation measures (that is, for the cost above the reference technology, or equivalently, the mitigation unit costs displayed in the Micro-MAC curve).

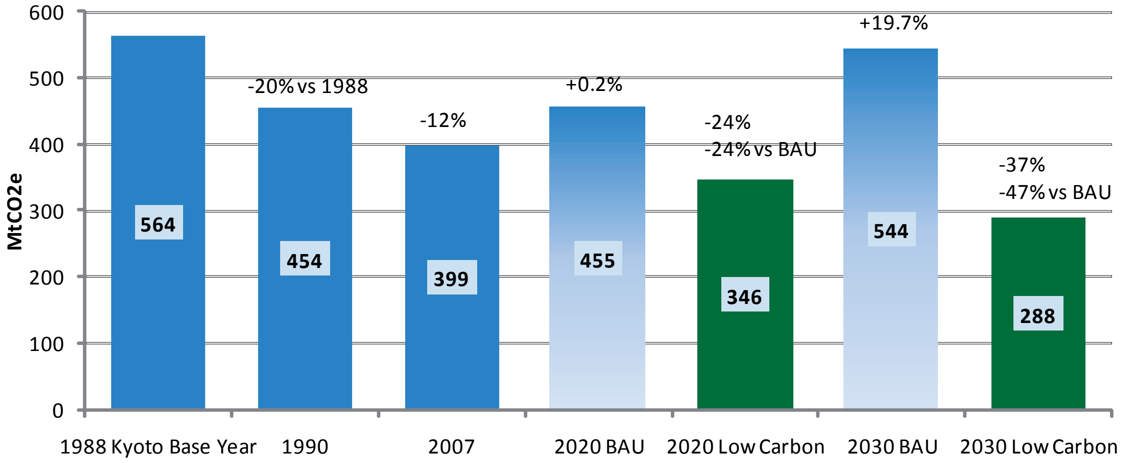
Every lever has an impact on fiscal revenues and expenditures—directly for the majority that require a public subsidy or a carbon tax, and also indirectly as a result of changes in the behaviors of economic agents due to the implementation of the mitigation measure. The model assumes fiscal neutrality; therefore, changes resulting from the levers must be "closed" adequately in the budget accounts to assure that public spending is equal to public revenues and the deficit level set by the government. Given Ricardian equivalence in the model, financing the deficit via debt is equivalent to financing by spending cuts or tax increases. However, the choice of which taxes to increase or which expenditures to cut does affect the model results. Thus, the model considers four closures:

- change in public consumption,
- change in social transfers,
- change in value-added taxes (VAT), and
- changes in personal income taxes (PIT).

As noted in the text, the simulations closing the model with adjustments to VAT are selected as the central model results.

Implementation of the comprehensive abatement package generates a low carbon scenario in which GHG emissions are reduced by 24 percent by 2020 and by 47 percent by 2030. (See Figure 32). In the low carbon scenario simulations of the MEMO model, Poland's GHG emissions in 2020 would fall from about 455 $MtCO_2e$ to 346 $MtCO_2e$. In 2030, GHG emissions would stand at about 288 $MtCO_2e$, as compared with about 544 $MtCO_2e$ in the BAU scenario. Because the BAU projection for 2020 is very close to actual emissions in 1990, the 24 percent reduction relative to 1990 is about the same as that relative to 2020. The 47 percent reduction relative to the BAU projection for 2030 corresponds to 37 percent abatement relative to 1990. Note that under this scenario, Poland would likely meet the overall EU 20-20-20 target of a 20 percent reduction in total emissions by 2020 as compared to 1990 (or emissions of 363 $MtCO_2e$).[55]

Figure 32. Historical emissions in Poland and under MEMO low carbon scenario



Note: If not otherwise indicated, the percentage changes above the bars indicate a change relative to 1990. The data for 2007 is the latest available year. The low carbon scenario is implementation of all 122 abatement options from the Micro-MAC curve.

Source: UNFCCC, IBS technical paper, McKinsey technical paper, World Bank staff calculations.

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[55] Unsurprisingly, these results are very close to those of the MAC curve model which projects emissions after abatement for 2020 at 373 and for 2030 at 267. Since total abatement in the MEMO model is constrained to match the 47 percent 2030 achievement of the MAC curve package, reductions in quantity terms should also be similar.

The economic impact of implementation of the full abatement package is generally negative but appears affordable. The effects on emissions, GDP, value added, employment, household welfare, and public expenditures and revenues under four different MEMO model closures (reduction in public consumption, reduction in social transfers, increase in VAT, and increase in PIT) are presented in Table 4. The impact of the entire package on GDP and value-added, relative to BAU, is consistently negative over the twenty-year period of the model, but the losses approach zero by 2030 (depending on the financing assumption). The losses in real GDP range from 1.5 to 2.2 percent for 2015, peaking at 1.8 to 3.1 percent for 2020, moderating to 0.3 to 2.4 percent for 2025, and settling at -0.7 (gain) to 0.7 percent for 2030. At the peak point for costs to GDP, around 2020, output losses are approximately comparable to one year's potential real GDP growth. (Note that the apparent positive influence on GDP under VAT financing is a GDP accounting artifact because the increase in VAT inflates GDP. Value-added, the better measure of impact under this closure, is reduced over the entire period. The VAT closure is the only variant in which the behavior of value-added and GDP diverge significantly.) The exception to the pattern of GDP losses is for simulations using adjustments in social transfers for financing, under which the impact on GDP turns positive by 2030. However, in this variant, the drop in welfare is the most substantial, since households react to shrinking transfers by giving up leisure, which diminishes their well-being.

Table 4. Macroeconomic and fiscal impact of GHG abatement package, deviation from BAU, in %

Closure	Variable	2015	2020	2025	2030
Reduction in public consumption	GHG emissions	-10.33	-24.01	-39.31	-47.34
	GDP	-2.13	-3.08	-2.42	-0.66
	Value Added	-2.20	-3.19	-2.53	-0.74
	Employment	-2.73	-2.09	-2.76	-2.33
	Household welfare	-1.03	-1.64	0.01	0.52
	Government expenditures	-2.64	-3.05	-2.15	-1.06
	Government revenues	-2.20	-3.15	-2.76	-1.13
Closure	Variable	2015	2020	2025	2030
Reduction in social transfers	GHG emissions	-10.38	-23.86	-39.03	-47.01
	GDP	-1.52	-1.89	-0.28	0.68
	Value Added	-1.51	-1.93	-0.35	0.69
	Employment	-0.67	3.16	6.34	3.34
	Household welfare	-2.88	-4.49	-3.27	-1.63
	Government expenditures	-2.86	-1.83	0.94	0.76
	Government revenues	-1.55	-1.86	-0.49	0.30
Closure	Variable	2015	2020	2025	2030
Increase in VAT	GHG emissions	-10.56	-24.14	-39.48	-47.50
	GDP	-1.53	-1.79	-0.83	0.16
	Value Added	-2.88	-3.42	-2.81	-1.63
	Employment	-2.59	-0.52	-0.20	-0.85
	Household welfare	-1.85	-2.88	-1.54	-0.66
	Government expenditures	1.75	3.23	6.06	5.58
	Government revenues	2.19	2.59	4.30	4.77
Closure	Variable	2015	2020	2025	2030
Increase in PIT	GHG emissions	-11.16	-24.63	-40.15	-47.92
	GDP	-2.18	-2.37	-2.07	-0.63
	Value Added	-2.17	-2.41	-2.03	-0.56
	Employment	-6.13	-4.84	-7.35	-6.79
	Household welfare	-1.82	-2.49	-0.88	-0.09
	Government expenditures	1.38	2.90	5.44	5.16
	Government revenues	1.74	2.41	3.93	4.38

Note: Household welfare is defined as the sum of discounted consumption flows of goods and leisure.
Source: IBS technical paper, MEMO model simulations.

Not only is GDP negatively affected, but employment is also reduced by the abatement measures, and fiscal impacts mimic the public financing choice. The employment loss, expressed as the deviation from BAU in 2015-2030, ranges from 2.8 to 2.1 percent under the reduced public consumption closure, 2.6 to 0.2 percent if VAT is increased, and 7.4 to 4.8 percent if personal income taxes are raised. In contrast, if social transfers were reduced in order to subsidize the transition to low emissions economy in Poland, the employment level would fall below the BAU scenario by 0.7 percent in 2015 but recover to levels above BAU by 2030 (by 3.3 percent). As noted above for the impact on GDP, restructuring of public spending away from less productive categories (such as social transfers) is supportive of job creation (because households react to shrinking transfers by giving up leisure). At the same time, the fiscal implications of the introduction of low carbon interventions are directly associated with the financing closure. If reductions in public consumption or social transfers are selected, then government expenditures are adjusted to the falling GDP level and the subsequent decline in public revenues. On the other hand, if the government covers its costs with VAT and PIT tax hikes, tax revenues rise. Since the VAT financing option generates results that lie about on the average of the four model closures, for the remainder of this section, only simulations using VAT financing will be discussed.

Table 5. Decomposition of the macroeconomic impact of GHG abatement package, deviation from BAU, in %

Variable	2015	2020	2025	2030
Value Added in ETS	-4.06	-5.76	-7.51	-9.06
Value Added in non-ETS	-2.72	-3.10	-2.16	-0.60
Employment in ETS	-3.38	-1.19	-2.73	-5.15
Employment in non-ETS	-2.29	-0.52	0.17	0.39
GHG emission in ETS	-11.60	-27.38	-44.20	-52.46
GHG emission in non-ETS	-8.7	-18.6	-30.6	-37.5
Emission intensity of Value Added	-7.91	-21.45	-37.73	-46.63
Energy intensity of Value Added	-0.53	-7.86	-11.02	-11.57

Note: Energy, heavy industry, and fuels are ETS sectors (see Table 2 note on approximation of ETS and non-ETS sectors based on national accounts data). The model closure for this simulation is an increase in VAT.
Source: IBS technical paper, MEMO model simulations.

The fall in GDP is driven by recession in emission-intensive sectors, which bear the heaviest burden of the entire abatement cost. Value-added in ETS sectors is projected to shrink by more than 9 percent by 2030, with employment falling by more than 5 percent. The shift away from ETS sectors reduces the overall energy intensity of value-added by about 12 percent by 2030 and emission intensity by almost half (see Table 5).

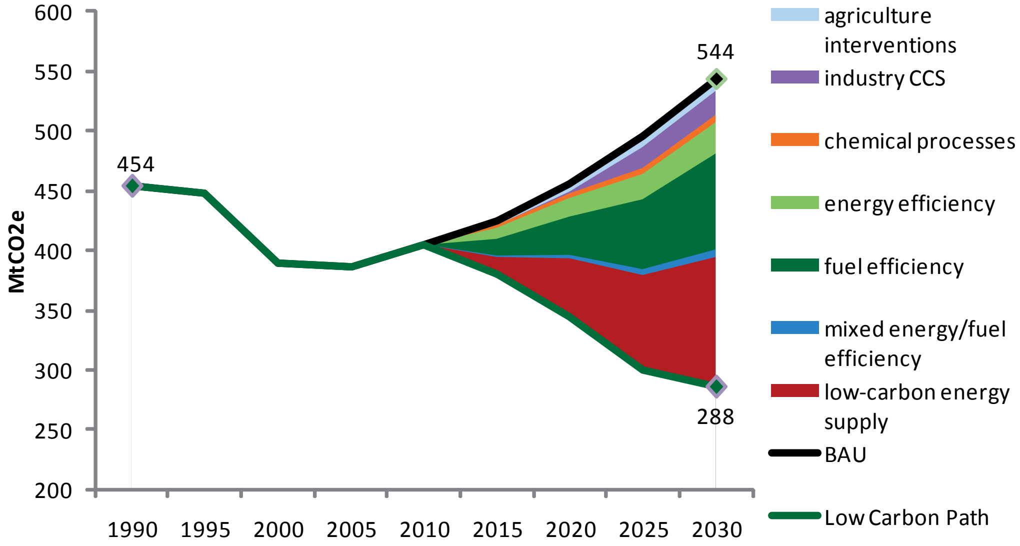
Table 6. Decomposition of abatement by micro-package, reduction relative to BAU, in %

Closure	Group of abatement levers	2015	2020	2025	2030
Increase in VAT	agriculture interventions	0.77	1.27	1.69	1.89
	industry CCS and distribution maintenance	0.01	0.41	3.65	3.79
	chemical processes	0.45	0.71	0.90	1.00
	energy efficiency	2.20	3.49	4.32	4.87
	fuel efficiency	3.39	7.14	11.90	14.84
	mixed energy/fuel efficiency	0.27	0.64	0.98	1.17
	low-carbon energy supply	3.46	10.48	16.03	19.95
Total impact on emissions		10.56	24.14	39.48	47.50

Note: Model closure is increase in VAT.
Source: IBS technical paper, MEMO model simulations.

Analyzed at the level of micro-packages, the switch to low-carbon energy and fuel efficiency measures provide the bulk of GHG abatement. Energy efficiency measures are most important in the early years, contributing 20 percent of mitigation in 2015. From 2020 onward, about 40 percent of potential mitigation derives from low-carbon energy supply measures (see Table 6 and Figure 33). The remaining interventions are dominated by fuel efficiency measures that concentrate mostly in the transport and waste management sectors (contributing about one-third of abatement).

Figure 33. Decomposition of abatement by micro-package



Note: Model closure is increase in VAT. Categories are micro-packages (mitigation options grouped by economic characteristics). Energy sector investments are low-carbon energy supply measures such as gas-fired power plants, onshore wind power generation, and IGCC coal plants. Fuel efficiency measures are mostly in the transport sector. Energy efficiency measures are mostly in buildings. Mixed energy/fuel efficiency measures building measures that also have fuel impact.
Source: IBS technical paper, World Bank staff calculations.

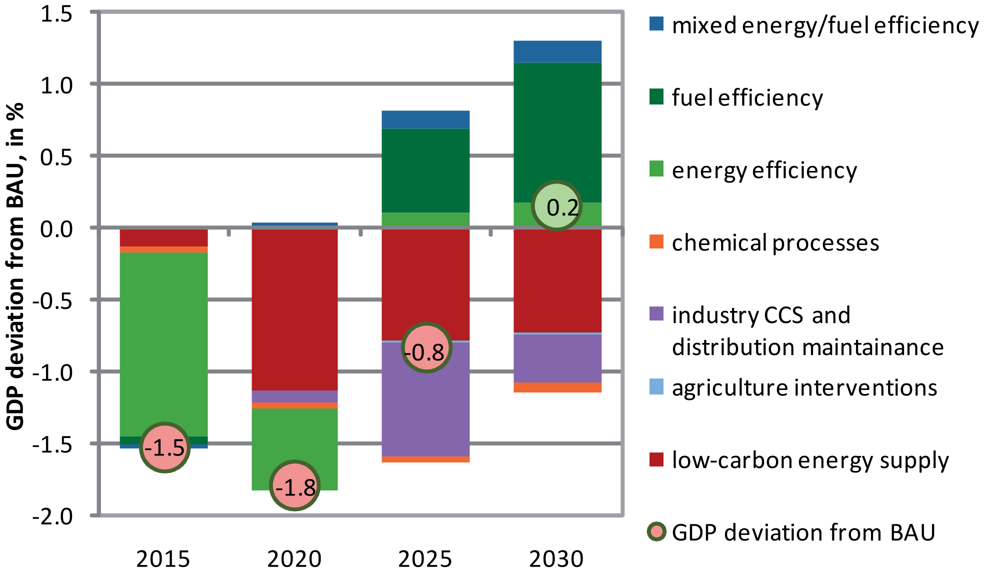
The technological micro-packages with the largest abatement potential do not necessarily impose the biggest macroeconomic cost. Is there a trade-off between growth and abatement that arises from the MEMO model simulations, at least in the projection window up to 2030? The switch to low-emissions energy supply provides about 40 percent of abatement through 2030 and also imposes the biggest negative impact on GDP through 2030 (of about one percent each year). Fuel efficiency measures, on the other hand, while contributing 30 percent of overall abatement, begin to enhance GDP significantly by 2025 and provide a net boost to growth overall. Energy efficiency measures are most important in the early years, contributing 20 percent of mitigation in 2015, while costing over one percent in GDP losses in 2015 but switching to mildly growth-enhancing by 2025. In contrast, industry CCS (carbon capture and storage) contributes only marginally to emissions abatement while costing about one-half percent per year in lower GDP after 2020, leaving it the second most expensive micro-package in terms of growth. While GHG abatement is projected to rise steadily over time as more levers become operational, the impact on macroeconomic performance demonstrates a U-shaped pattern. Losses to real GDP are highest in 2020 and then gradually reverse to a modest positive impact by 2030. (See Table 7 and Figure 34).

Table 7. Decomposition of GDP impact by micro-package, deviation of real GDP from BAU, in %

Closure	Group of abatement levers	2015	2020	2025	2030
Increase in VAT	agriculture interventions	0.00	0.00	-0.01	-0.01
	industry CCS and distribution maintenance	0.00	-0.08	-0.79	-0.34
	chemical processes	-0.04	-0.05	-0.05	-0.06
	energy efficiency	-1.28	-0.57	0.11	0.18
	fuel efficiency	-0.06	0.00	0.58	0.97
	mixed energy/fuel efficiency	-0.02	0.03	0.12	0.15
	low-carbon energy supply	-0.13	-1.13	-0.79	-0.73
Total impact on GDP		-1.53	-1.79	-0.83	0.16

Note: Model closure is increase in VAT. Source: IBS technical paper, MEMO model simulations.

Figure 34. Decomposition of GDP impact of low carbon package by micro-package



Note: Model closure is increase in VAT. Change in real GDP is measured against business-as-usual scenario. Categories are micro-packages (mitigation options grouped by economic characteristics). Energy sector investments are low-carbon energy supply measures such as gas-fired power plants, onshore wind power generation, and IGCC coal plants. Fuel efficiency measures are mostly in the transport sector. Energy efficiency measures are mostly in buildings. Mixed energy/fuel efficiency measures building measures that also have fuel impact.
Source: IBS technical paper, World Bank staff calculations.

The MicroMAC curve can be transposed into a macroeconomic abatement cost curve (or MacroAC curve) which shows the economic effects associated with the implementation of specific abatement measures. Like the MicroMAC curve, the appeal of the MacroAC curve is the visual presentation (see Figure 35).[56] The horizontal axis depicts CO_2e abatement relative to BAU levels in percent,[57] while the vertical axis shows real output deviation from BAU levels in percent. Growth enhancing measures are located above the X axis, while those which hamper growth are below the X axis. The colors of the bars indicate to which micro-package each lever belongs. It seems logical that a policymaker would be interested in these economic impacts of low carbon measures, as well as the net present value available from MicroMAC curve analysis.[58] (Note that, unlike the MicroMAC curve, the area under the MacroAC curve (the size of rectangles) has no economic interpretation.)

This disaggregation by individual measure allows the diversity within micro-packages to become evident, and both important similarities and contrasts to the MicroMAC curve appear. Table 7 above presented results by micro-package, showing that agriculture and chemical processes interventions have rather negligible macroeconomic impact, while industry CCS and distribution maintenance translate into negative effects on real GDP, second only to the cost of low-carbon energy supply. In contrast, the MacroAC curve illustrates that many individual energy efficiency measures are moderately supportive of economic growth, such as energy efficiency improvements in residential and commercial buildings (lighting, HVAC); also growth-enhancing are small hydro power plants, direct use of landfill gas, recycling and composting new waste, and on-shore wind. The messages of the MicroMAC and MacroAC curves are consistent on several levers: some of the most expensive measures in financial terms, such as CCS, also have a negative impact on real GDP. On others, the MacroAC analysis reorders the MicroMAC curve ranking: for example, on-shore wind power and small hydro power plants are superior to many energy efficiency measures by the metric of GDP growth. Nuclear power shifts rightward, to become among the most expensive measure (because even a 2030 horizon compares poorly with nuclear plants' 10-year construction phase but 60-year lifespan). Fuel efficiency measures still fare well (but note that the MicroMAC curve classifies these measures as energy efficiency).

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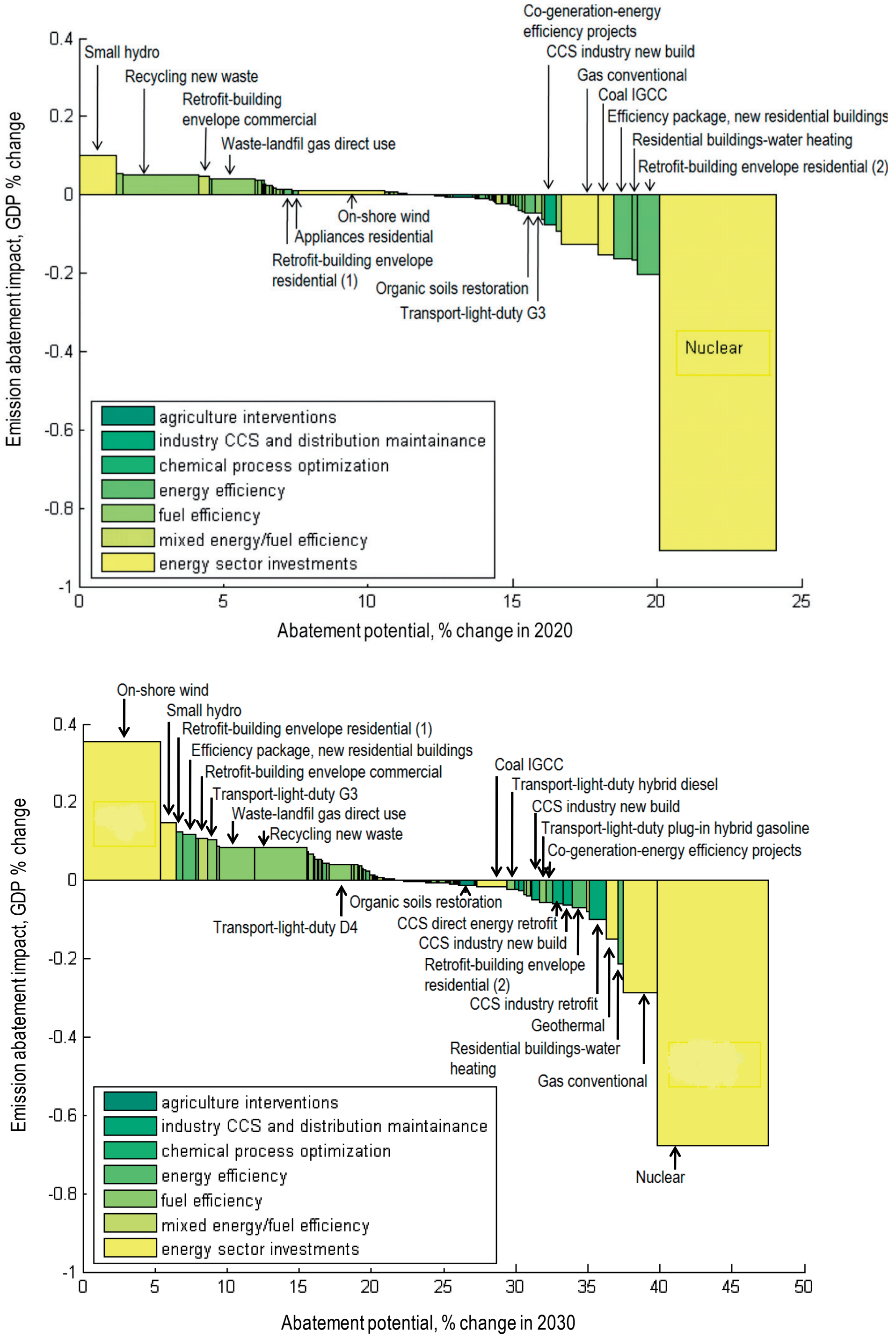
[56] The presentation derives from simulations using the VAT financing closure, but the results for the alternative closures are similar.

[57] To translate the horizontal axis between the MacroAC curve and the MAC curve, it should be noted that one percent GHG abatement relative to BAU 2020 corresponds to about 4.6 tCO_2e, while one percent in 2030 corresponds to about 5.4 tCO_2e.

[58] The units are somewhat different between the two models. For the MAC curve, costs are reported in € per tCO_2e abated, while for the MacroAC curve, costs are reported as a percent GDP deviation from BAU for implementation of each lever up to its abatement potential.

Figure 35. MEMO model: Macroeconomic Abatement Cost (MacroAC) curve, 2020 and 2030



Note: A positive value on the vertical axis means that an abatement measure increases GDP. Curve is for the whole abatement package. Model closure is increase in VAT. The area under the curve (the size of rectangles) has no economic interpretation. 1% GHG abatement potential in 2020 corresponds to about 4.6 tCO$_2$e, while 1% in 2030 corresponds to about 5.4 tCO$_2$e.

Source: IBS technical paper, MEMO model simulations.

The impact on GDP of various components of the abatement package shifts over time and becomes more positive, as investments are completed and operations begin for each lever. Comparing the 2020 and 2030 MacroAC curves, it can be seen that the GDP cost of many levers diminishes, and the shape of the curve flattens. Those with the most expensive and protracted investment phase will take longest to have a positive impact on GDP, in particular, some measures related to energy supply, such as nuclear installations with construction periods that extend over more than half of the projection horizon. By contrast, investments in on-shore wind energy farms contribute positively to growth by 2020, since they can start operations much faster and require much smaller capital expenditures. However, with an even longer projection horizon beyond 2030, the shift from GDP growth-hampering to growth-enhancing will certainly materialize for levers such as nuclear plants, which have the longest lifespan of any available energy sector technology. The ranking of coal IGCC installations also improves significantly over time, while the GDP impact of conventional gas, geothermal, and solar PV deteriorates between 2020 and 2030. The gains from energy efficiency improvements in retrofitted buildings increase over time. A number of other energy efficiency measures which undercut GDP in 2020 support growth by 2030, including lighting controls and replacements of bulbs in commercial buildings, HVAC enhancements and replacements of bulbs in residential buildings, higher energy efficiency standards in buildings, energy efficiency advances in transport vehicles, and landfill-gas-electricity generation.

An alternative presentation of the macroeconomic costs of the low carbon scenario is the Macroeconomic Marginal Abatement Cost (MacroMAC) curve, with unit costs of GDP change compared to abatement potential. When the impact on GDP compared to the business-as-usual levels is scaled to cost per percent of GHG abatement relative to BAU, it is easier to see which measures are 'cheaper' (see Figure 36). In other words, the Y values on the MacroMAC curve are elasticities of real GDP relative to carbon abatement. It follows that the area of each of the rectangles on the MacroMAC curve equals the height of the same rectangle on the MacroAC curve. While the area under the Macro AC curve (the size of the rectangles) has no economic interpretation, the area under the MacroMAC curve is of interest: the size of each rectangle equals the impact on GDP of carbon abatement via that lever. The area under the MacroMAC curve in total defines the overall impact of the entire abatement package on real GDP. This interpretation is similar to that of the bottom-up MAC curve (in which the area under the curve equals the financial cost of the abatement package)[59] (see Figure 36).

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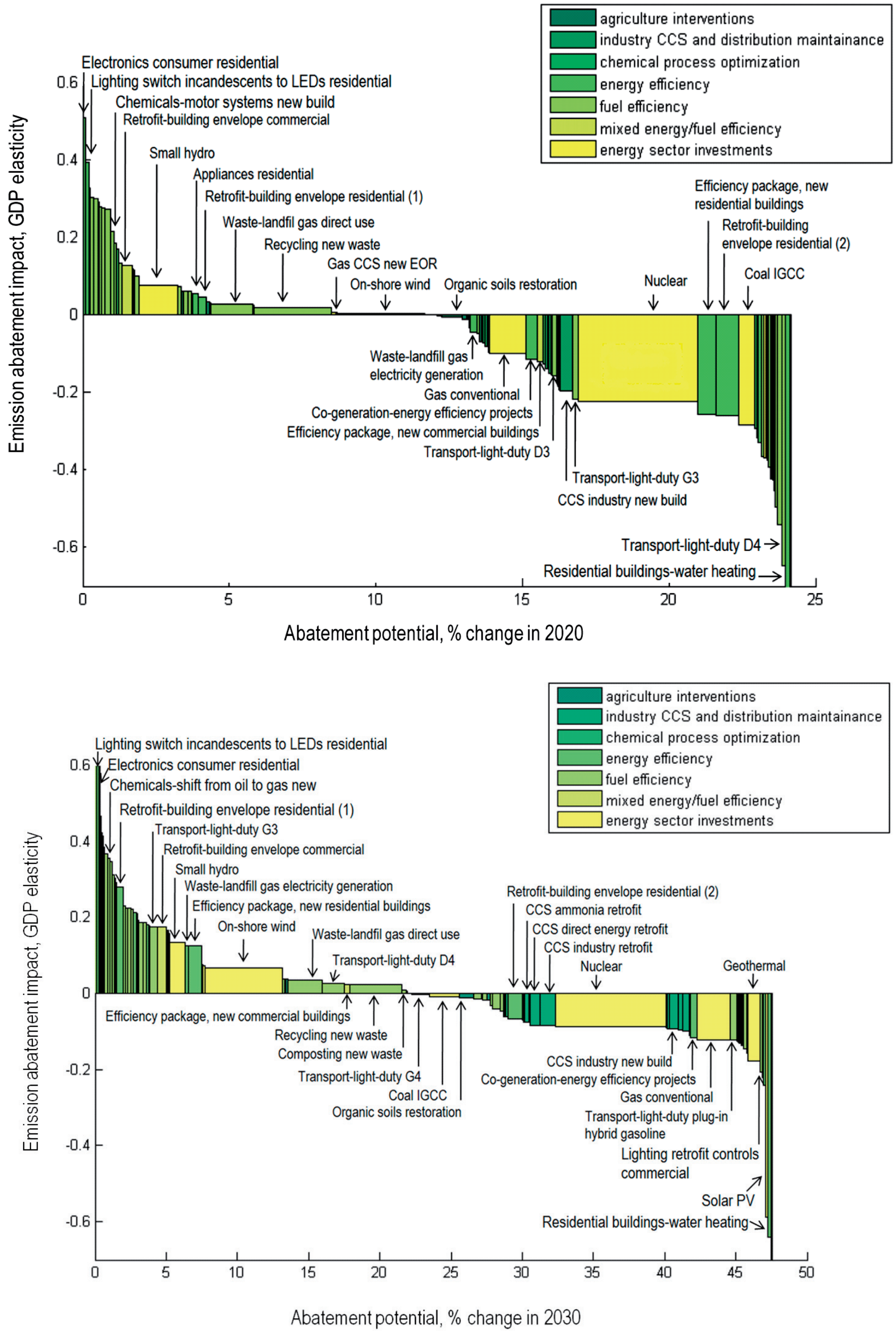
[59] Note that the units of measurement differ between the MAC curve and the MacroAC and MacroMAC curves. See footnote 61.

Figure 36. Macroeconomic Marginal Abatement Cost (MacroMAC) curve, 2020 and 2030



Note: A positive value on the vertical axis means that an abatement measure increases GDP. Curve is for the whole abatement package. Model closure is increase in VAT. The area of any rectangle equals the GDP effect (loss or gain) of carbon abatement via any specific lever.

Source: IBS technical paper, MEMO model simulations.

The MacroAC and MacroMAC curves are fully consistent; their differing formulations suit them to different policy applications. The curves may appear to show different magnitudes of carbon abatement levers' impact on real GDP; however, the GDP effect of a specific lever always has the same sign on the two curves, indicating either a GDP gain or loss, but the ranking of unit costs in terms of GDP change is not identical to the MacroAC curve's total GDP cost per measure. Two examples of a shift in ranking are nuclear plants, which no longer rank as the most expensive option on a per unit basis, and wind energy, which ranks further to the right (more costly) once abatement potential is considered. The MacroAC curve serves well to inform policymakers who have committed to a package of abatement measures (such as those recommended by the MicroMAC curve analysis) as to the impact of that package on growth. The MacroMAC curve is the preferable tool if policymakers are considering what the content of a package should be and impact on GDP is a factor to be used in that decision.

With the extension of the time horizon to 2030, some levers change their position on the MacroMAC curve and generate different macroeconomic effects. Between 2020 and 2030, the same flattening of the cost curve observed for the MacroAC curve holds for the MacroMAC curve, reflecting the unsurprising finding that in 2030 there are more abatement options which may enhance GDP growth. By 2030, additional measures related to fuel and energy efficiency improvements in transport and industry have positive impact. The biggest improvements from 2020 to 2030 in unit macro costs of carbon abatement appear in geothermal energy, introduction of hybrid cars, CCS installations (which remain GDP-reducing), and enhancements in lighting and HVAC in buildings.

Numerous, often diminutive energy efficiency measures deliver relatively little GHG reduction individually but a package of the most GDP-enhancing measures could achieve critical mass (and get policymakers attention). Rather than focusing only on the interventions capable of significant GDP impact on their own, a package of small but effective levers could raise growth to a greater extent and at lower macro cost. Thus, an abatement policy oriented to a broad range of energy efficiency measures could be more effective in the long term in stimulating economic growth than a policy focused solely on the largest interventions.

The MEMO model simulations provide a more complex assessment of possible abatement measures than the MicroMAC curve. This additional information changes the ranking of many technological abatement measures, although the new simulations also illustrate that there will be no single metric against which to judge the preferability of abatement choices. The creation of a new visual presentation helps summarize a good portion of these new findings. However, while this simplified graphic of results helps communicate the main findings of the MEMO model, and while this model remains both highly flexible and heavily detailed, the challenge of working with very large and complex models remains--they are not fully intelligible to anyone but their maker. Also, as noted in Section d, the convergence of Poland's economy towards EU averages, while clearly a technically superior approach to constructing a BAU scenario, builds in moderation of GHG emissions via the ongoing shift towards less emission-intensive sectors such as services and via improved efficiency in each sector. This presumption of flexibility of factors of production between sectors is critical also to the relatively modest long-term costs of a low carbon scenario. It is the self-evident appeal to policymakers of this path-breaking model and its deep integration of bottom-up and top-down approaches that makes it particularly important that underlying assumptions be kept in view as policymakers consider the policy actions that would constitute a low emissions growth path for Poland. Further, Poland also faces immediate and specific obligations under EU legislation, which tie policymakers' hands through predetermined targets and policies. The next chapter takes up this question of the cost of compliance to the EU 20-20-20 climate package.

g.

THE REGIONAL OPTIONS FOR CARBON ABATEMENT (ROCA) MODEL AND IMPLEMENTING EU CLIMATE POLICY

The Regional Options of Carbon Abatement (ROCA) model is a country-level CGE model for energy and GHG mitigation policy assessment adapted to Poland to analyze implementation of the EU 20-20-20 policy package. The model considers some key variations on climate policy design that meet the same emission reduction targets and some alternative model assumptions that further illuminate the impact on Poland's economy in 2020 through the analysis of 11 simulations. The 'Main' scenario, defining a central set of assumptions, finds that Poland bears a higher economic burden than the average EU country because of the predominance of coal in power generation. The market segmentation created by the EU's division of economic sectors into ETS and non-ETS categories greatly elevates the marginal cost of abatement for non-ETS industries, and removing that segmentation reduces overall compliance costs for Poland. Similarly, relaxing the restriction on use of 'where-flexibility' (allowing emission reductions in the least-cost location) dramatically reduces compliance costs and the need for adjustment, as most abatement is off-shored. Then, an additional aspect of EU policy is incorporated into the ROCA model—overlapping regulation in the form of an EU target for renewable energy sources—to determine conditions in which it may be (counter-intuitively) welfare-improving. The model considers various policy choices under the control of the Polish government. First, alternative revenue recycling via wage subsidies is analyzed, which generates a weak 'double dividend' (reducing emissions while easing distortions in the labor market) and lower unemployment. Then, the loosening of restrictions on the scope of nuclear power is found to cut compliance costs for Poland by about one-third (although the engineering feasibility of installation of nuclear power by 2030 is generally agreed to be about 6 GW, about half the capacity necessary to generate the 35 percent of electricity projected under this scenario). Lastly, the granting of free emission allowances to energy-intensive and trade-exposed sectors, which might be vulnerable to carbon leakage, preserves sector output but generates overall losses in GDP.

The ROCA model is a multi-sector, multi-country CGE model incorporating a hybrid bottom-up and top-down representation of the power sector. Starting from a much-reviewed CGE model framework and drawing data from the GTAP database, the ROCA model has eight sectors (with the disaggregation focused on energy intensive sectors) as well as five energy subsectors to allow for detailed analysis. Some key market distortions such as energy and trade taxes and unemployment are included. The model emphasizes spillover and feedback effects from international markets, with four countries or regions (Poland, other EU, other industrialized countries, and developing countries). The energy sector gets innovative treatment, with a hybrid bottom-up and top-down representation of power sector production possibilities. The model's horizon stretches to 2020, the deadline for the EU 20-20-20 package obligations, and institutional settings and policy instruments for climate policy implementation are included, including the complex rules for the ETS and non-ETS sectors, and revenue recycling possibilities from carbon pricing. For data limitation reasons, it models only CO_2 emissions, and it derives a business-as-usual scenario in line with external projections that foresees less energy-saving sectoral transformation (than the MEMO model baseline) (see Sections c and d and Annex 4 and Annex 6 for more details).

The ROCA model is applied to assess compliance costs of the main features of the EU 20-20-20 package. The central constraint on Poland's economy in 2020 in this modeling exercise is the need to meet the targets for emissions set out in the December 2008 EU climate change and energy package for emission-intensive (or ETS) sectors and for other sectors (non-ETS) such that the EU overall can reduce emissions by 20 percent in 2020 compared with 1990. Across all scenarios, these central provisions of EU climate policy legislation hold. Differential emission reduction targets are imposed for the ETS and non-ETS segments of the respective economies. For Poland, these targets are taken to be a 21 percent reduction in ETS sectors compared to 2005 (which is the EU-wide target) and a 14 percent increase in non-ETS sectors (the agreed national target). For ETS sectors, EU-wide carbon trading ensures equal prices of emissions abatement across the EU in all scenarios. For non-ETS sectors, the model assumes that each EU country imposes a domestic CO_2 tax which equalizes marginal abatement costs only across each country's domestic non-ETS emission sources. The ROCA model is a multi-region model, designed to analyze international feedbacks (both the impact of EU policy choices on global markets and international spillovers triggered by emission abatement policies of other major industrialized regions). Other industrialized countries (the third region in the model) are assumed to face a 2020 target of 4.8 percent abatement compared to 2005, roughly corresponding to pre-Copenhagen official pledges. They do not participate in carbon trading or offsets but rather set a uniform domestic carbon tax. The fourth region, developing countries, faces no target and supplies CDM projects. (See Table 8).

The model considers some key variations on climate policy design that meet the same emission reduction targets and some alternative model assumptions that further illuminate the impact on Poland's economy in 2020. In addition to setting multiple abatement targets, EU policy segments sectors into two groups, creates additional requirements on renewable energy and sets indicative targets on energy efficiency. The agreed legal and regulatory structure for ETS sector emissions is likely to generate significant fiscal revenues from auctions for governments, conditional on the proportion allocated for free to assist affected industries; and governments will need to decide how to spend these revenues. Further, countries are free to design their own domestic policies to achieve non-ETS targets, including a domestic carbon tax.. To better understand how climate regulations generate economic costs, the ROCA model analyzes scenarios on the excess costs of emission market segmentation and of ceilings on foreign offsets (CDM limits) and on the efficiency losses of overlapping regulations. The importance of the method selected for revenue recycling for the economy-wide costs of emission abatement is addressed. Then some central features of the model are explored, through scenarios that vary the role of technology and technological policy constraints in power generation and the implications of international market spillovers (terms-of-trade) for the costs and effectiveness of sub-global (e.g., EU) climate policy action. The scenarios considered by the ROCA model are summarized in Table 8.

Table 8. Summary of scenario characteristics simulated in the ROCA model

Scenario	Basic assumptions

All scenarios	• Emission reduction targets for 2020 are set as in EU climate package and Copenhagen pledges:
	  • Poland must reduce emissions in ETS sectors by 21 percent compared to 2005 and may increase emissions in non-ETS sectors by no more than 14 percent; the EU-26 (for the 'rest of the EU') faces 21 and 12.5 percent reduction targets for ETS and non-ETS sectors respectively (see Table 3).
	  • Other industrialized countries must achieve 4.8 percent reduction as compared to 2005 levels, roughly corresponding to pre-Copenhagen official pledges. This region represents key other Kyoto Protocol Annex 1 countries: Canada, USA, Australia, New Zealand, Japan, and Russia.
	  • The remaining region, developing countries, has no emissions target.
	• Emissions trading focuses on the existing EU carbon market:
	  • There is EU-wide emissions trading for energy-intensive industries (ETS sectors).
	  • Access for EU non-ETS sectors varies according to scenario.
	  • The other regions do not participate in international emissions trading.
	• Flexibility in the form of CDM offsets is included:
	  • For the EU, varying access according to scenario.
	  • The other industrialized region does not have access to CDM offsets.
	  • The developing countries region is the supplier of CDM offsets.
	• Domestic carbon taxes are used:
	  • For EU non-ETS sectors, each EU country imposes a domestic tax.
	  • The other industrialized region sets a uniform domestic carbon price.
	  • Revenue recycling varies by scenario.

Main	• No access for EU non-ETS sectors to carbon market. • Limits to CDM offsets for EU as prescribed by the EU climate package: non-ETS sectors are allowed to offset up to 33 percent of emission reductions, ETS sectors, 20 percent. • Lump-sum recycling to households of revenues from carbon tax and auctioning of allowances in carbon market. • Bottom-up activity analysis characterization of power supply technologies in the EU. • Restricted use of nuclear power at BAU capacity level.
Flexible emissions trading	Like Main but with access for EU non-ETS sectors to carbon market.
Flexible trading & offsets	Like Main but with EU non-ETS sector access to carbon market and no CDM limits.
Renewables target	Like Main but with target quota for renewable power generation in EU.
Wage subsidy	Like Main but with revenue recycling via wage subsidies.
Unrestricted nuclear	Like Main but without nuclear expansion ceiling in Poland.
Restricted gas	Like Main but with ceiling on gas use in Poland's power generation at BAU level.
Free 30 % allowances	Like Main but with output-based allowance allocation to energy-intensive and trade-exposed (EITE) sectors in EU (free allocation of 30 percent of EITE sectors' 2005 emission level).
Free 70% allowances	Like Main but with output-based allowance allocation to EITE sectors in EU (free allocation of 70 percent of 2005 emission level).
Top-down power sector	Like Main but with top-down characterization of power production.
Small open economy	Like Main but without international terms-of-trade effects (Poland is treated as a small open economy).

Source: Loch Alpine technical paper.

A summary of results of the 11 simulations, that explore aspects of meeting the EU targets, identifies which components of regulations are more costly, and demonstrates the interaction with other policy choices and model assumptions, is below. (See Table 9). Changes in real GDP in 2020, in unemployment, and in output of energy-intensive and trade-exposed sectors are compared to the business-as-usual scenario for 2020, as variables of central concern to economic policymakers. The structure of the power sector is determined for each simulation (except the case in which the power sector is simplified). Marginal costs of abatement are indicated as the price per metric ton of CO_2 (tCO_2). (More detailed results are available in Annex 6, in particular for the other industrialized countries and developing countries). Differences in marginal abatement costs across regions and sectors (e.g., ETS versus non-ETS) in the table reveal scope for direct overall cost savings through increased "where-flexibility" (the degree to which emission reductions are allowed to take place at the least-cost geographic location, regardless of nation-state boundaries).[60] Abatement achievements before the use of flexibility mechanisms for each scenario illustrate how the off-shoring of abatement varies. While where-flexibility enhances efficiency, nevertheless, it is possible that an individual country such as Poland can be worse off from (more comprehensive) emissions trading due to adverse terms-of-trade effects for energy goods, energy-intensive commodities or CO_2 emission allowances.

The 'Main' scenario sets out the central set of assumptions that will be altered in other scenarios. No trading is allowed between ETS and non-ETS emissions. Current regulations' limits on use of CDM offsets hold (see Annex 1 for details). There is no target for renewables in power supply[61]. There is no free allocation of emission rights—all are auctioned[62]; and the revenues from auctioned ETS allowances and domestic taxation of non-ETS emissions are recycled lump-sum to households. The use of nuclear power–both in Poland as well as the rest of the EU–is limited to the BAU level, reflecting public concerns on the operation of nuclear power plants and the unresolved issue of long-term nuclear waste management. However, despite concerns about energy security, there is no ceiling on gas-powered electricity generation. Two of the innovative aspects of the ROCA model are applied here: this scenario includes detailed technology in the power sector; and the modeling of the interplay of four countries/ regions allows analysis of international terms of trade effects.

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[60] Greater flexibility lowers implementation costs. The Kyoto Protocol includes several mechanisms that allow for 'where-flexibility' (see Box 2).

[61] The targets for renewables in the power sector were analyzed in one of the simulations, but note that because of data limitations, the ROCA model is not able to capture these targets exactly as formulated in EU regulations. The simulations in this report refer to the share of renewable in power supply, while the EU targets refer to the share of renewa bles in final energy demand.

[62] The potential derogations in the energy sector for the modernization of electricity generation were not modeled in the 'Main' scenario both because of limitations of the model and also the evolving interpretations of these regulations. In order to capture derogations in further work, some approximation of the projected adjustment path from 30 percent of allowances for the energy sector auctioned in 2013 to full auctioning in 2020 will be required.

Table 9. ROCA model: economic impacts of alternative emission mitigation scenarios

Outcome indicator		BAU	Main scenario	Flexible emissions trading	Flexible trading & offsets	Renewables target	Wage subsidy	Unrestricted nuclear	Restricted gas	Free 30% allowances	Free 70% allowances	Top-down power sector	Small open economy
Real GDP (% change from BAU)													
Poland			-1.40	-1.16	-0.28	-1.02	-0.98	-1.12	-1.02	-1.46	-1.40	-1.40	-1.74
EU26			-0.55	-0.41	-0.08	-0.37	-0.42	-0.45	-0.54	-0.56	-0.55	-0.54	
Other industrialized			-0.28	-0.28	-0.25	-0.27	-0.2	-0.28	-0.28	-0.28	-0.28	-0.28	
Developing countries			-0.11	-0.09	-0.08	-0.09	-0.09	-0.1	-0.1	-0.11	-0.11	-0.11	
Unemployment (change in percentage points, relative to BAU unemployment rate)													
Poland			0.53	0.41	0.10	0.35	-0.39	0.37	0.55	0.53	0.52	0.44	0.49
EU26			0.17	0.12	0.03	0.04	-0.07	0.16	0.17	0.17	0.17	0.14	
Output of energy-intensive and trade-exposed sectors (% from BAU)													
Poland			-2.66	-2.82	-0.29	-1.13	-2.08	-1.86	-2.85	-2.40	-2.05	-1.94	-4.42
EU26			-0.73	-0.78	0.20	0.14	-0.55	-0.66	-0.74	-0.64	-0.51	-0.37	
Technology shares of power sector (in % from total)													
Poland	coal	84.1	73.5	70.2	81.9	75.6	73.3	50.7	78.9	73.4	73.4		73.5
	gas	5.1	11.8	14.0	6.4	6.2	12.0	6.9	5.8	11.8	11.9		11.5
	oil	0.9	1.1	1.1	1.0	1.0	1.1	1.0	1.1	1.1	1.1		1.1
	nuclear	5.2	5.9	6.0	5.4	5.5	5.8	35.5	5.9	5.9	5.9		6.0
	renewable	4.5	7.8	8.7	5.3	11.7	7.8	5.9	8.2	7.8	7.8		7.9
CO_2 values (US$ per tCO_2)													
ETS			29.7	36.4	7.9	10.7	30.1	26.9	30.1	29.8	29.8	22.0	29.7
Non-ETS	Poland		87.2	36.4	7.9	86.6	91.3	88.3	87.4	87.3	87.3	87.8	67.6
	EU26		81.9	36.4	7.9	79.6	84.0	81.8	81.9	82.0	82.1	81.0	
CO_2 reduction (inland, % from BAU)													
Poland			-20.1	-19.7	-4.9	-15.8	-19.9	-24.2	-23.3	-18.4	-20.0	-20.0	-21.2
EU26			-14.7	-14.7	-2.8	-15.1	-14.7	-14.3	-14.4	-14.8	-14.7	-14.7	
Other industrialized			-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	
Developing countries			-0.8	-0.8	-3.3	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	

Note: Simulation based on CO_2 , not GHG, reduction. EU26 is the EU excluding Poland. Inland CO_2 reduction excludes credits from CDM offsets. See Table 8 for definitions and description of scenarios.
Source: Loch Alpine technical paper; ROCA model simulations; World Bank staff calculations.

The findings of the 'Main' scenario illustrate that Poland bears a higher economic burden than the average EU country because of its relatively high abatement targets for non-ETS sectors with strong baseline emissions growth. Setting a non-zero price of carbon generates a negative shock to emissions-intensive sectors. Since power generation in Poland is predominantly coal-based, it will be hard hit. CO_2 reduction from the sector takes place through rising electricity prices (by about 20 percent, much more than in the rest of the EU), a decline in output by about 10 percent, the expansion of CO_2-free renewable power production, and, to a more limited extent, fuel shifting to gas (since nuclear power is assumed restricted to BAU levels) (see Figure 49). The higher costs of production for those sectors in which (fossil fuel) energy inputs represent a significant share of direct and indirect costs leads to a loss in competitiveness, depressing production. In the new equilibrium, real wages are lower, and unemployment rises (although by only half a percentage point). The effects on real GDP are modest but more than twice as high for Poland as for the rest of the EU (with a loss of 1.4 percent of GDP).[63] Ceteris paribus, differences in economic adjustment costs between countries and regions can be traced back to differences in the effective emission reduction targets: Poland faces the highest reduction requirement vis-à-vis the BAU situation in 2020 for non-ETS sectors (of about 22 percent, see following paragraph and Table 3), driven by expected strong baseline emission growth in its non-ETS sectors. Another important cost determinant is the ease of carbon substitution which is embodied implicitly in the sector-specific production technologies and consumer preferences. A third determinant is international feedback and spillover effects, when countries' terms of trade and global prices are affected by abatement policies.[64] (See Table 9 and Figure 37, Figure 38, and Figure 39).

Energy-intensive and trade-exposed industries are not devastated by carbon abatement, but market segmentation drives the marginal cost of abatement in non-ETS sectors to almost three times the level in ETS sectors. The common EU price for ETS emissions amounts to roughly US$30 per mt of CO_2. Energy-intensive and trade-exposed (EITE) industries (a subset of ETS sectors) are worried about 'carbon leakage'[65] and negative repercussions of emission constraints on production and employment.[66] However, the simulations suggest that policy concerns in Poland as well as the rest of the EU about drastic adjustment effects in EITE sectors are unwarranted—these sectors are harmed more than the average (with 2.7 percent loss in output in 2020 compared to GDP losses of 1.4 percent), but the contraction is still moderate in size. A key reason is that, in the 'Main' scenario, other industrialized countries also undertake abatement, and CDM offsets put a scarcity rent on carbon emissions for developing countries such that the shift in comparative advantage is dampened. (However, it must be acknowledged that the impact on EITE sectors is reported as an average; and, at a more disaggregated level, production and employment shocks for specific sectors can be markedly higher.) At the same time, marginal abatement costs in the non-ETS sectors for both Poland and the rest of the EU are much higher than the ETS value (at a shadow price of US$87 per tCO_2 for Poland, and US$82 for other EU), revealing less potential for cheap emission abatement in the non-ETS sectors given that the effective relative reduction requirements in the non-ETS sectors are similar (in the case of Poland: 21 percent effective reduction in ETS, 22 in non-ETS) or even lower (in case of the EU: 24 ETS, 14 non-ETS). The differences between ETS and non-ETS prices drive the direct excess costs of EU emission market segmentation, which are alleviated to some degree through limited low-cost CDM imports (at a price of only US$1 per tCO_2).

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[63] The welfare cost to Poland is close to 1 percent, more than three times the cost to the rest of the EU. The cost in GDP and welfare to other industrialized countries is about half to two-thirds that of the EU (see Annex 6).

[64] The impact of spillover effects dominates in the case of developing countries. Although they have no emission reduction pledges and should benefit through CDM, they face non-negligible welfare losses because of deterioration in their terms of trade (see Annex 6).

[65] In this context, carbon leakage refers to the possibility that countries with more relaxed emissions policy may gain a trading advantage and production may move offshore to the cheaper country with lower standards.

[66] According to EU criteria, a sector is considered at risk of emission leakage if the direct and indirect additional production from emissions controls costs exceed 5 percent of gross value added and the total value of its exports and imports exceeds 10 percent of the total value of its turnover and imports.

Figure 37. 'Main' scenario : carbon emissions, % change vs. 2005

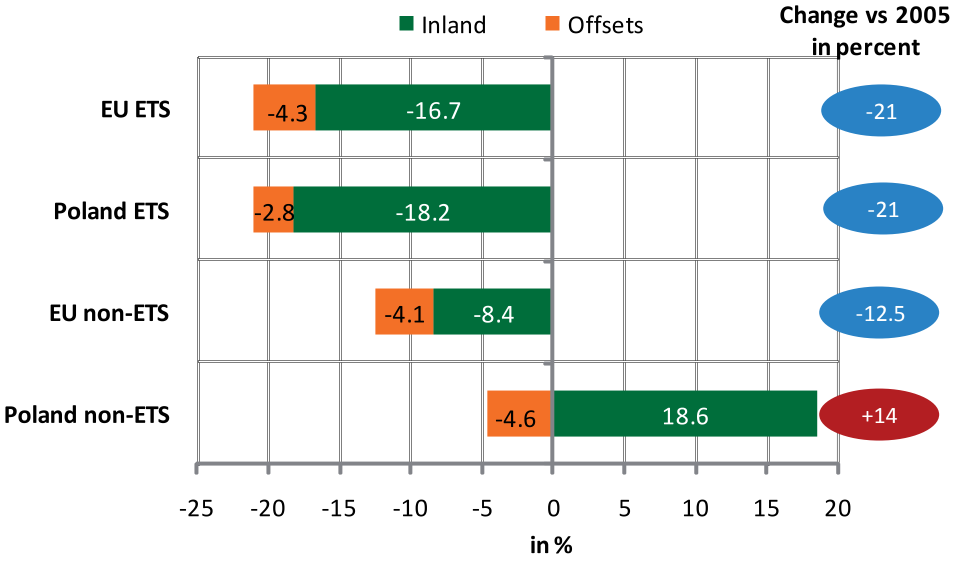


Figure 38. 'Main' scenario 2020: carbon prices

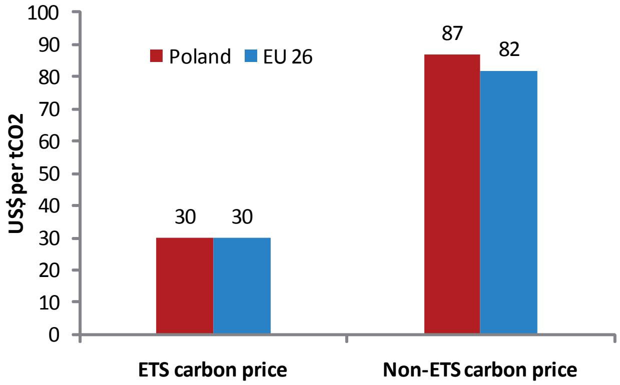
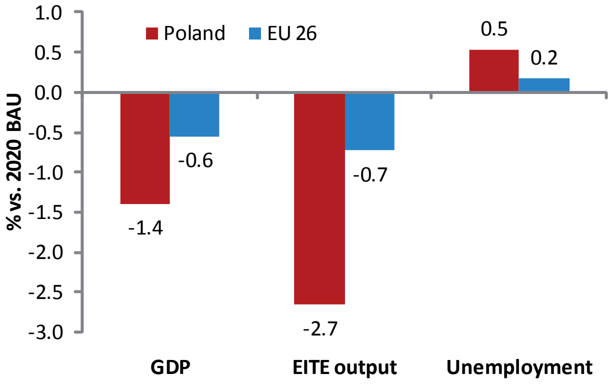


Figure 39. 'Main' scenario 2020: macroeconomic variables in Poland and the EU



Note: 2004 is the base year in the model and can be treated as an approximation for 2005, which is the base year for the EU 20-20-20 regulations. EU is rest of the EU excluding Poland. Inland carbon emissions are from within the region. Offsets are carbon emissions achieved by the region through CDM. EITE is value-added of energy- and trade-exposed sectors (non-metallic minerals, iron and steel products, non-ferrous metals, paper–pulp–print, and refined oil products). UR is the change in the unemployment rate in percentage points. The carbon price in non-ETS sectors is a shadow price.
Source: Loch Alpine technical paper; ROCA model simulations.

Equalizing the carbon price between ETS and non-ETS sectors in the 'Flexible emissions trading' scenario raises costs to ETS sectors but reduces overall compliance costs for Poland by about one-sixth of lost GDP and for the EU by about one-quarter. In this alternative, Poland and the rest of the EU are assumed to establish a comprehensive emission trading market so there is only one EU-wide CO_2 price. In 2020, the ROCA model finds that price to be about US$36 per ton (against US$30 per ton for ETS sectors in the 'Main' scenario). The integrated EU carbon market generates greater pressure on the electricity sector and other ETS sectors. In this scenario, the ETS sectors must undertake more emission abatement in order to reduce the expensive abatement burden of the non-ETS sectors. As a consequence, electricity prices rise further, power production declines more sharply, and the structural shifts in power generation across technologies become more accentuated. Likewise, the negative repercussions on EITE sectors are slightly more pronounced. Equalization of marginal abatement costs across all EU emission sources reduces compliance costs for the EU compared to the cost identified in the 'Main' scenario by roughly 10 percent in welfare terms, or by 17 of lost GDP for Poland and 25 percent for other EU. At first glance, the excess costs of CO_2 segmentation seem rather modest, but they might easily be significantly higher if, instead of the assumptions of the 'Main' scenario, the EU contained 27 differentiated non-ETS markets, cost-effective non-ETS regulation via a uniform carbon tax were replaced by a more realistic patchwork of overlapping domestic regulations, or if CDM access were more restrictive (since the EU regulations are complex and open both to interpretation and revision). (See Table 9 and Figure 40, Figure 41, and Figure 42).

Relaxing the restriction on use of 'where-flexibility', in the 'Flexible trading and offsets' scenario, dramatically reduces compliance costs and the need for adjustment, as most abatement is off-shored. The 'Flexible trading and offsets' scenario assumes a comprehensive EU carbon trading regime and, in addition, relaxes the supplementarity constraints on CDM. Poland and the rest of the EU are now allowed to import up to their nominal emission reduction requirement with respect to 2005 levels (which still leaves obligations for domestic abatement from the substantial gap to the higher effective reduction requirement with respect to 2020). Access to more CDM abatement drastically decreases overall economic costs for Poland and the rest of the EU: CO_2 prices drop to around US$8 per ton. Poland and the rest of the EU shift the bulk of abatement to the developing world, paying only about US$2 per tCO_2 in CDM credits. While other EU emission reduction in the 'Main' and 'Flexible emissions trading' scenarios amounts to 15 percent compared to BAU levels, it is only about 3 percent in this scenario. The difference between the costs of US$2 per tCO_2 for a CDM credit and the EU-internal CO_2 price of US$8 is captured by the shadow price on the CDM quota, with quota revenues accruing to EU governments. The required economic adjustment in the power sector and the rest of the economy as compared to BAU is greatly reduced (see Figure 49). This scenario stands in stark contrast to the 'Main' scenario, and its assumptions are illustrative rather than highly realistic. For example, if the EU were to allow substantial use of foreign offsets, other industrialized countries would also likely be competing for CDM imports, pushing up their price. (See Table 9 and Figure 40, Figure 41, and Figure 42).

Figure 40. 'Where-flexibility' scenarios: carbon emissions, % change vs. 2005

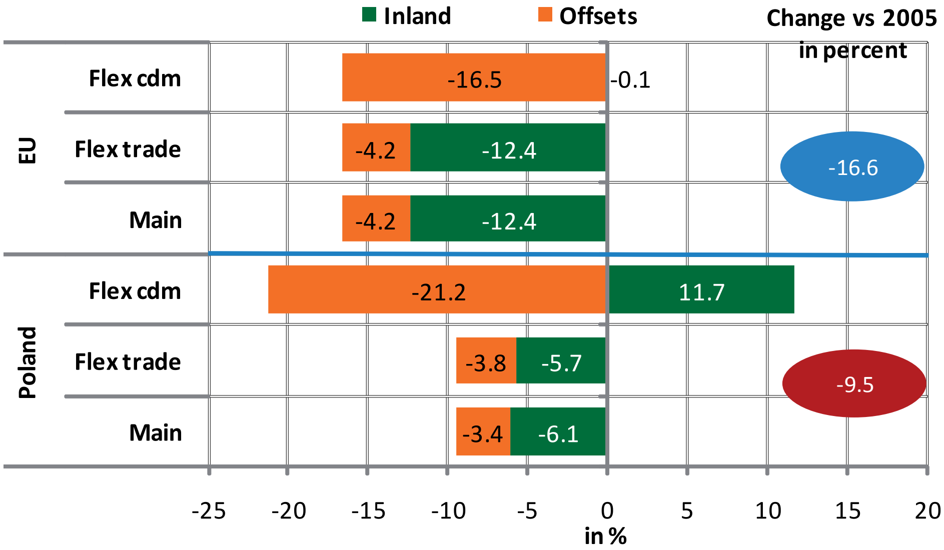


Figure 41. ‘Where-flexibility’ scenarios: carbon prices

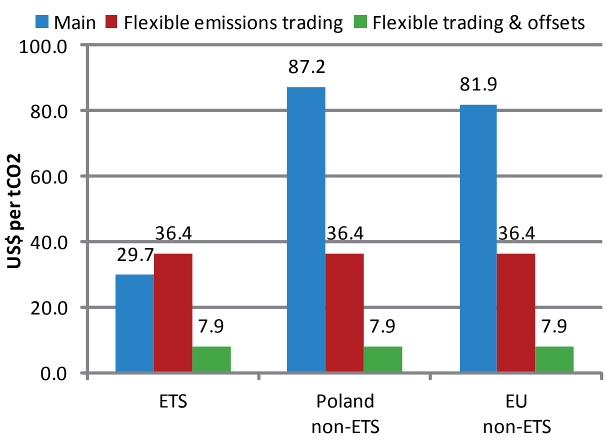
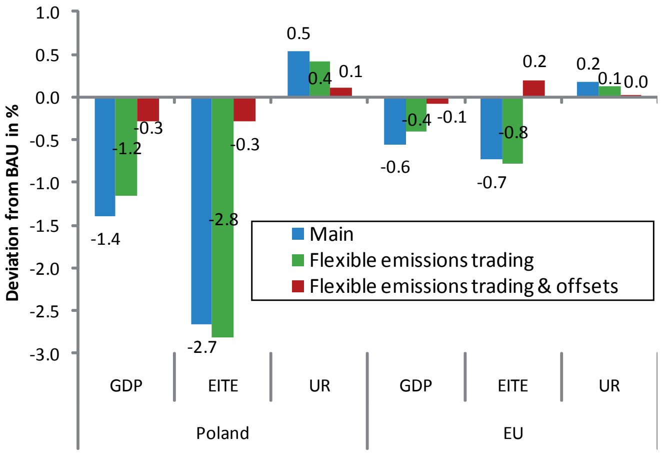


Figure 42. ‘Where-flexibility’ scenarios: macroeconomic variables, in % vs. BAU



Note: See the explanation under Figure 37 to Figure 39.
Source: Loch Alpine technical paper; ROCA model simulations.

Figure 43. ‘Renewables target’ scenario: carbon emissions, % change vs. 2005

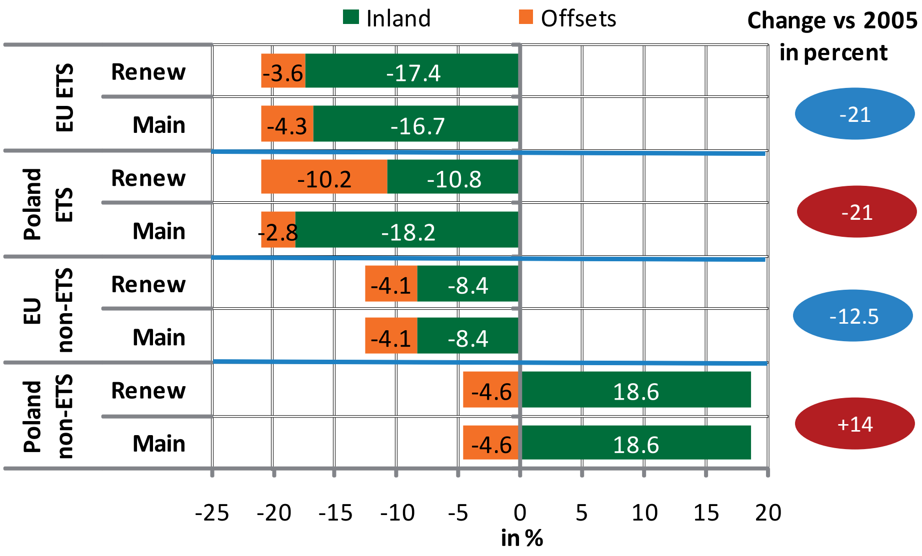


Figure 44. 'Renewables target' scenario: carbon prices

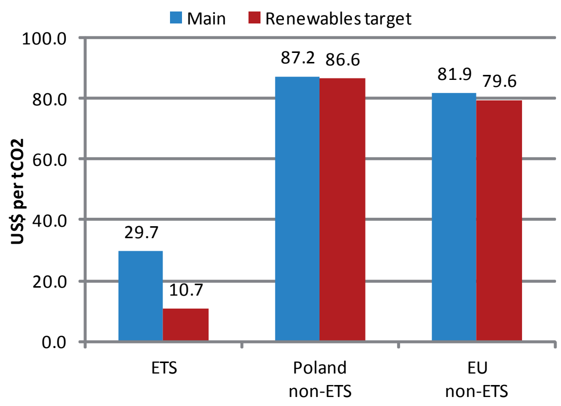
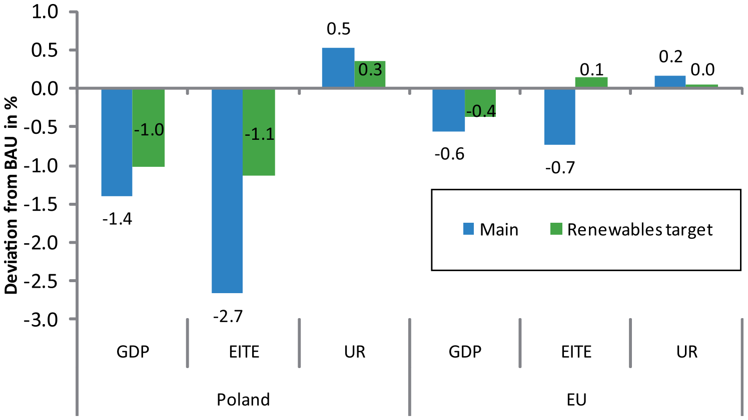


Figure 45. 'Renewables target' scenario: macroeconomic variables, in % vs. BAU



Note: See the explanation under Figure 37 to Figure 39.
Source: Loch Alpine technical paper; ROCA model simulations.

Overlapping regulation in the form of an EU target for renewable energy sources, modeled in the 'Renewables target' scenario, can improve welfare rather than imposing additional costs, because of initial distortions and market imperfections. The use of multiple overlapping instruments in climate policy would seem to pose the risk of additional costs, e.g., the EU's 20-20-20 policy package target of a 20 percent penetration of renewable energy by 2020 in primary energy consumption, with specific targets for each Member State.[67] To impose this green quota on top of the explicit emission reduction targets for ETS and non-ETS sectors, the 'Renewables target' scenario starts from the 'Main' scenario and adds subsidies for renewable power generation, financed lump-sum by EU governments, sufficient to increase the renewables share in the power sector by 50 percent above the share in the 'Main' scenario.[68] However, this policy has a presumably unintended side effect: the increased share of renewables reduces pressure on the ETS emission ceiling, reducing the ETS carbon price.[69] As a consequence, both renewable power producers and the most emission-intensive power producers—coal—benefit (see Figure 49). Surprisingly, the simulations find that the GDP impact of an additional green quota for Poland and the rest of the EU is positive. While counterintuitive at first glance, it is the ROCA model's inclusion of initial distortions (taxes, subsidies, and unemployment) which allows the possibility of welfare-improving second-best effects of additional policy constraints. Since Poland and the EU have relatively high taxes on energy use, imposition of subsidies to renewables moves regulation toward a more uniform and lower tax on carbon (with efficiency gains). Then, in the presence of initial unemployment, subsidies to renewables reduce the downward pressure on the real wage and thereby alleviate the increase in unemployment. Note that if all initial taxes and subsidies are set to zero in the model and then a green quota is imposed on top of an overall carbon emissions cap, the expected result emerges that the additional green constraint generates excess costs. (See Table 9 and Figure 43, Figure 44, and Figure 45).

Revenue recycling via wage subsidies reveals a weak double dividend in which unemployment is reduced. The next alternative scenario reflects upon the scope of a double dividend from environmental regulation.[70] Instead of the lump-sum transfer of rents from CO_2 regulation, the 'Wage subsidy' scenario assumes revenue-neutral subsidies to labor. If pricing of carbon joint with wage subsidies effects an increase in real wages, unemployment will be lower, reducing the costs of emission mitigation (the 'weak' double dividend hypothesis). In the presence of initial tax distortions and labor market imperfections, deliberate revenue recycling may be able to ameliorate the negative impacts of emission regulation. The 'Wage subsidy' scenario supports this weak double dividend hypothesis when revenues from emission regulation are not returned lump-sum but used to subsidize labor costs. In this case, the downward pressure

[67] The EU climate package contains explicit promotion of renewable energy production both because of its importance to emissions mitigation but also the possibility of technology spillovers and concerns about energy security.

[68] Note that this target falls short of Poland's commitment to a 15 percent share of renewable energy in gross final energy consumption by 2020.

[69] Although in theory, the price of electricity could either increase or decrease as a consequence of renewable targets, in this scenario, it is markedly lower than in the 'Main' scenario (together with higher electricity production and demand).

[70] The double dividend hypothesis postulates that increased taxes on polluting activities can provide two kinds of benefits: an improvement in the environment; and, an improvement in economic efficiency from the use of environmental tax revenues to reduce other taxes that distort labor supply and saving decisions. A weak double dividend claim is that returning tax revenues through cuts in distortionary taxes leads to cost savings relative to the case where revenues are returned lump sum.

of emission pricing on wages can be more than offset through wage subsidies such that real wages increase and unemployment falls. Revenue recycling through labor cost cuts rather than lump-sum transfers does not change the marginal costs of abatement but generates substantial infra-marginal cost savings through the implicit relaxation of labor market rigidities. As a consequence, the changes in the power generation mix and the sectoral structural change compared to the 'Main' scenario are relatively small with labor-intensive industries performing slightly better. (See Table 9 and Figure 46, Figure 47, and Figure 48).

Figure 46. 'Wage subsidy' scenario: carbon emissions, % change vs. 2005

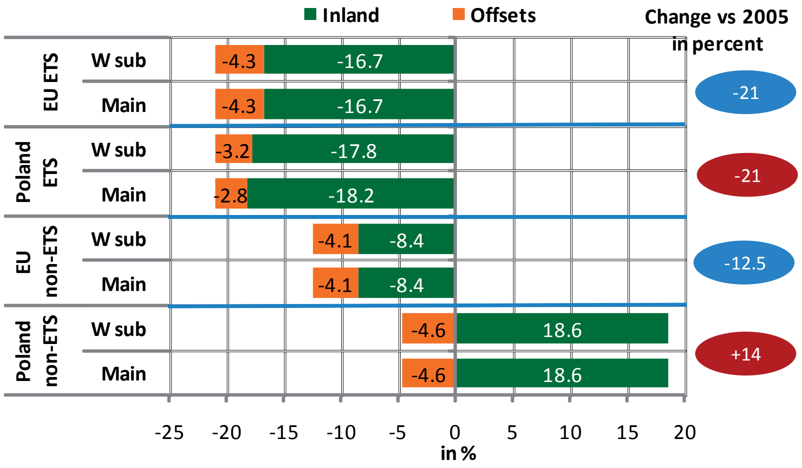


Figure 47. 'Wage subsidy' scenario: carbon prices, in US$ per tCO_2

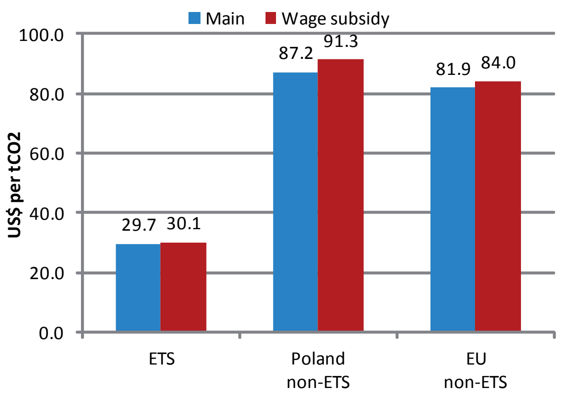
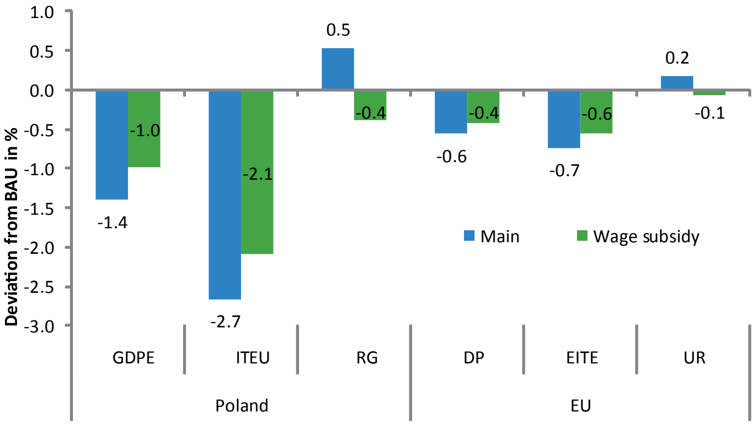


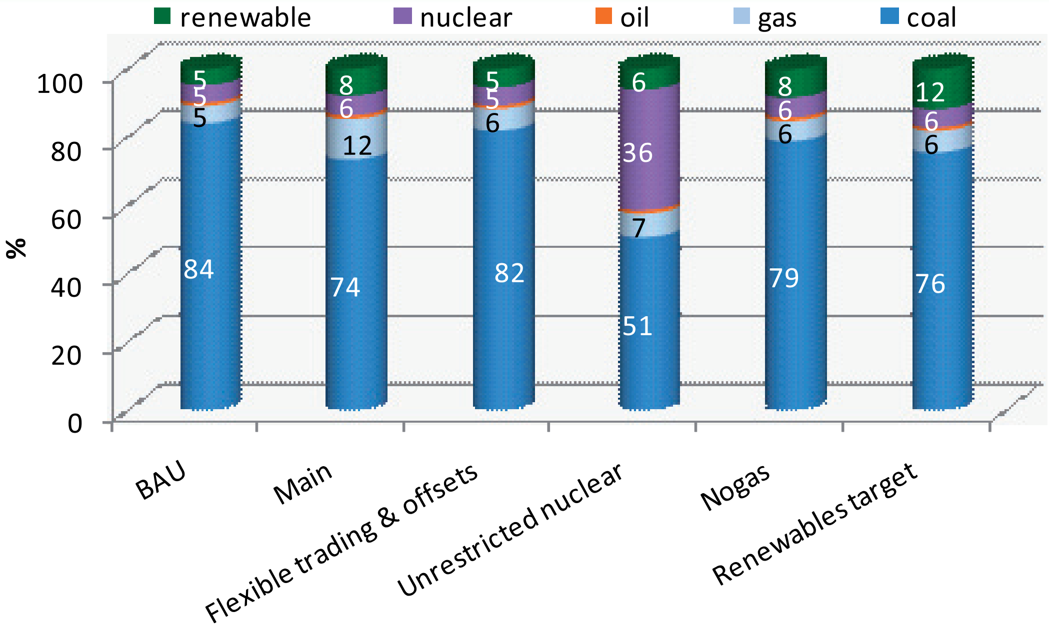
Figure 48. 'Wage subsidy' scenario: macroeconomic variables, in % vs. BAU



Note: See the explanation under Figure 37 to Figure 39.
Source: Loch Alpine technical paper; ROCA model simulations.

Technology-specific policy constraints in power generation for Poland, in particular safety concerns related to nuclear power and energy security concerns related to imported gas, are exogenous to this modeling; however, removing any restriction on the scope of nuclear power cuts compliance costs for Poland by about one-third. The role of technology-specific policy constraints in power generation for Poland is investigated by two additional scenarios. The 'Unrestricted nuclear' scenario allows for the expansion of nuclear power in Poland beyond BAU levels, and the 'Restricted gas' scenario limits the use of gas in Poland's power system to the BAU level. Apart from the costs and potentials of alternative renewable sources for power production, the ease of substituting away from coal in Poland's electricity system hinges to a large extent on policy constraints and long lead times for nuclear expansion and the willingness to increase dependency on foreign gas imports. Both the nuclear and the gas option are subject to political economy concerns; yet economic analysis can at least provide a price tag to these options. Under the 'Unrestricted nuclear' scenario, the increase of electricity prices and, in turn, the decline of electricity output is roughly halved as the share in nuclear power generation goes up from about 6 percent in the 'Main' scenario to more than 35 percent in this scenario (see Figure 49) (although installation of so much nuclear capacity is unlikely to be feasible by 2020).[71] Overall compliance costs are cut by one-third for Poland. By comparison, the 'Restricted gas' scenario keeps the nuclear ceiling and, in addition, restricts the use of gas-fired power plants in Poland to the BAU level (see Figure 49). The additional costs of constrained fuel switching from coal to gas in Poland's power production are relatively modest. (See Table 9 and Figure 50, Figure 51, and Figure 52).

Figure 49. ROCA model: electricity generation mix, in %



Note: See Table 8 for definitions and description of scenarios.
Source: Loch Alpine technical paper; ROCA model simulations.

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[71] The MEMO model's detailed optimization modeling of the power sector concludes that only about 11 percent of electricity supply can be nuclear by 2020.

Figure 50. ‘Technology constraint’ scenarios: carbon emissions, % change vs. 2005

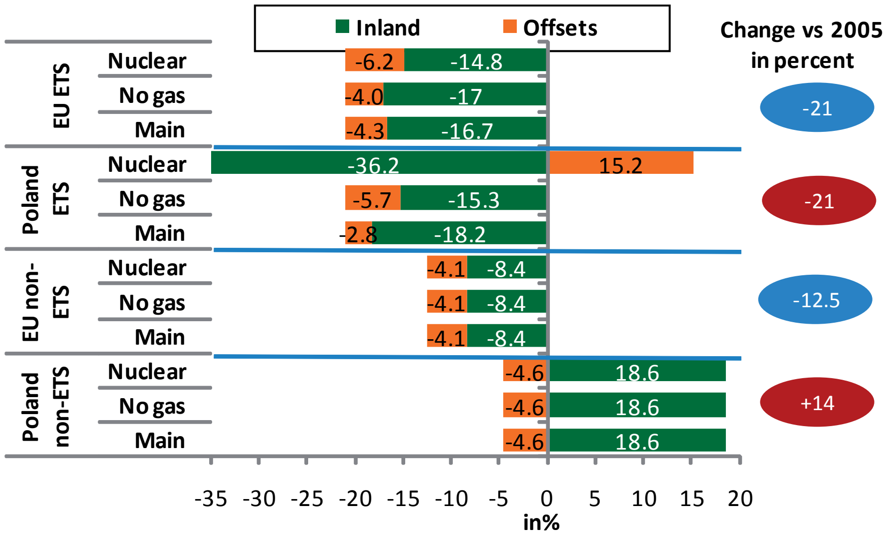


Figure 51. ‘Technology constraint’ scenarios: carbon prices

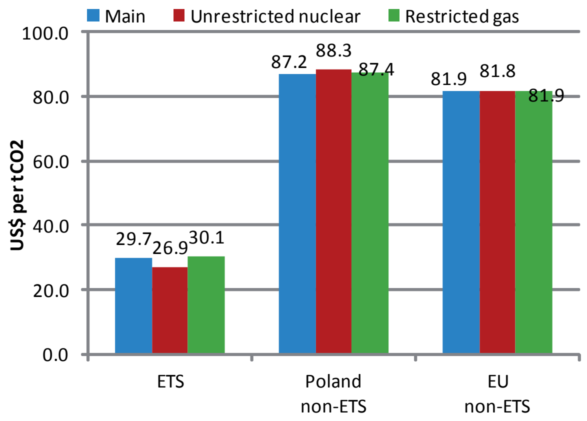
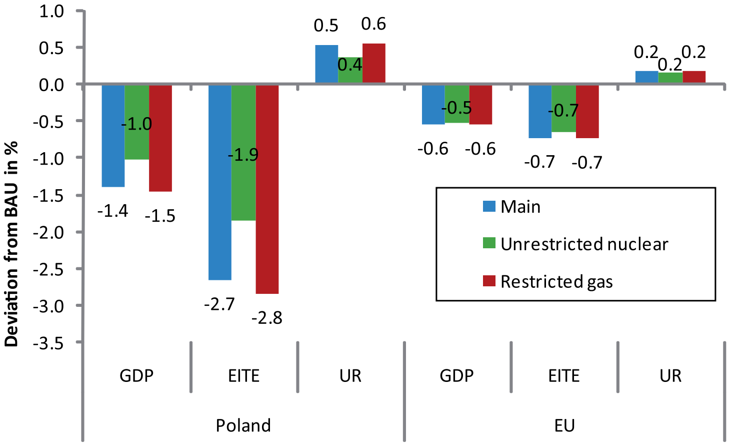


Figure 52. ‘Technology constraint’ scenarios: macroeconomic variables, in % vs. BAU



Note: See the explanation under Figure 37.
Source: Loch Alpine technical paper; ROCA model simulations.

Figure 53. 'Competitiveness risk' scenarios: carbon emissions, % change vs. 2005

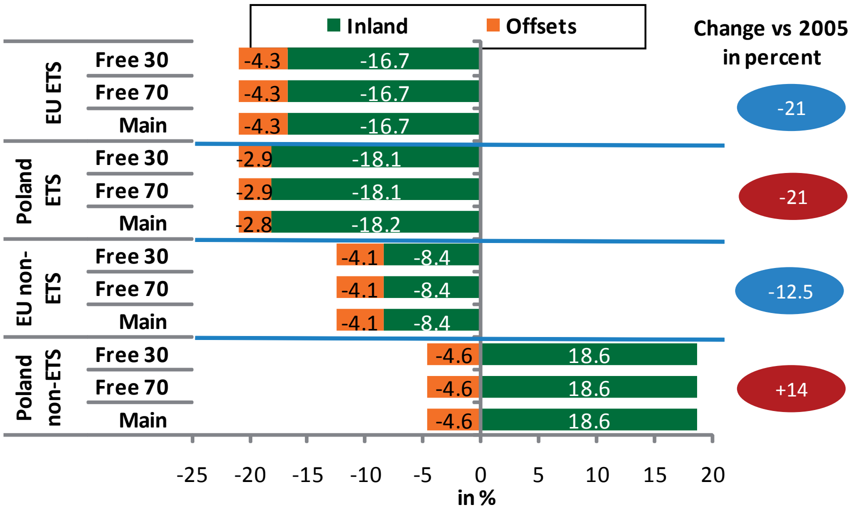


Figure 54. 'Competitiveness risk' scenarios: carbon prices, in US$ per tCO_2

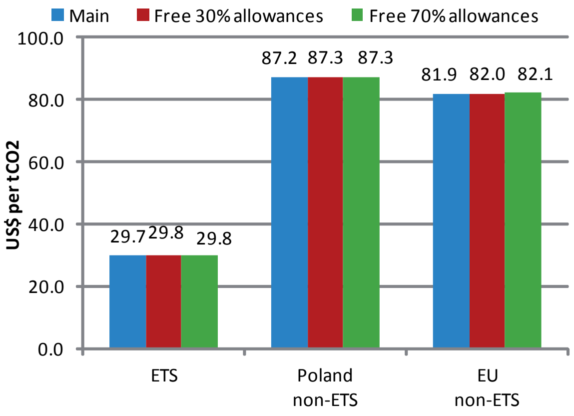
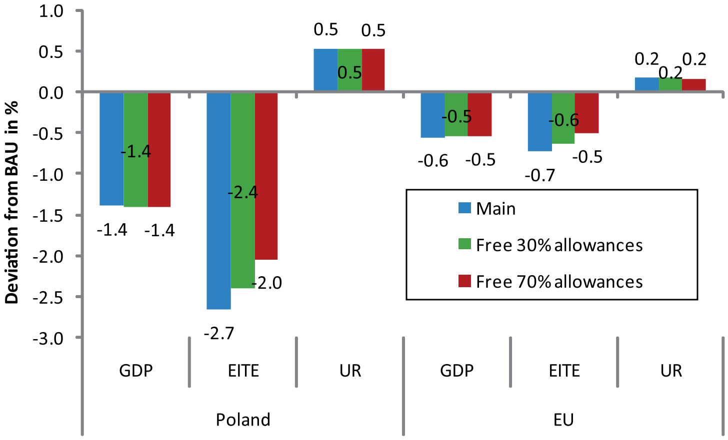


Figure 55. 'Competitiveness risk' scenarios: macroeconomic variables, in % vs. BAU



Note: See the explanation under Figure 37.
Source: Loch Alpine technical paper; ROCA model simulations.

Granting free allowances to energy-intensive and trade-exposed sectors, which might be vulnerable to carbon leakage, is equivalent to a production subsidy that preserves sector output while generating overall losses in GDP. Unilateral emission caps with rising CO_2 prices raise concerns on the competitiveness of energy-intensive and trade-exposed (EITE) industries and the potential for carbon leakage, particularly to emerging economies that lack comparable regulation.[72] As a response, the EU 20-20-20 package allows for free allocation of emission allowances to EITE sectors.[73] The 'Free 30 percent allowance' and 'Free 70 percent allowance' scenarios include partial free allocation of emission rights to EITE sectors in Poland and the rest of the EU. In the 'Free 30 percent allowance' scenario, 30 percent of the EITE sectors' 2005 emissions are handed out for free; for the 'Free 70 percent allowance' scenario, the share is 70 percent. The allowance allocation is provided conditional on firms' production decisions (via dynamic allocation) so as to provide an implicit subsidy to firms' output.[74] While the emissions price ensures producers still have economic incentives to reduce their emissions intensity, the subsidy discourages them from reducing emissions by decreasing production. While eligible sectors may benefit and leakage may be reduced, to meet the domestic cap those foregone domestic reductions must be made up elsewhere, driving up the emissions price and abatement costs. Since EITE sectors do not dominate overall emissions and production activity, real GDP and welfare losses of production subsides under the 'Free 30 percent allowance' and 'Free 70 percent allowance' scenarios are small. However, these costs can go up substantially if the share of EITE sectors increase or the scope of smart revenue recycling decreases. From a global efficiency perspective, the distortionary effects of output subsidies may be justified to a certain extent as a second-best policy for reducing counterproductive carbon leakage. A more subtle, selfish motive for output-based allocation from the perspective of a unilaterally abating region could be the strategic manipulation of the terms-of-trade. (See Table 9 and Figure 53, Figure 47, and Figure 55).

Simulations run with a top-down representation of production possibilities in power generation generates a flatter marginal abatement cost curve and significantly lower marginal abatement costs in the ETS sector, illustrating again that model assumptions must remain in the forefront as results are presented. The 'Top-down power sector' scenario serves as a sensitivity analysis on the characterization of production possibilities in power generation, replacing the activity analysis representation of electricity generation in Poland and the rest of the EU with a conventional top-down approach. The direct costs of emission abatement in production are determined through the ease of fuel switching and energy efficiency improvements. A bottom-up modeling approach captures these costs through the activity analysis representation of discrete alternative technologies with different input intensities. The merit ordering of technologies with respect to abatement costs then yields an explicit marginal abatement cost curve where the area below the step function equals total abatement cost. The bottom-up approach describes current and prospective technologies in detail and, therefore, is well suited to the analysis of technology-oriented regulation. However, there are practical shortcomings to the bottom-up approach when it comes to economy-wide analysis.[75] In contrast, a top-down representation of production technologies captures substitution possibilities through constant elasticities of substitution which can be estimated from aggregate market data on prices and quantities.[76] Estimates for marginal abatement costs in the ETS sector are significantly lower for the 'Top-down power sector' scenario which translates into distinctly lower overall compliance costs compared to the 'Main' scenario. The reason is the flatter marginal abatement cost curve associated with the specific estimates for the top-down cross-price substitution elasticities–a difference between bottom-up and top-down approaches which indicates the need for further sensitivity analysis on technology characterization in key industries. (See Table 9 and Figure 56, Figure 57, and Figure 58).

[72] There is by definition no leakage in the ROCA model, since CDM offsets are allowed (as in the 'Main' scenario) which requires the definition of an emission ceiling for developing regions (set at the BAU level); and other industrialized countries also have emission reduction pledges.

[73] These simulations provide interesting insights on a related issue: national requests for EU permission to provide some portion of ETS allowances for free to the power sector starting in 2013 (or "derogations").

[74] If instead, the free allocation were tied to criteria exogenous to firms (static allocation), then the free allowances would be equivalent to a lump-sum transfer of scarcity rents to firms without affecting potential relocation or shut-down decisions.

[75] The activity analysis representation of multiple production sectors becomes quickly intractable. In particular, there is the challenge to mimic reasonable supply price responses through the deliberate choice of lower (decline) bounds and upper (expansion) bounds for technologies as well as the calibration of technologies to specific supply elasticities. The substitution and transformation possibilities of aggregate production then are implicitly provided by the weighted input and output choices across all technologies.

[76] As described in Section c, the multi-sector, multi-region CGE model developed for Poland combines a bottom-up characterization of the power sector with a top-down representation of all other industries. While the former approach reflects the paramount role of technology choices and technology regulations in the power sector for overall CO_2 abatement, the latter can be based on empirical estimates for cross-price elasticities between capital, labor, material and energy inputs.

Figure 56. 'Power options and trade effects' scenarios: carbon emissions, % change vs. 2005

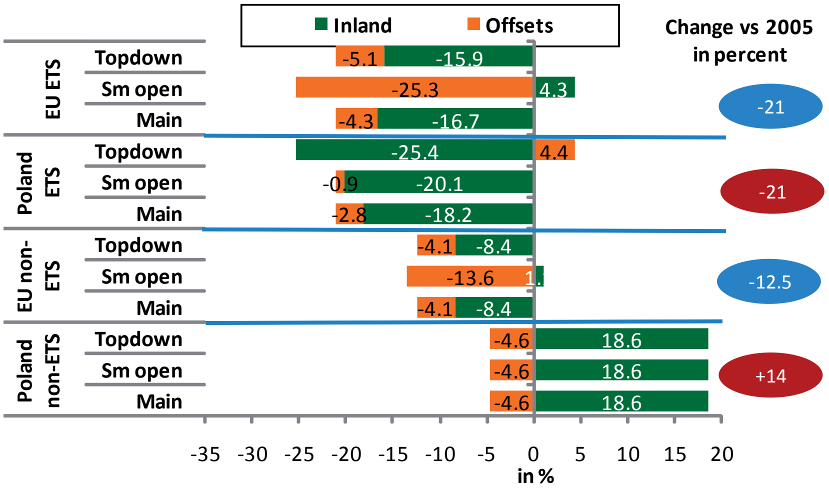


Figure 57. 'Power options and trade effects' scenarios: carbon prices, in US$ per tCO2

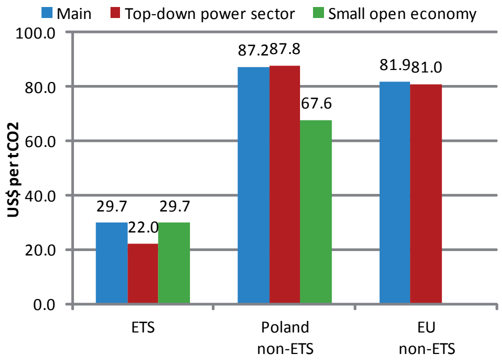
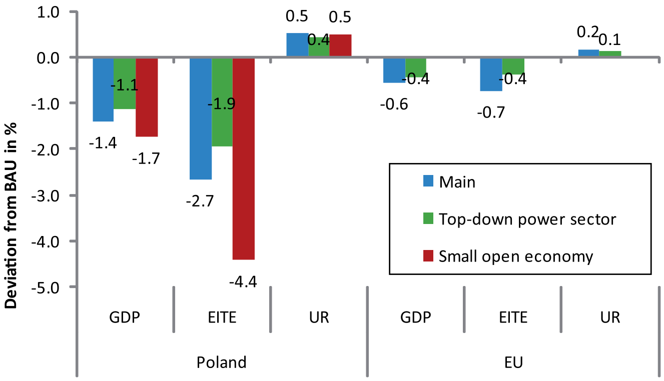


Figure 58. 'Power options and trade effects' scenarios: macroeconomic variables, in % vs. BAU



Note: See the explanation under Figure 37.
Source: Loch Alpine technical paper; ROCA model simulations.

Secondary terms-of-trade effects on the costs of emission abatement in Poland are found to be critical for Poland: In the 'Small open economy' scenario, the costs of compliance are roughly 50 percent higher than in the 'Main' scenario. The final scenario highlights the importance of secondary terms-of-trade effects for the costs of emission abatement in Poland. The 'Small open economy' scenario treats Poland as a small open economy, keeping international prices at the BAU level (suppressing terms-of-trade changes from international spillover effects).[77] This scenario eliminates the feedback effects from international markets (by assuming that international prices are fully exogenous) and excludes international spillover effects from policy actions of trading partners (which for Poland is clearly omitting an important dimension of economic interactions since its economy is integrated in the EU common market and trades predominantly with EU partners). The strong mutual interdependence suggests that Poland is not only affected by the partners' reaction to their own domestic policy actions but in turn responds to policy actions of trading partners. It would be expected that in any economic impact analysis of CO_2 mitigation strategies in Poland, international spillover effects from emission regulation in the rest of the EU (and beyond) are likely to play an important role. The bulk part of Poland's emission is regulated through the EU ETS where the marginal abatement costs emerge from supply and demand responses across all energy-intensive industries in the EU. The impact on the competitiveness of Poland's industry primarily hinges on reciprocal action by the rest of the EU. Finally, international fuel market responses are driven by abatement of all major world economies. (All these spillover effects are incorporated in a consistent manner

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[77] The scenario adopts the international CDM prices and the EU ETS price generated by the 'Main' scenario.

into the ROCA model.) In the small open economy setting, the costs of compliance are roughly 50 percent higher as compared to the 'Main' scenario. However, as noted above, this scenario is useful as a comparator, not as an accurate representation of reality: the shift in comparative advantage at the expense of Poland's industries is overstated because comparable emission regulation in the rest of the EU (and other industrialized regions) is omitted; and similarly, important terms-of-trade effects from global energy markets are missing. (See Table 9 and Figure 56, Figure 57, and Figure 58).

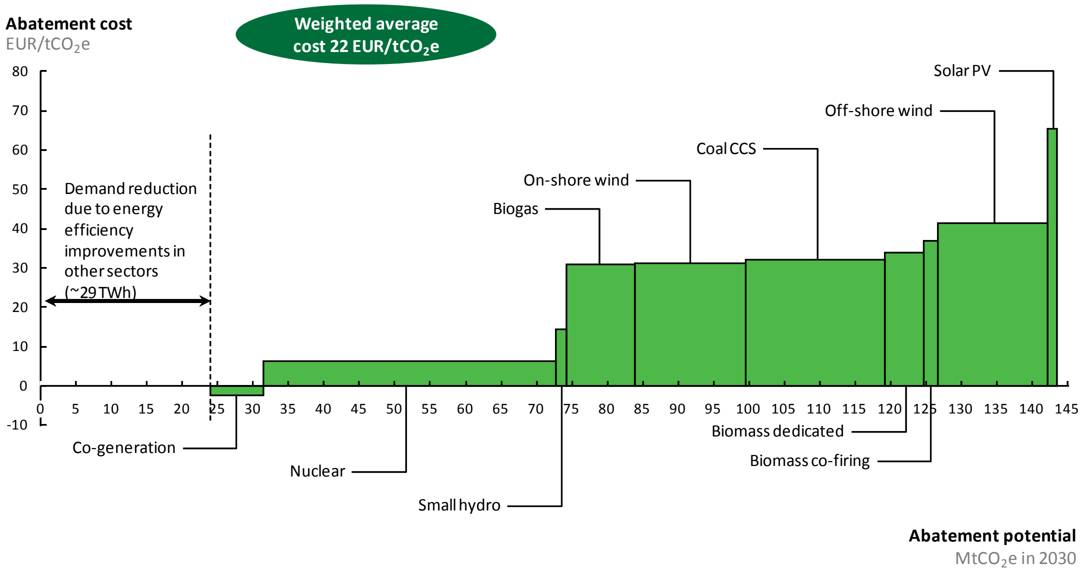
The ROCA model's analysis of the cost of compliance with the EU 20-20-20 climate policy for Poland's economy in 2020 provides an informative counterpoint to the MEMO model's assessment of the macroeconomic impact of an ambitious abatement package. This section has called attention to the important principle that the design of policy matters for its effectiveness and efficiency. Simulations demonstrated that reducing the market segmentation designed into EU climate policy and allowing more 'where-flexibility' should foster overall cost-efficiency of emission abatement. These simulations move forward from the simpler policy world of the MEMO model, where a public subsidy induces implementation of abatement measures and a tax increase (or one of three other public financing options) balances the budget. Nevertheless, the ROCA model also assumes optimal policy responses within the constraints of the EU regulations. That is, ETS sectors trade emissions rights in an EU-wide carbon market, allowing for reasonably cost-efficient abatement through a decentralized market mechanism. In non-ETS sectors, the model assumes a unified domestic CO_2 tax. In practice, however, various EU members have shown an inclination to adopt a myriad of command-and-control measures (such as standards for tire pressure or mandatory tests for efficient driving), which will drive up the real-world costs of abatement compared to the ROCA model results. Policymakers should conclude that complex rules and regulations usually impose extra costs at the macroeconomic level, even if they seem well-tailored to the sector or issue. To explore this question of responses at the sectoral level, and to complement the last three sections' exploration of economy-wide modeling, the next sections turn to details in three sectors critical to a low emissions growth path: energy, energy efficiency, and transport.

ENERGY SECTOR OPTIONS AND THEIR MACROECONOMIC IMPACT

Although the energy sector has been at the center of all the analysis so far, this section sets out a more detailed examination of some key aspects of energy sector options, and, in particular, the careful optimization of the future structure of the electricity sector carried out for the MEMO model. Low-carbon energy supply options present significant opportunities for abatement, but they are usually quite expensive up front, take a long time to build, and then become long-lived assets with low operating costs. The power sector requires long lead times and, for some technologies, has very long technical lifespans. The combination of technologies chosen or new investments will depend not only on capital costs, operational savings, and carbon abatement potential, but also energy security, domestic sourcing, and a raft of other issues. It is not surprising that the models applied here forecast the structure of the power sector to shift only slowly. The ROCA model's results argue that a strong shift towards nuclear power is the option most likely to reduce emissions without harming the economy. The MEMO model, which takes the most sophisticated approach to selecting the structure of the sector, uses an optimization model to determine the cheapest feasible energy-mix package within multiple constraints. The additional fact that the average age of Poland's existing energy infrastructure is high and, therefore, ready for replacement, provides an opportunity for the country's energy sector agenda to largely coincide with the low-emissions agenda.

Choices about the energy fuel mix today will have lasting implications for Poland's power sector emissions, but at the same time, given the lumpiness and complexity of low-carbon energy sector investments, maximizing potential abatement requires decisiveness and swift action. The power sector both produces the most emissions (at 38 percent of total) and holds the most potential for mitigation, including both demand reductions through energy efficiency, and fuel mix decisions. Figure 59 has extracted energy sector options from the MicroMAC curve and shows the full technical potential of abatement from the energy sector at 120 $MtCO_2$ or 60 percent below 2005 levels. Five abatement scenarios for the power sector were constructed as part of the MicroMAC curve analysis to illustrate the impact of different technologies on abatement potential. The maximum abatement potential is delivered by a 'low emissions' scenario in which coal power blocks are allowed to undergo natural retirement, with remaining power demand met by wind and nuclear energy. If the remaining power demand is instead met by gas plants, then the abatement potential falls from 120 $MtCO_2$ to just 68. Implementation challenges for these scenarios are not only technological but also involve complicated tradeoffs related to energy security, nuclear waste risk, the economic importance and employment impact of local coal mining, and upfront investment costs versus future savings on operating costs.

Figure 59. Microeconomic Marginal Abatement Cost (MicroMAC) curve for low-carbon energy sector investments



Note: Each column is one of the 10 abatement measures. The height of the columns is the cost in € per abated tCO_2e. The width is the amount emissions can be reduced. Some measures are shown with net benefits (negative costs). The scenario assumes that 6 GW of nuclear power will be installed by 2030, providing about 19% of electricity.
Source: McKinsey technical paper

The power sector, clearly central to any switch to a low emissions economy, requires long lead times. Most of the energy sector capital stock will need to be replaced, which not only involves the substantial time required to construct new energy facilities, but also for a good portion of today's capital stock to pass through a normal lifespan before replacement. New investments today will be required to be able to provide the energy supplies needed to satisfy higher energy demand in the future. For example, construction of an integrated gasification combined cycle (IGCC) coal plant takes 3 years while around 5 years are needed for a natural gas power plant. The first nuclear energy blocks of 1.5 GW might be able to start operating in Poland in 2020 at the earliest.[78] There are also differences in the technical lifespan of power plant operations. For example, a gas-fired power turbine can operate for about 25 years and a conventional coal power plan for 45 years while nuclear power plants can operate for up to 60 years (see Table 10).[79] Benefits from investments in energy sector generation and infrastructure pay off in the long term. However, in order to secure benefits in the future, e.g., after 2020, modernization efforts have to be launched now. Given the enormous investment needs in energy infrastructure and housing, it is also critical that Poland does not lock into unsustainable development patterns for long-lived infrastructure (see Table 10).

Table 10. Key features of energy sector technologies available in Poland until 2030

Technology	Life span	Max Installed Base		Production Uptime		Investment time
	years	2005 (GW)	2030 (GW)	2005 (%)	2030 (%)	Construction (years)
Coal CCS retrofit	40	0.0	5.8	38%	64%	4-6
Coal CCS new built	40	0.0	3.5	79%	87%	5-8
Coal IGCC	25	0.0	5.8	90%	90%	4-6
Gas CCS retrofit	40	0.0	2.8	68%	68%	4-6
Gas CCS new built	25	0.0	0.7	29%	35%	4-6
Biomass dedicated	40	0.0	0.9	80%	80%	3-5
Biomass CCS new built	40	0.0	5.8	80%	80%	4-6
Nuclear	60	0.0	6.0	90%	90%	10-12
On shore wind	20	0.1	10.0	24%	24%	2-4
Off shore wind	20	0.0	6.0	32%	34%	3-5
Solar PV	25	0.1	1.7	10%	10%	1-2
Solar conc.	20	0.0	1.4	91%	91%	5-7
Geothermal	30	0.0	0.7	80%	90%	4-6
Small hydro	25	0.9	1.7	35%	35%	3-7
Coal conventional	45	30.8	32.0	54%	74%	5-7
Gas conventional	25	0.7	3.6	75%	65%	4-6

The structure of the power sector will shift only slowly, even with government commitment to a low emissions scenario. Figure 60 summarizes the energy sources for electricity generation in Poland today, under the ROCA model's BAU 2020 structure of electricity generation, two low carbon scenarios for 2020, and the MEMO model's 2030 projection. In the ROCA BAU, power production in Poland is projected to be heavily coal-based (84 percent) while gas-fired power generation (5 percent) and electricity from renewables (5 percent) play a smaller role. Nuclear power, which is not operating in Poland today, will be phased in by 2020 with a projected share of around 5 percent in the BAU scenario. This outcome contrasts with the projected structure of power generation in the rest of the EU in 2020 under BAU, which is much more balanced across coal (20 percent), gas (30 percent), nuclear (26 percent) and renewables

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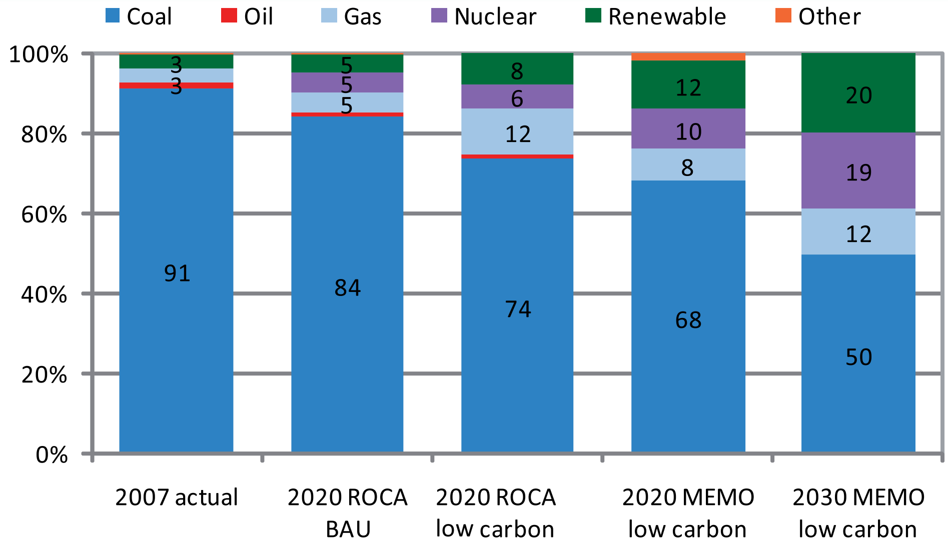
[78] Already factoring in that the first decisions on nuclear power have already been made by the Government in early 2009 when the Council of Ministers adopted a resolution on the development of the nuclear energy program in Poland (January 13, 2009) and designated the Minister of Treasury to cooperate with the state-owned company Polish Energy Group (PGE), which will have a leading role in the program's implementation. Also, on May 12, 2009, the Council of Ministers established the Government's Plenipotentiary to the Polish Nuclear Power.

[79] Production uptime also varies between technologies: for example, 90 percent for nuclear versus only 10 percent for solar PV. Uptime is expected to increase significantly by 2030 as compared to 2005 due to technological progress. For example, conventional coal-fired power generation is projected to be able to operate for 74 percent of the time by 2030, as compared with 54 percent in 2005. The predicted decline in production uptime for conventional gas (from 75 percent in 2005 to 65 percent in 2030 is driven by the assumption that these plants will be back-up options for renewable energy sources such as wind turbines.

(21 percent). Twenty years from now, under an ambitious program of abatement, coal may diminish to fueling just half of Poland's power. By 2020, however, even if meeting the EU 20-20-20 targets, coal is likely to remain either three-quarters (under the ROCA model projections) or two-thirds (under the MEMO model forecast) of the power sector.

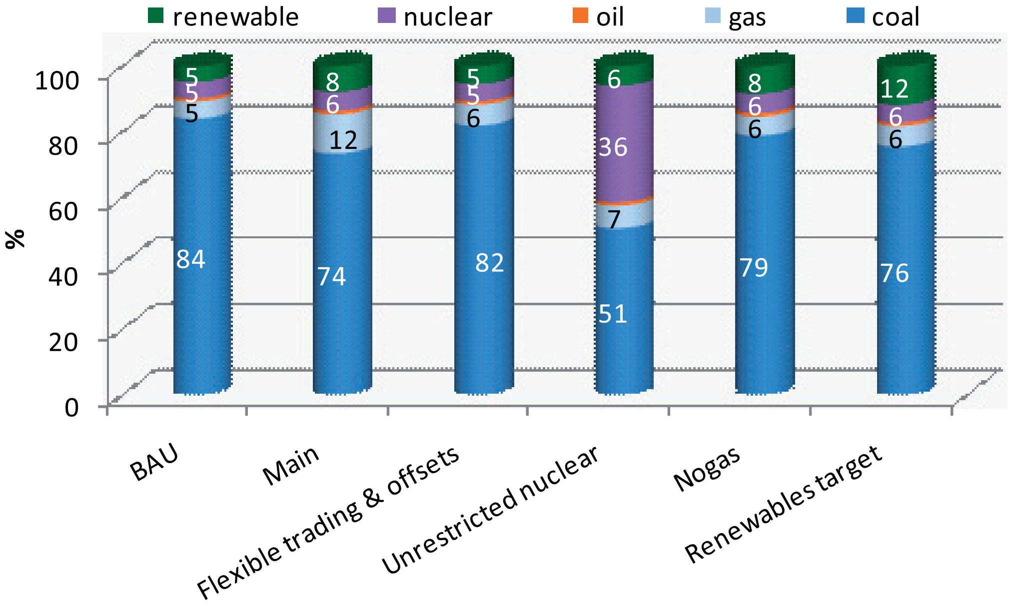
Figure 60. Current and projected electricity mix in Poland, 2020 and 2030



Note: In the MEMO model, Coal is Coal conventional, Coal IGCC, Coal CCS new built, and Coal CCS new built with enhanced oil recovery (EOR); Gas is Gas conventional, Gas CCS new built, and Gas CCS new built with EOR; Renewable is On shore wind, Small hydro, Geothermal, and Biomass dedicated.
Source: Loch Alpine technical paper, ROCA model simulations, IBS technical paper, MEMO model simulations, World Bank staff calculations.

The ROCA model simulations provide some further insights on possibilities for transformation in the power sector. As noted above, with implementation of a 'best guess' set of policies to meet the EU 2020 targets (the 'Main' scenario), coal remains 74 percent of the sector. The outcome is even more biased towards coal if offshore offsets (CDM transactions) are unrestricted because then the country can use cheap coal and cheap abatement (bought from developing countries). The only stronger shift away from coal by 2020 comes if there is no ceiling on nuclear power (as a policy matter, not as a technological constraint, although engineering feasibility likely limits nuclear in 2020 well below this ROCA simulation). In that case, coal falls to just over half of power generation, and nuclear power picks up one-third of generation (see Figure 61).

Figure 61. ROCA model: electricity generation mix, in %



Note: See Table 8 for definitions and description of scenarios.
Source: Loch Alpine technical paper; ROCA model simulations.

An optimal energy mix scenario was constructed to be used in the MEMO model's macroeconomic simulations. The Microeconomic Investment Decisions (MIND) module of the MEMO model is applied to the power sector, as described in section c, to determine the cheapest feasible energy-mix package, taking into account technological constraints such as the maximum availability of onshore wind power, the necessary electricity production to meet projected demand, the emissions reduction target, and the goal of minimizing the public subsidies necessary for all power options more expensive than coal power plants. The MIND optimization module finds the combination of energy sources which provides the biggest CO_2 abatement at the lowest cost. The model suggests that the share of conventional coal in the overall energy mix should decline over the next two decades and be replaced by coal IGCC, nuclear, and onshore wind. There are only two types of energy plants that have positive net present values: geothermal and conventional coal. The disadvantage of the first is low capacity, and of the latter, high CO_2 emissions. The alternative power plants which can effectively help to mitigate CO_2 emissions in the energy sector all have negative NPVs. Among them, the cheapest are onshore wind and nuclear power plants, and the most expensive are dedicated biomass and new built biomass with CCS (see Table 11 and Figure 62).

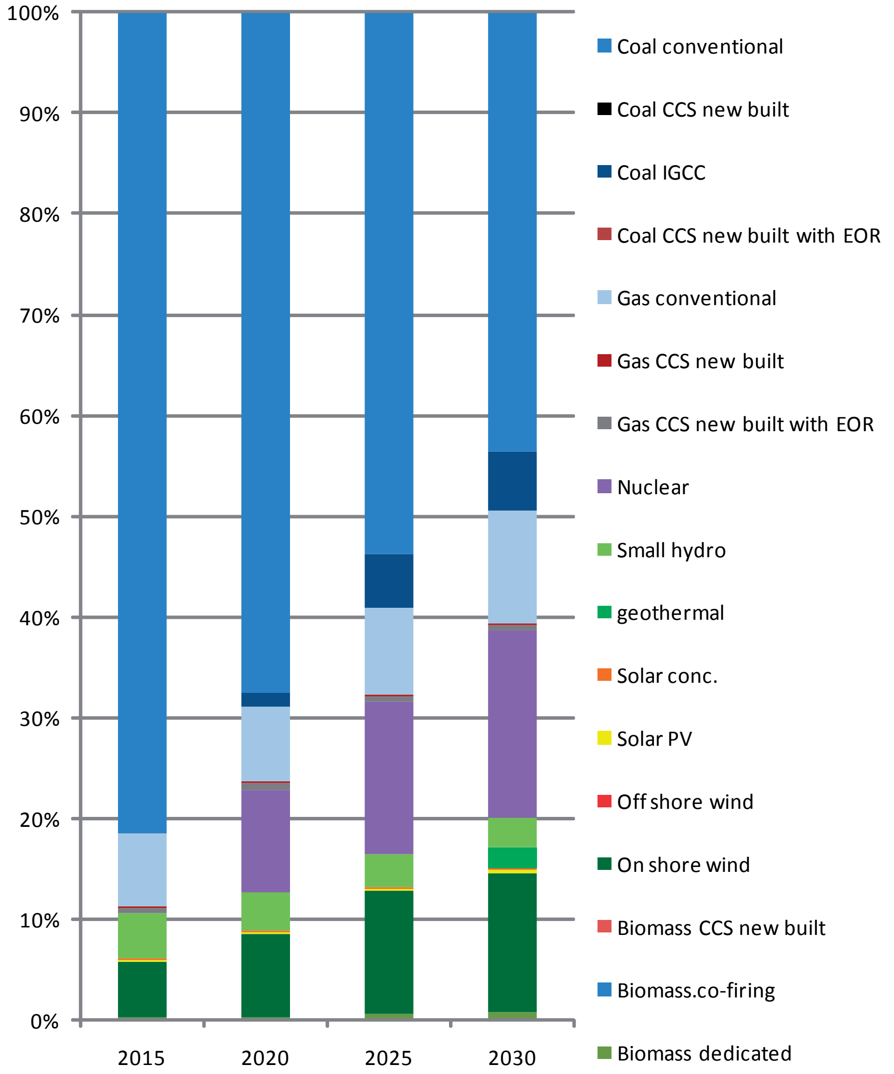
Table 11. Basic economic features of individual energy investment levers

	NPV	CO_2 emitted per GWh	Potential capacity in 2030 in GW	Energy price subject to NPV=0	CO_2 price subject to NPV=0, PLN
Coal CCS, new built	-0.45	103.3	3.5	0.53	202
Coal CCS, new built with EOR	-0.45	145.7	0.5	0.53	205
Coal IGCC	-0.46	69.8	5.8	0.52	181
Gas CCS, new built	-0.93	47.2	0.7	0.58	253
Gas CCS, new built with EOR	-0.09	134.6	0.5	0.43	61
Biomass, dedicated	-1.64	558.1	0.9	0.63	921
Biomass, co-firing	-0.28	714.8	0.5	0.45	401
Biomass, CCS new built	-1.41	80.2	5.8	0.92	740
Nuclear	-0.30	0.0	6.0	0.52	167
Onshore wind	-0.12	0.0	10.0	0.45	78
Offshore wind	-0.49	0.0	6.0	0.60	270
Solar PV	-0.63	0.0	1.7	1.14	946
Solar concentrated	-0.93	0.0	1.4	1.15	962
Geothermal	0.38	0.0	0.7	0.35	-44
Small hydropower	-0.07	0.0	1.7	0.43	56
Coal conventional	0.01	796.8	38.0	0.42	N/A
Gas conventional	-0.69	386.1	3.6	0.47	161

Source: IBS technical paper, MIND module simulations.

Figure 62. MEMO model: optimal energy sector scenario

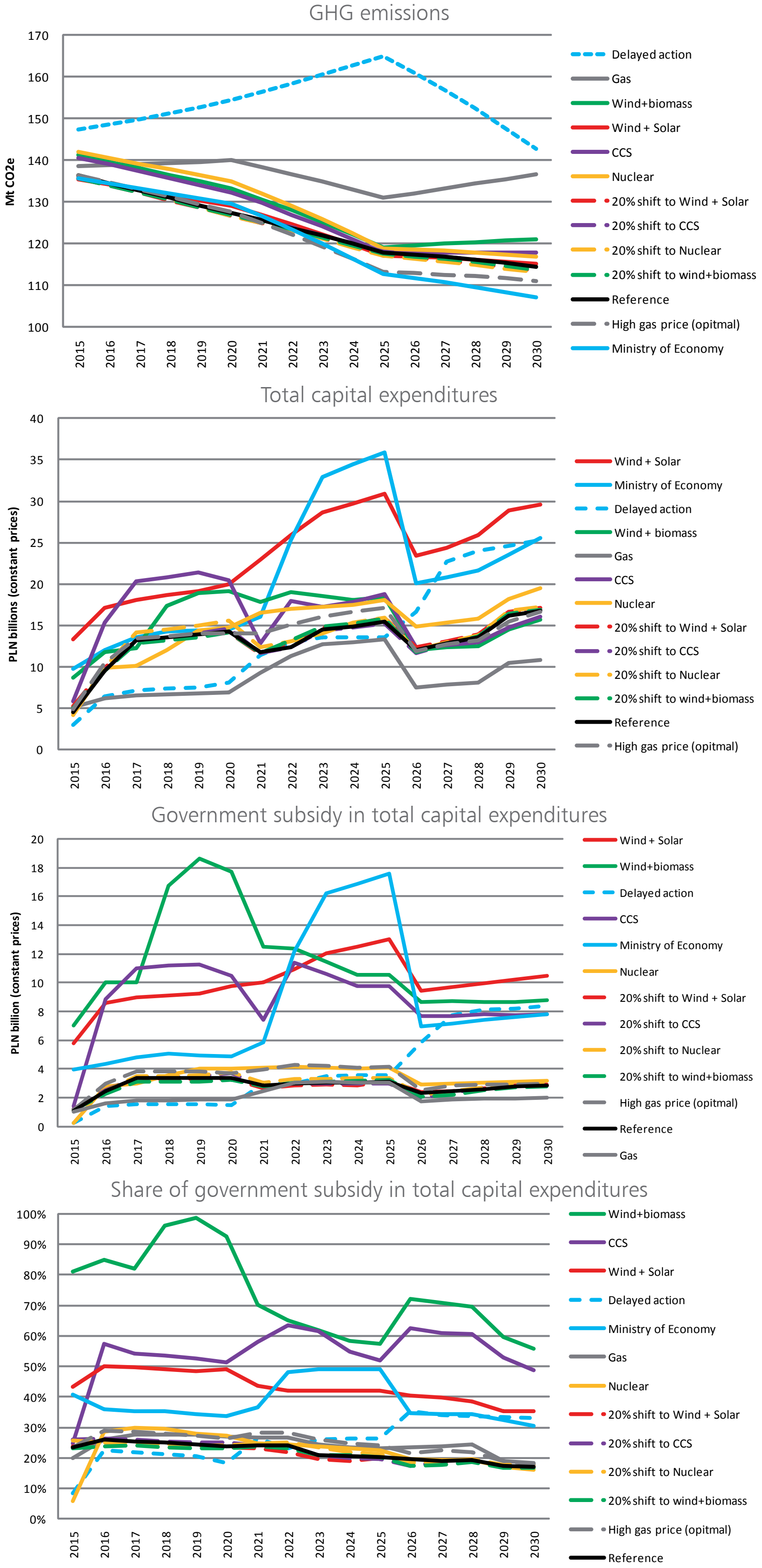
The energy mix in this scenario shows a sharp decrease in the utilization of conventional coal plants and a strong uptick in the share of nuclear and wind plants as well as IGCC coal. The increase in share of gas plants can be attributed to relatively low gas prices. Thus, coal remains the main source of energy despite the increases in alternative sources.



Source: IBS technical paper, MIND module simulations.

The power sector scenarios deliver different patterns of emissions abatement, cost varying amounts of capital, and require differing levels of government subsidy to break even. Figure 63 presents basic features of 13 alternative energy mixes (see Annex 9 and Annex 10 for definitions). To enable direct comparisons, they were 'standardized' to achieve similar reduction in GHG emissions, except the Delayed Action (which cannot reach the same abatement level) and Gas (with relatively high GHG intensity) scenarios. The Wind + Solar and Ministry of Economy scenarios are the most expensive options, due to the relatively high reliance on expensive solar plants, and require the highest government subsidies. Through 2030, the share of the public contribution to capital expenditures exceeds the contribution by the private sector, whereas in the Optimal and other more balanced scenarios, public contribution is about 20 percent.

Figure 63. Comparison of alternative energy investment scenarios



GHG emissions

Total capital expenditures

Government subsidy in total capital expenditures

Share of government subsidy in total capital expenditures

The macroeconomic impact of alternative energy packages is inversely related to the average annual required capital expenditures. (See Figure 65). Only the cheapest packages (which includes the optimal scenario) keep the deviation of GDP close to zero over the entire 20 year period. Scenarios that include sharp investment peaks (including the Ministry of Economy scenario) impose a higher cost on GDP, because they are not more equally balanced over time (see Figure 65 and Figure 66). Below is a summary table on macroeconomic impact of the optimal scenario and its sensitivity analysis (see Table 12).

Figure 65. Relation between investment cost and GDP elasticity of energy packages

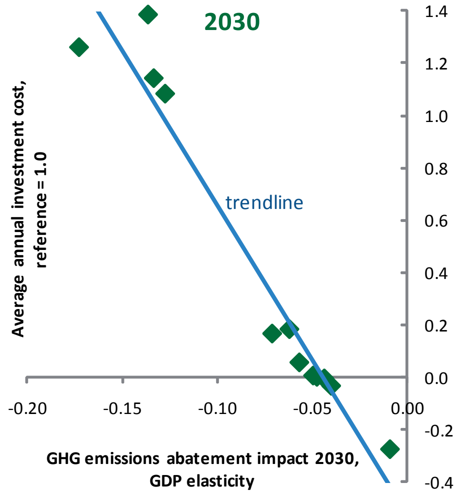
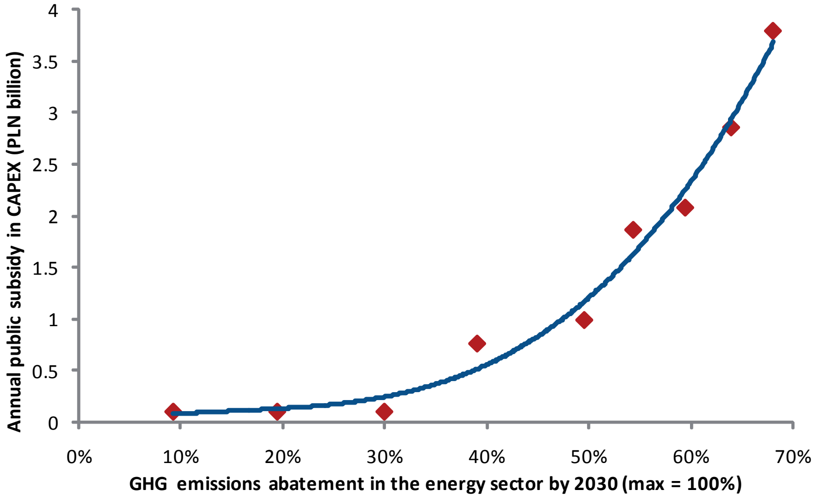


Figure 66. Emission abatement in the energy sector and the required public subsidy in total capital expenditures (CAPEX)



Source: IBS technical paper, MIND module simulations.

Energy sector modernization is important and can facilitate a shift to a lower emissions economy. Because energy assets in Poland, including energy infrastructure, are already far along in their lifespan, widespread rehabilitation or retirement will be necessary in order to assure undisrupted energy supplies and safety. The concurrence of new obligations for carbon abatement requiring substantial new investment with, at the same time, assets nearing their replacement point could greatly improve outcomes for Poland. The country should be well-placed to avoid stranded assets such as large new coal power plants that become too expensive once carbon is taxed (or restricted administratively). It seems that Poland's energy sector agenda largely coincides with the low-carbon agenda. A well-managed modernization agenda of the energy intensive sectors (covered by the EU-ETS), in particular the power sector, may allow Poland to meet the goal of emissions abatement while providing needed infrastructure at an affordable price.

Table 12. Macroeconomic impact of the optimal energy mix scenario: sensitivity analysis

Closure	Scenario	GHG abatement (in % vs BAU)				GDP change (in % vs BAU)				GDP elasticity vs GHG abatement			
		2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
Public consumption	Reference (low gas price)	3.39	10.40	16.03	19.91	-0.15	-1.68	-1.31	-0.95	-0.04	-0.16	-0.08	-0.05
	20% shift to Wind + Solar	3.61	10.54	16.21	20.16	-0.22	-1.56	-1.34	-0.88	-0.06	-0.15	-0.08	-0.04
	20% shift to CCS	3.40	10.38	16.01	19.95	-0.19	-1.81	-1.24	-0.99	-0.06	-0.17	-0.08	-0.05
	20% shift to Nuclear	3.40	10.64	16.30	20.29	-0.15	-2.00	-1.46	-1.15	-0.04	-0.19	-0.09	-0.06
	20% shift to Wind + Biomass	3.57	10.50	16.12	20.06	-0.15	-1.59	-1.24	-0.80	-0.04	-0.15	-0.08	-0.04
Closure	Scenario	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
Social transfers	Reference (low gas price)	3.41	10.40	15.98	19.90	-0.06	-1.23	-0.89	-0.71	-0.02	-0.12	-0.06	-0.04
	20% shift to Wind + Solar	3.62	10.54	16.16	20.15	-0.10	-1.11	-0.95	-0.65	-0.03	-0.11	-0.06	-0.03
	20% shift to CCS	3.42	10.38	15.95	19.94	-0.08	-1.35	-0.83	-0.76	-0.02	-0.13	-0.05	-0.04
	20% shift to Nuclear	3.41	10.65	16.24	20.28	-0.04	-1.52	-1.00	-0.90	-0.01	-0.14	-0.06	-0.04
	20% shift to Wind + Biomass	3.58	10.51	16.07	20.05	-0.04	-1.18	-0.82	-0.59	-0.01	-0.11	-0.05	-0.03
Closure	Scenario	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
VAT	Reference (low gas price)	3.46	10.48	16.03	19.95	-0.14	-1.13	-0.78	-0.73	-0.04	-0.11	-0.05	-0.04
	20% shift to Wind + Solar	3.68	10.61	16.22	20.20	-0.17	-1.02	-0.83	-0.66	-0.05	-0.10	-0.05	-0.03
	20% shift to CCS	3.47	10.47	16.00	20.00	-0.16	-1.24	-0.72	-0.77	-0.04	-0.12	-0.05	-0.04
	20% shift to Nuclear	3.47	10.74	16.30	20.34	-0.13	-1.39	-0.88	-0.91	-0.04	-0.13	-0.05	-0.04
	20% shift to Wind + Biomass	3.63	10.58	16.12	20.10	-0.12	-1.07	-0.69	-0.61	-0.03	-0.10	-0.04	-0.03
Closure	Scenario	2015	2020	2025	2030	2015	2020	2025	2030	2015	2020	2025	2030
PIT	Reference (low gas price)	3.55	10.71	16.10	20.06	-0.16	-1.33	-0.92	-0.89	-0.05	-0.12	-0.06	-0.04
	20% shift to Wind + Solar	3.78	10.83	16.29	20.31	-0.20	-1.21	-0.96	-0.83	-0.05	-0.11	-0.06	-0.04
	20% shift to CCS	3.58	10.72	16.06	20.11	-0.19	-1.47	-0.86	-0.93	-0.05	-0.14	-0.05	-0.05
	20% shift to Nuclear	3.57	11.00	16.38	20.46	-0.16	-1.62	-1.06	-1.09	-0.05	-0.15	-0.06	-0.05
	20% shift to Wind + Biomass	3.72	10.80	16.18	20.20	-0.15	-1.26	-0.85	-0.76	-0.04	-0.12	-0.05	-0.04

Source: IBS technical paper, MIND module simulations.

i.

ENERGY EFFICIENCY OPTIONS AND THEIR MACROECONOMIC IMPACT: A FIRST LOOK

Energy efficiency measures hold out the promise of relatively low cost abatement that works directly to delink carbon from growth, the essence of a low-carbon economy. While energy sector abatement options are generally about reducing emissions intensity (CO_2e created by energy use), energy efficiency focuses on reducing energy intensity (energy required for each euro of output). Both of these factors will reduce Poland's emissions elasticity (with respect to growth) (see Figure 21). Poland's economy is still more than twice as energy intensive as the EU average, suggesting that potential improvements should be easy to find. Indeed, energy efficiency measures are essential to the MicroMAC curve analysis, and many are growth-enhancing by 2030 in the MEMO model analysis. Deeper detailed analysis of energy efficiency options in Poland is needed to be able to provide more specific recommendations on how to overcome implementation obstacles that are preventing households and businesses from realizing the financial savings embedded in many of these measures.

Energy efficiency measures play a central role in the MicroMAC curve analysis because of their substantial potential, apparent low price, and impact on growth. Together energy efficiency levels generate about one-third of the MicroMAC curve's potential abatement for Poland. Many of these measures are assessed to have negative financial costs, generating net savings through reduced energy costs after an initial investment. Lastly, energy efficiency measures in general reduce the energy intensity of the economy, beginning the necessary delinking of economic growth from CO_2 emissions. Of the 60 energy efficiency measures analyzed by the MicroMAC curve model, about two-thirds of the abatement potential is in the buildings sector (at an average savings of €14 per tCO_2e), including better insulation, more energy-efficient appliances, water heaters, and lighting. About 20 percent of savings come from energy efficiency measures in the transport sector (saving €8 per tCO_2e), from more fuel-efficient vehicles.[80] The remaining 15 percent is in industry (saving €6 per tCO_2e), and such measures as improving motor systems in chemical plants and implementing energy efficiency projects in petroleum and gas (see Figure 67).

Abatement measures do not in reality have negative net costs after implementation barriers are considered. Households and businesses are not ignoring significant savings opportunities from implementing these measures. Instead, it is accepted that various implementation barriers are discouraging action. As mentioned in section e, the types of barriers likely to be preventing up-take are: high upfront investment costs (for example, for an energy-efficient car), principal-agent problems (such as the owner, operator, occupant, and bill payer of a building being separate entities), and lack of information (about what savings are likely). A fourth, and potentially most difficult obstacle, is the costs of implementation across a high number of small entities (for example, with residential lighting). In the absence of analysis of these barriers, a simple assumption is that no NPVs for abatement levers can drop below zero. If so, then the weighted average cost across the MicroMAC curve of €10 per tCO_2e will rise to €15 per tCO_2e, and the overall cost of implementing the MicroMAC curve levers will rise by at least 50 percent.

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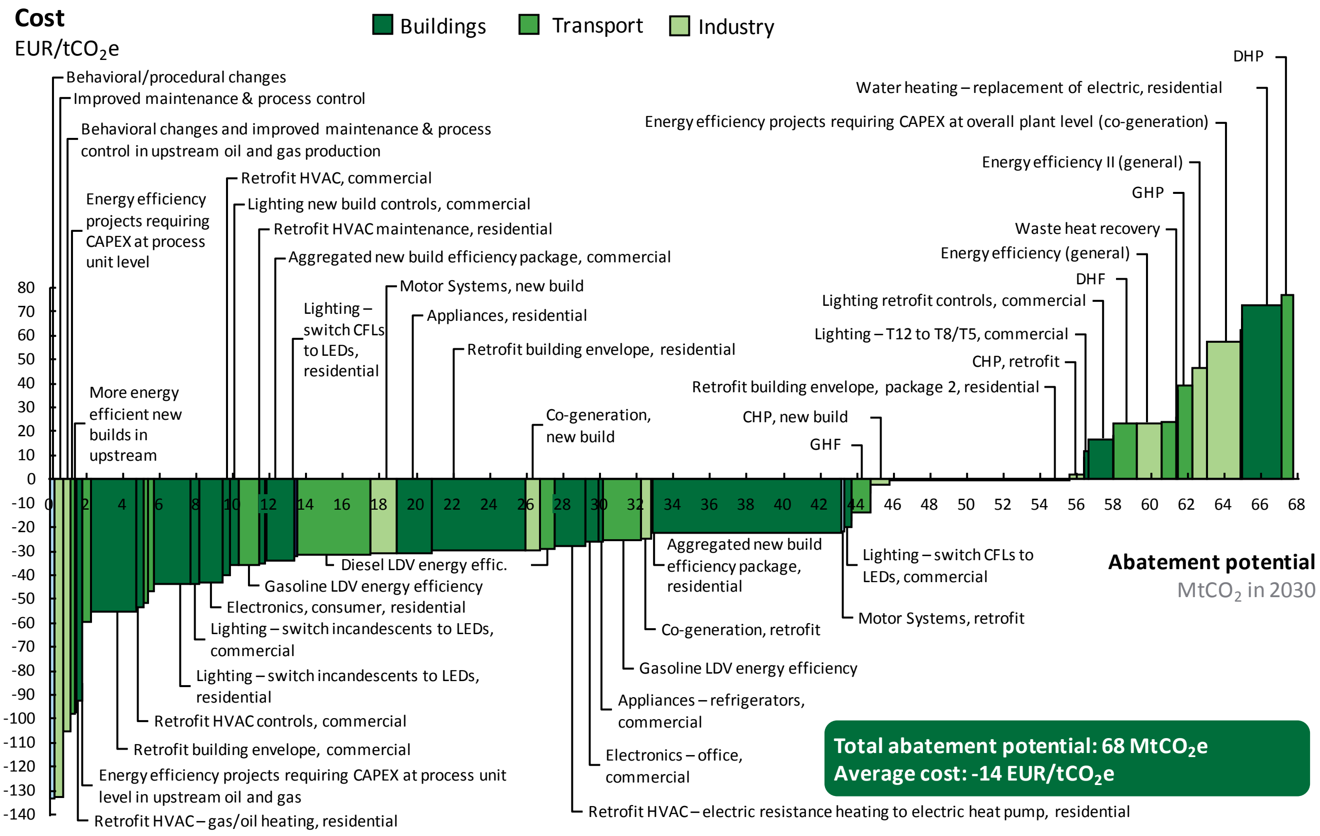
[80] The MicroMAC curve analysis includes transport energy efficiency measures in the broad category of energy efficiency. These levers, combined with other transport measures, are considered together by the TREMOVE Plus model of road transport in section j.

Figure 67. Microeconomic Marginal Abatement Cost (MicroMAC) curve for energy efficiency levers

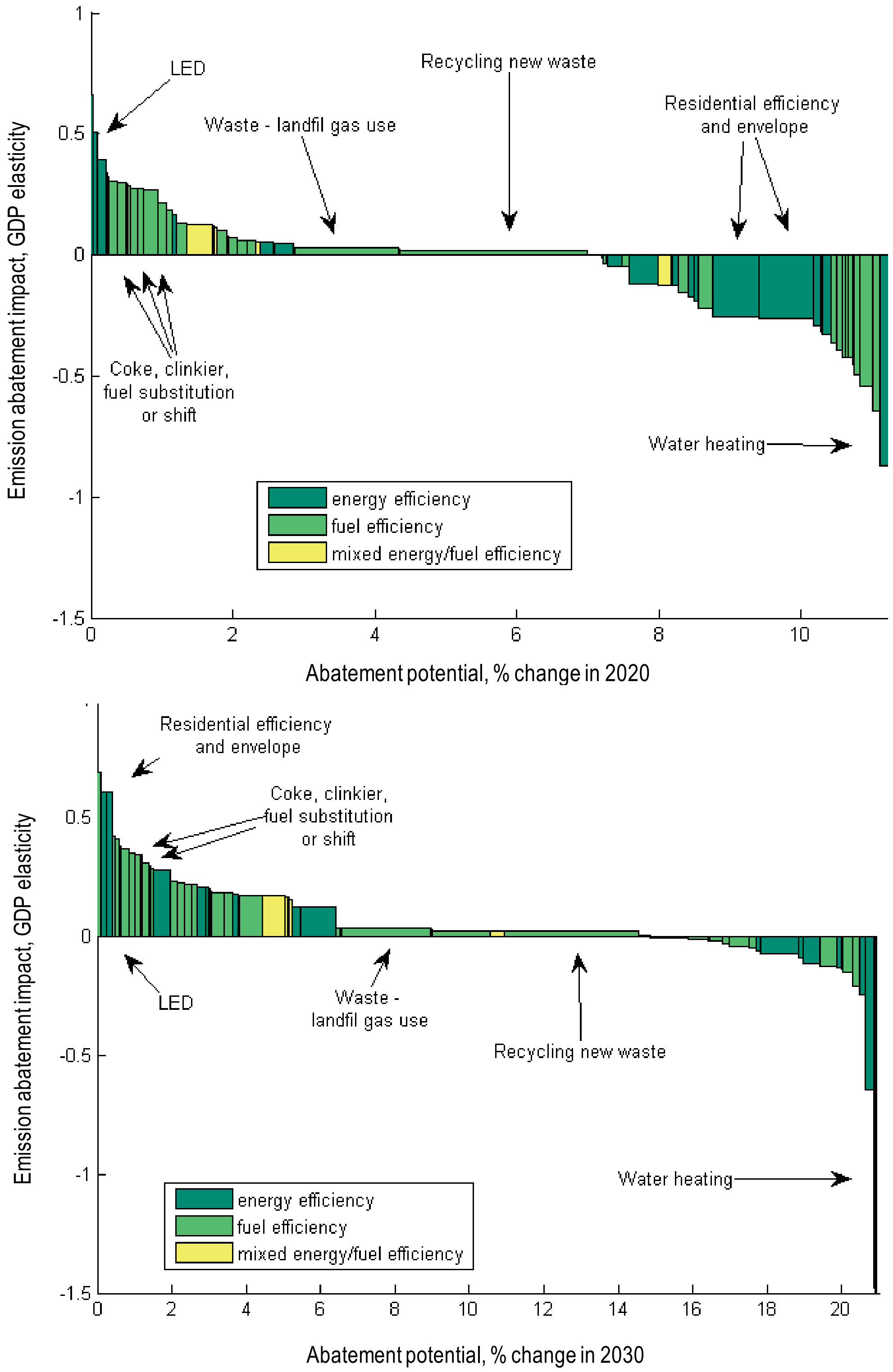


Note: Energy efficiency measures include transport sector. Each column is one of the 60 abatement measures (only the most significant ones are named). The height of the columns is the cost in € per abated tCO$_2$e. The width is the amount emissions can be reduced. Some measures are shown with net benefits (negative costs).

Source: McKinsey technical paper.

Initial analysis of the macroeconomic impact of energy efficiency measures in the MEMO model found that although most energy efficiency measures individually have little potential, if they could be grouped together for implementation, they could be an important carbon abatement tool. Figure 67 presents the MacroMAC curve for just energy efficiency interventions. Among energy efficiency measures, the waste management levers are the most promising for abatement potential and also for their impact on economic growth. As for low-carbon energy supply options, energy efficiency measures are expected to switch from growth hampering towards growth enhancing as soon as the investment phase is finished, and the curve flattens between 2020 and 2030. For example, residential efficiency and envelope shifts drastically from far on the right, with the most costly measures in terms of growth, in 2020, to the far left and the most growth-enhancing.

Figure 68. Macroeconomic Marginal Abatement cost (MacroMAC) curve for energy and fuel efficiency micro-packages, 2020 and 2030



Note: Model closure is increase in VAT.
Source: IBS technical paper, MEMO model simulations.

Exploiting the energy efficiency agenda is not easy, but it is often seen as a 'win-win' option, with benefits realized relatively quickly and lower upfront costs. Much of energy efficiency potential remains untapped because of the many obstacles to investments: inadequate domestic energy prices and lack of payment discipline, insufficient information on suitable technologies, too few contractors and service companies, and financing constraints. The government needs to address these issues in a coordinated manner. Effective energy efficiency interventions combine critical market-based approaches (which send correct price signals) with irreplaceable regulatory activity (which supports changes in practices and behaviors of economic agents). Numerous but limited energy efficiency measures deliver little abatement individually, but a package of the most growth-enhancing measures could achieve critical mass (and warrant policymakers attention). Rather than focusing only on the interventions capable of significant GDP impact on their own, a package of small but effective levers could raise growth to a greater extent and at lower macroeconomic cost. Thus, an abatement policy oriented to a broad range of energy efficiency measures could be more effective in the long term in stimulating economic growth than a policy focused solely on the largest interventions.

j.

TRANSPORT: AN ALTERNATIVE ENGINEERING APPROACH TO MITIGATION OPTIONS

While the energy sector, as the dominant source of today's emissions, necessarily receives a much attention and analysis in any study of low carbon policies, and while energy efficiency, with well-known potential for 'no-regrets' actions, is rightfully high on policymakers' agendas, Poland also needs to consider how to address the sector with the fastest growing emissions—transport. This section presents the findings of an alternative engineering approach to transport sector mitigation options, applying the TREMOVE Plus model to the road transport sector in Poland. Road transport GHG emissions in Poland are converging from a low historic base towards EU averages. While contributing about 10 percent of overall emissions, road transport constitutes about 30 percent of non-ETS emissions. The objective of sustainability and greening of the transport sector is not new for the EU, but the EU 20-20-20 climate package is now the centerpiece. A business-as-usual scenario through 2030 was developed for passenger and freight road transport in Poland, using the TREMOVE Plus model. This forecast incorporated key characteristics of Poland's transport sector, in particular, a high number of imported used cars, low motorization rates and low mileage, and a highly competitive freight sector that has been shifting to newer and bigger trucks. Emissions from road transport are expected to almost double between 2005 and 2030. Because steady technological improvements are already incorporated into the BAU projections, the two low carbon scenarios developed by the TREMOVE Plus model include only modest technological improvements and concentrate on other emissions-reducing policy measures. The results of the scenarios present a more worrying vision than previously established for the road transport sector in Poland, with abatement unlikely to hold emissions growth below 35 percent through 2020.

The TREMOVE Plus model is a bottom-up activity-based transport model is based on the familiar EU transport and environmental model. The EU-wide model was updated for Poland with new projections of transport activity and the latest disaggregated data. Working from a slightly different set of assumptions than the MicroMAC curve analysis, the TREMOVE Plus model considers explicitly the characteristics of Poland's road transport sector and assesses the impact of existing policy commitments and possible mitigation options. The model takes a very different, detailed sector approach to constructing a business-as-usual scenario for passenger and freight road transport in Poland, allowing for more of the distinctive character of Poland's road transport sector, in particular, expected high growth in passenger cars and distances travelled. Importantly, the BAU calculations consider explicitly which transport and environment policies should be included in the reference scenario, and in this aspect, the transport BAU is quite different from the other BAU scenarios. The preponderance of imported used cars in Poland and the advanced age of the passenger fleet; low motorization rates and very low mileage driven per car compared with the EU15; and a road freight sector already highly competitive are found to be decisive factors for a projection of GHG emissions from road transport that shows almost doubling between 2005 and 2030.

Emissions from the transport sector have been growing at a high rate since accession to the European Union. Transport constitutes a modest 10 percent of overall GHG emissions in Poland but grew by 74 percent between 1988 and 2006. Within Polish transport, road transport is particularly dominant, generating 92 percent of sectoral GHG (see Figure 69).[81] Sharply rising trade volumes, increasing at an annual rate of more than 20 percent, and quickly expanding GDP, at an annual rate of 6.7 percent between 2000 and 2007, have been directly stimulating the demand for road freight transport. EU accession has also increased household incomes which, together with the sudden availability of affordable secondhand cars from other EU member states—principally Germany, has led to a dramatic increase in private motorization (measured as passenger cars per thousand people). Although the motorization rate in Poland is still quite low compared to the EU15 countries, it is fast catching up, fuelled by the import of second hand vehicles. At the national level in 2007 there were 383 cars per 1000 inhabitants, whereas only four years earlier, the average figure stood at 294 vehicles per 1000 inhabitants. (In Western Europe, the current average is about 500-600 cars per 1000 inhabitants.) Increasing car ownership and use is translating into higher GHG emissions, particularly given the age structure of the Polish vehicle fleet. Out of 13.4 million passenger cars registered in 2006, every fourth car was 6 to 10 years old, and two-thirds were over 10 years old. Only one in eight passenger car is less than 5 years old. As a result, the Polish passenger car fleet is relatively fuel inefficient and polluting.

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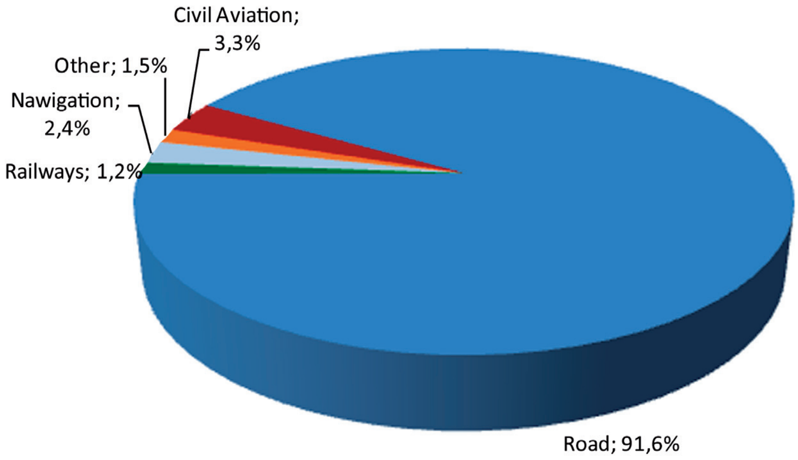
[81] Although energy, followed by agriculture and forestry, are the major sources of global GHG emissions, transport—emitting 13 percent of global CO_2e—is the fastest growing sector and the one most closely linked to the consumption of fossil fuels. In the EU, transport is the only sector where the emissions of greenhouse gases increased between 1990 and 2006, rising 28 percent while emissions overall shrunk by 3 percent. Road transport is the largest contributor to EU transport emissions, accounting for 71 percent of all EU GHG emissions in 2006.

Figure 69. Transport CO_2 emissions in Poland by mode, 2006



Source: Poland's Greenhouse Gas Inventory Report.

The EU has numerous policies, regulations, and laws aimed at sustainability and greening of the transport sector, of which the EU 20-20-20 climate package is now the centerpiece. As discussed in Section b and elsewhere in this report, the climate package sets national ceilings for emissions from non-ETS sectors, which includes transport (contributing about 30 percent of non-ETS emissions). Poland is limited to 14 percent growth in non-ETS emissions during 2005 to 2020 (which translates to a reduction compared to the business-as-usual level projected for 2020). In addition, the package sets a target for renewable energy at 20 percent of gross final energy consumption, including a 10 percent share of biofuels in the transport fuel market. Various transport policy measures have been put in place (see Table 13), and the European Commission expects that this package will contribute about one-third of the reductions required from the non-ETS sectors. At the same time, Poland has national transport policies, aimed at the high-level goal of developing an efficient and modern transport system but also including numerous measures to improve air quality, reduce pollution, and reduce GHG emissions. For example, in order to meet EU requirements, in 2007 Poland adopted a long-term plan on the promotion of biofuels and other renewable fuels for 2008-2014. Outside of emissions mitigation issues, as a member of the EU, Poland is required to (i) ensure the development of a competitive internal market for transport through market opening and liberalization, (ii) facilitate investment in prioritized transport infrastructure and (iii) reform infrastructure pricing and taxation to encourage more efficient use of transport infrastructure. Over the coming two decades, these transport policies are expected to work at somewhat cross-purposes with climate policies, encouraging significant additional private motorization and increasing mobility of the population.

Table 13. EU sustainable transport policy measures

Policies and laws	Year	Description
Greening transport package	2008	EC initiatives through 2009 on transport sustainability
Marco Polo II	2007-13	Funding for projects to achieve modal shift for freight transport
Directive promoting the use of cleaner vehicles through public procurement	2009	Public authorities and operators to take into account energy consumption, CO_2 emissions and local air pollutants when purchasing road transport vehicles
Directive promoting biofuels in road transport	2009	Sets mandatory national targets for renewable energy share in transport
Passenger car and light duty CO_2 emission standards	2009	Targets for new passenger cars to reach 130g/km by 2015
Rules on vehicle labeling to promote more energy-efficient vehicles	1999	Fuel economy and CO_2 information available for consumers.

Source: Transport technical paper, World Bank 2010.

A business-as-usual scenario through 2030 was developed for passenger and freight road transport in Poland, using the TREMOVE Plus model. A plausible development scenario for the road transport sector in the absence of new policy measures, to provide a reference for comparing the future effects of policy measures and combinations of policy measures, was developed by detailed analysis of: (i) the demand for road transport; (ii) vehicle ownership and the impact of secondhand car imports; (iii) size and composition of the vehicle fleet; (iv) driving conditions (urban, rural and highways); and, (v) emission factors (i.e., the diffusion of technology). This analysis was undertaken using the TREMOVE Plus model, building on the EU transport and environmental model TREMOVE (v2.9-2009) for Poland which was taken as a starting point and updated with projected development of the transport activity and vehicle stock (by type, technology, fuel use, age and GHG emissions factors for each class of vehicle), from a wide range of sources including, vehicles sales and car imports data, and as a result of interviews with stakeholders in Polish governmental organizations. Table 14 gives an overview of the resulting business-as-usual vehicle stock and mobility indicators, taking into account the expected growth in demand for passenger and freight transport based on GDP, population, motorization and the improvement in quality and extension of road infrastructure. The pattern of overall road transport emissions through 2030 can be seen in Figure 70.

Table 14. Overview of the business-as-usual vehicle stock and mobility indicators

	2008	2010	2015	2020	2025	2030
Population (million)	38.0	37.9	37.6	37.3	37.0	36.6
Motorization (per 1,000 inhab.)	422	451	523	562	590	605
Vehicle kilometers (billion VKM)	105.0	118.0	158.1	184.7	213.7	246.6
Passenger car VKM per capita	2,762	3,113	4,203	4,951	5,772	6,737
Passenger cars (million)	15.3	16.4	18.4	20.2	21.6	22.3
VKM per passenger car	6,882	7,218	8,599	9,153	9,913	11,058

Source: Transport technical paper, World Bank 2010.

A high number of imported used cars has a direct impact on the age and technology structure—and hence, the emissions performance—of the vehicle fleet. Secondhand cars flooded the Polish market after EU accession in 2004, and sales of new cars stood at about half the level of imported used car sales. Between 2006 and 2010, about 75 percent of cars registered for the first time in Poland were secondhand imports. In 2004, 73 percent of imported cars were over 10 years old. These cheaper cars have fostered rapid growth in vehicle ownership so that in 2008, Poland had 422 cars per 1000 inhabitants (compared to about 600 cars in Western Europe). In recent years, the average age of secondhand car imports has been dropping, and it is projected to continue to do so in the BAU projection, with the net effect of pushing down the average age of new registrations from 5.6 years in 2010 to 2.7 years by 2030.

The annual mileage driven per passenger car is expected to increase dramatically from its current level of about 2800 kilometers to typical EU15 levels of about 6700 kilometers by 2030. (See Table 14). Spurred by tighter integration of Poland within the EU, improved highway system, and higher family income, this increase in mileage per vehicle, when coupled with the expected increase in the motorization rate, is a main source of expected growth in fuel consumption and CO_2 emissions. Fleet-weighted average emissions factors are then needed to compute overall fuel consumption and emission of local and global pollutants. The TREMOVE Plus model assumes that the present EU long-term targets for new car CO_2 emissions will be met; and since these standards are outside of the control of Poland, they should be included in the BAU scenario. Consequently, new car emissions are assumed to fall to 95 gram CO_2 per vehicle kilometer by 2020. To achieve these emissions standards, a series of improvements to internal combustion engine vehicles will be necessary. Potential options include a wide range of technologies and measures that constitute 14 bundles for passenger cars and light duty vehicles in the MicroMAC curve, estimated to generate about 8 $MtCO_2e$ in GHG mitigation. In this model, these measures are part of the reference scenario because vehicle manufacturers are expected to use these 14 bundles to comply with the EU vehicle efficiency regulations. The BAU scenario shows emissions for passenger cars growing from 21.2 $MtCO_2e$ in 2010 to 31.2 $MtCO_2e$ in 2030.

Freight transport in Poland has witnessed a rapid increase in freight ton kilometers. The Polish road trucking sector is very competitive both nationally and internationally, partially because a large fraction of owner-drivers and small freight companies has provoked cut-throat competition that has kept prices down. Road haulage is considered more reliable, flexible and faster than rail and the trucking sector has grown substantially. Even low value bulk materials like coal are increasingly transported by trucks. In contrast to passenger cars, the age of Poland's truck fleet has been falling since EU accession, since many Polish trucks operate on international routes within the EU where they are required to comply with current EU standards. At the same time, fuel use has been shifting towards diesel, which by 2007 had an 85 percent share in the truck sector, leading to lower emissions factors for freight. Truck size has also been rising, and larger trucks are substantially more efficient per ton-kilometer than smaller commercial vehicles. The impact of these changes in technology, fuels, and increasing truck size comes together in the BAU scenario as a steady decline in the emissions factor. As for passenger cars, part of the projected gains come from an assumption that many of the efficiency improvements in medium and heavy duty trucks analyzed in the MicroMAC curve will occur in the BAU scenario. For trucks, 12 bundles of measures, estimated to create mitigation of approximately 1 $MtCO_2e$ by 2030 are part of the reference scenario.

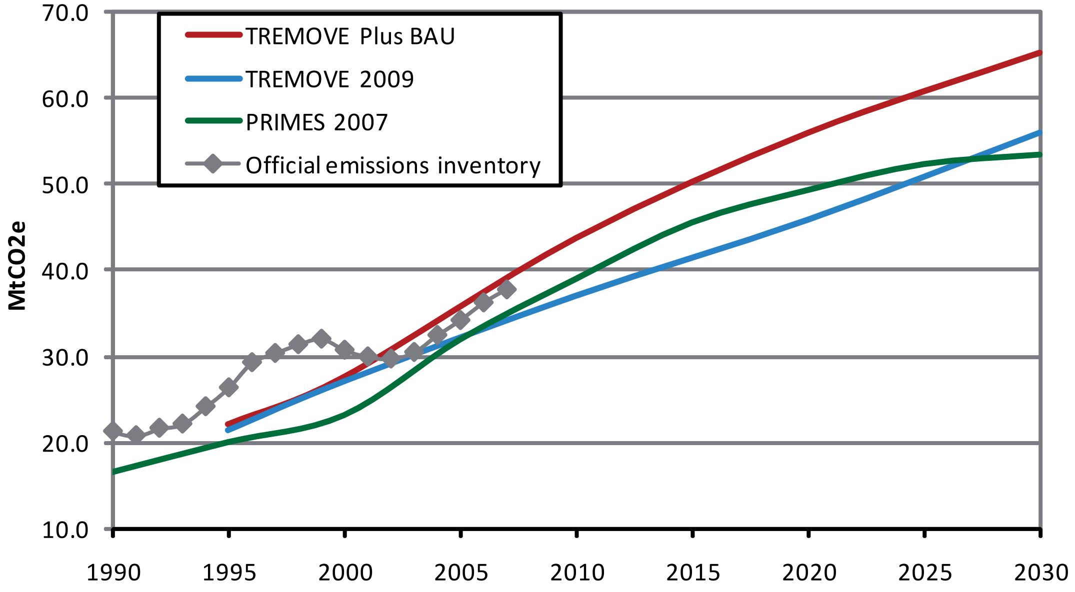
The business-as-usual scenario of the TREMOVE Plus model projects total CO_2e emissions from road transport to climb by 210 percent compare to 1990 and 93 percent compared to 2005 emissions levels despite the inclusion of technological progress. Emissions are projected to increase from 21.3 $MtCO_2e$ in 1990 and 34.2 $MtCO_2e$ in 2005 to 65.9 $MtCO_2e$ in 2030. A detailed breakdown of emissions by source is provided in Table 15 below. These projected emissions push Poland far above its agreed 14 percent growth in emissions for non-ETS sectors. Freight transport appears the bigger challenge, with a higher growth rate of emissions of 124 percent forecast through 2030 and, in consequence, a rising share of overall road transport emissions. The TREMOVE Plus BAU scenario projects faster growth in emissions than some other road transport projections, for example, that from the EU PRIMES model or the EC's TREMOVE model, but the TREMOVE Plus BAU matches more closely the path of actual emissions (see Figure 70). The overall growth rates match fairly closely the transport scenarios that are part of the BAU projections for the MicroMAC curve model (which estimates 100 percent emissions growth for the transport sector overall during 2005 to 2030) and somewhat higher than the MEMO model (with 64 percent emissions growth forecast but for a more broadly defined transport sector). However, the assumptions of policies included in the BAU scenarios varies, explicitly in the case of the MicroMAC curve analysis as compared to TREMOVE Plus and implicitly in the case of the MEMO model BAU scenario. These assumptions are critical to define the possibilities for mitigation from BAU emissions levels in the low carbon scenario analysis that follows below.

Table 15. TREMOVE Plus BAU scenario of Poland road transport CO_2 emissions, 1995-2030

CO_2 emissions BAU (million tonnes)	1995	2000	2010	2020	2030	Annual change 2010-2030 (%)	Total growth 2005-2030 (%)
HDV (heavy duty vehicle >16t)	4.8	6.4	14.2	19.0	22.0	4.5%	131%
MDV (medium duty vehicle 3.5-15t)	1.2	1.6	3.4	4.6	5.4	4.7%	132%
LDV (light duty vehicle <3.5t)	0.3	0.4	0.9	1.2	1.4	4.5%	133%
Vans	1.1	1.7	2.3	2.8	3.5	4.3%	77%
Total commercial truck transport	7.3	10.0	20.8	27.6	32.3	4.5%	124%
Motorcycles, moped, buses, tractors	2.5	2.4	2.3	2.3	2.4	0.4%	2%
Passenger cars	12.2	15.1	21.2	28.9	31.2	3.9%	74%
Total road transport sector	22.0	27.5	44.3	58.8	65.9	4.1%	93%

Source: Transport technical paper, World Bank 2010.

Figure 70. TREMOVE Plus BAU carbon emissions scenario for Poland's road transport sector, 1990-2030



Note: TREMOVE 2009 is EC BAU projection.
Source: Transport technical paper, World Bank 2010.

Because steady technological improvements are already incorporated into the BAU projections, the two low carbon scenarios developed by the TREMOVE Plus model include only modest technological improvements and concentrate on other emissions-reducing policy measures. The BAU scenario already projects relatively high efficiency of medium and heavy duty vehicles, with a pathway determined by increasing truck capacity and load utilization. Passenger car developments, guided by tighter emissions standards, similarly reflect relatively high efficiency along the BAU path. Thus, abatement from technological improvements will be limited across the road transport sector. Instead, the two lower carbon scenarios for the TREMOVE Plus model include few technological improvements and focus on policy measures that require behavioral changes. These scenarios add a set of 'Precautionary' and a set of 'Proactive' non-technological measures such as road pricing, fuel tax increases, eco-driving, parking policies and the promotion of public mass transport together with greater mode share for walking and cycling. To determine which policies to model, fifteen bundles, or areas, of road transport policies were evaluated for abatement cost, effectiveness, and potential timing. The policy areas with highest potential were then used to create the scenarios (see Table 16).

Table 16. Overview of TREMOVE Plus low carbon scenario policy measures

Policy measure	Description	Reduction in 2030 vs. BAU, in %
Road pricing	Introduction of electronic tolling on motor and expressways; and gradual introduction of congestion charging in major cities	4.2%
Fuel tax increase for passenger cars	Gasoline price increase of 10%	5.2%
Fuel tax linked to CO_2 standard for passenger cars	Annual gasoline price increase equal to emissions standard tightening3	18%
Fuel price increase for trucks	Diesel price increase of 10%	1.8%
Eco-driving	Introduction of eco-driving course to improve fuel efficiency	4.7%
Parking policies	Parking fees for entire inner city regions of all cities	3.5%
Promotion of non-motorized and public transport	Promotion of walking and cycling; and of metro, trams, and buses; and park and ride	2.3%
Larger heavier trucks and logistics efficiency	More use of larger and heavier vehicles with more efficient logistic chains and distribution efficiency	25%

Source: Transport technical paper, World Bank 2010.

The results of the TREMOVE Plus model's two low carbon scenarios present a more worrying vision than previously established for the road transport sector in Poland, with abatement unlikely to hold emissions growth below 35 percent. The 'Precautionary' and 'Proactive' abatement scenarios contain similar measures, but they have been quantified under different levels of effort in each scenario. For example, the 'Proactive' scenario includes the fuel tax policy linked to CO_2 standards and a 10 percent fuel tax for trucks, while the 'Precautionary' scenario includes a fuel price increase of 5 percent for both cars and trucks. The other measures also deliver significantly less abatement under the 'Precautionary' scenario, due to less effort. The impact of the 'Precautionary' scenario's policy measures is disaggregated in Table 17, and the 'Proactive' scenario in Table 18. Overall, the freight sector has greater potential for emissions cuts; and the single most powerful policy measure is larger heavier trucks plus logistics improvements (with 4.3 percent or 7.2 percent abatement). In the 'Proactive' scenario, a near competitor is the fuel tax linked to auto emissions standards, which delivers 5.6 percent abatement. In 2020, the two scenarios still leave emissions 58 percent and 35 percent higher than in 2005 respectively, exceeding the 14 percent growth target for non-ETS sectors by 21 percentage points even in the more stringent 'Proactive' scenario. The abatement potential in 2030 is estimated at approximately 12 percent and 27 percent in the 'Precautionary' and 'Proactive' scenarios with respect to the BAU scenario. The path of GHG emissions in each scenario are shown in Figure 71.

Table 17. TREMOVE Plus 'Precautionary' scenario emissions reduction by policy intervention, $MtCO_2e$

Emissions reduction ($MtCO_2e$)	2020	2030
Passenger cars:	2.6	3.1
Road pricing	0.6	0.7
Fuel tax increase	0.8	0.8
Eco-driving	0.5	0.7
Parking policy	0.5	0.5
Promotion non-motorized (public) transport	0.3	0.4
Freight trucks:	2.1	4.6
Fuel price increase truck transport	0.2	0.3
Larger heavier trucks, logistics efficiency	1.9	4.3
Total reduction in 'Precautionary' scenario	4.7	7.7

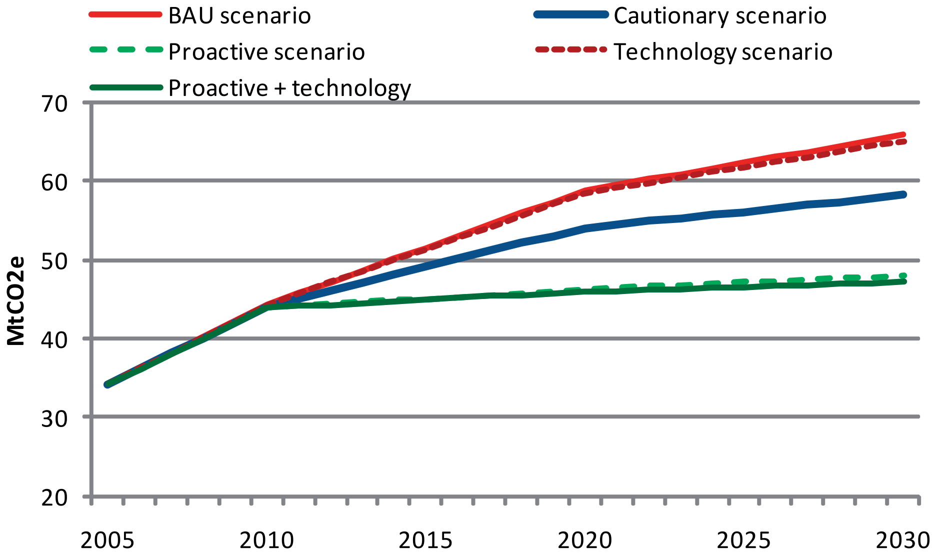
Source: Transport technical paper, World Bank 2010.

Table 18. TREMOVE Plus 'Proactive' scenario emissions reduction by policy intervention, $MtCO_2e$

Emissions reduction ($MtCO_2e$)	2020	2030
Passenger cars:	9.0	10.2
Road pricing	1.1	1.3
Fuel tax linked to CO_2 standard	5.2	5.6
Eco-driving	1.0	1.5
Parking policy	1.0	1.1
Promotion non-motorized (public) transport	0.7	0.7
Freight trucks:	3.5	7.7
Fuel price increase truck transport	0.4	0.5
Larger heavier trucks, logistics efficiency	3.1	7.2
Total reduction in 'Proactive' scenario	12.5	17.9

Source: Transport technical paper, World Bank 2010.

Figure 71. TREMOVE Plus carbon emissions projections for road transport by scenario



Note: Precautionary scenario contains policy measures such as road pricing, fuel tax increases, and eco-driving. Proactive scenario contains same measures but with greater effort. Technology scenario contains policy measures for modest technological improvement in trucks (medium and heavy duty vehicles).
Source: Transport technical paper, World Bank 2010.

Abatement of emissions in the transport sector is likely to require diverse and coordinated action by both local and national government. In transport, the authorities at all levels will need to encourage lower-emission modes of transport and design infrastructure and, especially, public spaces in cities with better access for public and non-motorized transport. To shift passenger traffic away from cars, integrated ticketing and integrated terminals for air, rail, bus, and tram transport will be important as well as expansion of rail and bus rapid transit service.[82] Critical for freight traffic will be improvements in intermodal freight transport[83] and other measures to encourage a shift away from roads towards inland water and rail, as well as interoperability of transport modes between countries.[84] Urban planning needs to consider carbon abatement. Cities, towns and districts can and should be designed and redesigned to minimize transport needs and with alternative transport in mind. Instead of building infrastructure to accommodate increasing numbers of cars, governments should invest in alternative arrangements that allow and encourage cyclists, pedestrians, and public transport riders (see Box 7).

Box 7. The impact on emissions of Poland's urban transport and urban planning policies

A key area of transport not discussed elsewhere in this chapter is urban transport which accounts for a large share of overall emissions from the transport sector. Poland has a relatively high urbanization rate (of 61 percent), and most recent population growth in Poland has happened in and around larger cities. The suburbs of larger metropolitan areas have absorbed much of the population growth and been the site of the majority of new housing developments. While population overall is declining, the suburbs of Warsaw are growing, as are smaller cities' suburbs.

The shift towards suburban sprawl of Polish cities has significant implications for urban transport as well as other urban services. It is accompanied by a shift towards single-family units, likely with greater per capita residential energy requirements. Importantly, expansion into peri-urban areas has been occurring at great distances from the city center, with haphazard new developments along main arteries driven by low land prices. Residents depend on private cars for commuting into the city. Meanwhile, public investment has focused on improving and expanding roads rather than public transport. Most metropolitan areas do not have properly integrated public transportation networks: Warsaw's network is fragmented and focused in the center city.

A main result has been that the hard urban cores that defined Polish cities before 1990 have given way to scattered suburban developments that make public transportation networks in those areas impractical as well as raising challenges for provision of water, sewage, electricity, and solid waste management services. All of these aspects will contribute to raising GHG emissions in metropolitan areas. The jurisdictions that make up Polish metropolitan areas need to come together around an integrated regional urban planning approach to guide new developments in a more sustainable fashion and fostering opportunities to involve the private sector in regional service provision.

The TREMOVE Plus model generates a BAU scenario for road transport against which reducing emissions from transport will be particularly difficult. The transport BAU scenario illuminates the kinds of policies that must be considered part of business-as-usual for convergence to EU averages to happen over the next decades. That is, while the MEMO model abstracts from how Poland's economy comes to resemble the EU average, this engineering approach must be specific. Similarly, the MicroMAC curve presumes some unidentified efficiency gains, but then counts as an option every possibility for GHG abatement. The transport modeling shows that many of these options are already part of business-as-usual and are not available to create additional mitigation. Within this modeling framework, the analysis finds that Poland still has relatively low rates of motorization, which argues that the growth of road transport will likely be high going forward. Further complicating the picture is the very high share of used vehicles, which tend to be much more fuel-inefficient and polluting. Long distance freight and passenger transport need substantial changes; to achieve a strategic shift towards a lower carbon intensity (per passenger- and tonne-kilometer transported) while promoting long-term development and contributing to a better quality of life. A paradigm shift is urgently needed to reshape and refocus the urban transport sector toward transport systems that not only get urban inhabitants where they need to go, but get them there sustainably and with little impact on the environment. Transport infrastructure design and development decisions taken over the coming years will directly affect this long term sustainability. Infrastructure investments have a long life; design decisions made centuries ago are still evident in many European towns and cities. If cities develop around the needs of private motorization and other unsustainable aspects of transport, as many cities currently do, they will lock in to a high energy-consuming development trajectory which will be difficult to change at a later date.

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[82] Bus rapid transit (BRT) is a term applied to a variety of public transportation systems using buses to provide faster, more efficient service than an ordinary bus line. Often this is achieved by making improvements to existing infrastructure, vehicles and scheduling. The goal of these systems is to approach the service quality of rail transit while still enjoying the cost savings and flexibility of bus transit.

[83] Intermodal freight transport involves the transportation of freight in an intermodal container or vehicle, using multiple modes of transportation (rail, ship, and truck), without any handling of the freight itself when changing modes. The method reduces cargo handling, and so improves security, reduces damages and losses, and allows freight to be transported faster.

[84] The challenge of interoperability across national borders is most clear for railways, which have greater or lesser interoperability depending on whether both countries conform to standards of gauge, couplings, brakes, signaling, communications, loading gauge, and operating rules.

CONCLUSIONS AND ADDITIONAL ISSUES

Better understanding of technological options, economic ramifications, and policy impact enhance the likelihood that Poland can move quickly towards a low emissions growth path. Such a transition will deliver additional benefits, including added energy security from increased energy efficiency and use of renewable energy sources, human health benefits from transport and other improvements that reduce local air pollutants, and strategic and competitive advantages that are more likely to accrue to countries that pursue low emissions development early. While this report provides some complex assessments and new analytic tools for policymakers, its analysis, rather than exhausting the central issues related to a transition to low-emissions growth, has identified a number of additional economic issues for further work.

One area for further research is follow-on development of the economywide and engineering models and the links between them. Having developed a suite of models with some new methods of integrating bottom-up with top-down, a direction for further work would be additional integration and harmonization of the models. In particular, remaining differences in the business-as-usual projections, the approach to modeling the power sector, and transport sector treatment could be resolved, albeit not easily Alternatively, and perhaps more fruitfully, these models can be transferred to government or local ownership to serve as tools for policymakers going forward. Further, the preservation of alternative models, which produce differing results, highlights continually for model users the criticality of model assumptions and simplifications.

Supplementary analysis using the existing economy-wide models or off-the-shelf models suited to the topic might fruitfully be applied to a number of issues. Extending the time horizon to 2050 would allow a more balanced treatment of the impact of long-gestation mitigation opportunities such as nuclear power plants in the MEMO model. The inclusion of R&D expenditures and technological progress would allow improved analysis of the long-term gains in the economy from implementation of energy efficiency measures. Distributional and regional impacts would be of interest and could be approached simply using existing household survey data.

Sectoral and bottom-up or engineering analysis could also be usefully supplemented. More detailed bottom-up analysis of energy efficiency options in Poland would help clarify the nature of implementation barriers and assign costs to them. This richer database could then be linked to the MEMO model to assess the macroeconomic impacts of a coordinated and significant program of energy efficiency. Sector studies of agriculture, land use, and forestry would assist in moving from the financial costing of the MicroMAC curve to understanding how to implement abatement measures in these sectors in Poland.

The complexity of EU policy leaves many questions and regulatory aspects still to be analyzed. Public subsidies warrant further attention, since existing distortions and overlapping regulations mean that the impact of an additional tax or subsidy is hard to predict. In particular, a better understanding is needed of the system of ‘white certificates’ which are intended to encourage investment in energy efficiency measures. The macroeconomic and fiscal implications of derogations (or free allowances) in the ETS system, of various recycling options of revenues from ETS auctions, of the possible introduction of carbon taxation in non-ETS sectors, and the proposal to re-introduce an excise tax on coal from 2012 also merit analysis. Lastly, better modeling of renewable energy sources and their complex EU regulations would better inform decisions on power sector investments.

One last area that this report did not investigate was how to foster the new business opportunities that may arise for those countries that move earlier to a low-emissions economy. For all the same reasons that Poland has thrived following its transition to a market economy and its accession to the EU—high levels of education, conservative macroeconomic management, respect for the rule of law, middling infrastructure, and proximity to Europe—it might be expected that in the transition to a low-emissions economy, Poland would find a way to maximize the benefits and minimize losses.

This report provides a detailed assessment of many aspects of a low emissions growth strategy for Poland, developing insights via a suite of models that should provide ongoing assistance to policymakers in Poland. Policymakers may find reassuring the report’s main message that Poland’s transition to a low-emissions economy, while not free or simple, is affordable. However, capturing the full package of technologically feasible and economically sensible abatement measures requires coordinated and early action by the government. With an ambitious approach, Poland can aim to reduce its GHG emissions by about one-third by 2030 (relative to 1990) with little cost to incomes and employment. Similarly, meeting the EU targets for 2020 appear generally feasible for Poland at modest cost, albeit likely more challenging for less energy-intensive sectors such as transport than for sectors that can access the efficiencies of EU-wide carbon trading. Poland has already weathered one economic transition and emerged with a strong and flexible economy. This next transition—to a low emissions growth path—while requiring an evolution in lifestyles and priorities over the next 20 years, may well turn out to be much easier.

Annex 1.

EU CLIMATE AND ENERGY PACKAGE: DETAILS OF THE 20-20-20 TARGETS FOR 2020

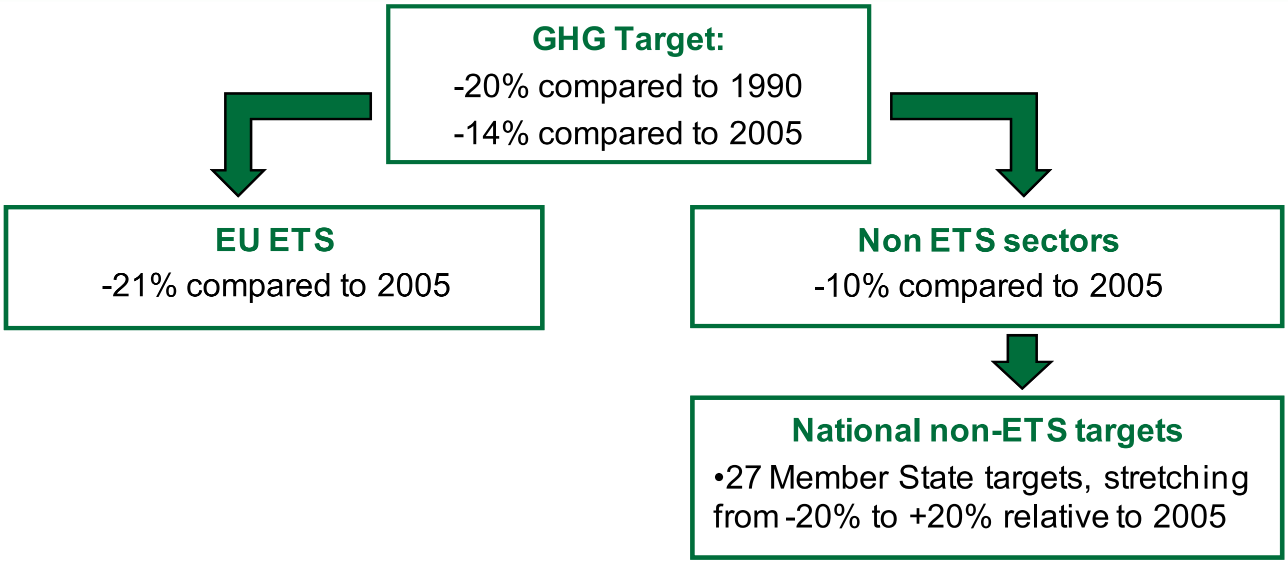
EU CLIMATE AND ENERGY PACKAGE: DETAILS OF THE 20-20-20 TARGETS FOR 2020

The EU Climate and Energy Package follows the mandate from the Spring 2007 Summit of the European Council. The Council committed to:

- reduce the EU's GHG emissions by 20 percent below 1990 levels by 2020 (or 30 percent conditional on an international "post-Kyoto" agreement[1]
- increase renewable energy sources to 20 percent of the EU's overall energy mix by 2020 (including a minimum of 10 percent biofuels in overall fuel consumption)
- improve energy efficiency by 20 percent by 2020 relative to business-as-usual scenario
- set a legal and policy framework for carbon capture and storage (CCS), as well as an incentive framework, support programs and external elements such as technology cooperation with key countries.

At the same time, the EU advocated that industrialized countries should reduce their emissions collectively by 60-80 percent by 2050 compared to 1990. To meet the 20 percent EU-wide GHG reduction target by 2020, a 14 percent reduction of carbon emissions is required as compared to 2005 levels. Figure 72 demonstrates the breakdown of EU's 2020 targets, which assumes a 14 percent reduction of carbon emissions as compared 2005. It is to be achieved by a 21 percent reduction in ETS sectors and a 10 percent reduction in non-ETS sectors. For ETS, the emissions cap will be reduced each year in a linear fashion to reach 1720 million tons of CO_2 by 2020.

Figure 72. Illustration of EU's 2020 climate change and energy targets



Source: Loch Alpine technical paper and European Commission.

The EU package extends and deepens the EU commitments to greenhouse gas emission reduction contained in the Kyoto Protocol. The EU carbon abatement targets are more ambitious than Kyoto targets and will require more efforts, sectoral adjustments, and resources from EU members to achieve. In contrast to Kyoto targets (see Table 19), there are no overall country targets, while the regulations concern specific sectors or installations emitting GHGs.

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[1] Provided that other developed countries commit themselves to "comparable" reductions and economically more advanced countries to contributing "adequately" according to responsibility and capabilities.

Table 19. Comparing the Kyoto Protocol and EU 20-20-20 policy package

	Kyoto Protocol	EU 20-20-20 by 2020
Commitment period	2008-2012 average	2005-2020, Second Phase of EU ETS implementation (2008-2012) is consistent with the Kyoto period
Base year for abatement commitments	1990 (for Poland – 1988)	1990 as reference year for EU overall commitment; 2005 for specific commitments on ETS volume, share of renewable energy in energy demand, emission changes of non-ETS sectors, and biofuels
Sector specific abatement targets	No, only overall country-wide targets	Yes, major breakdown into ETS (in particular, energy) and non-ETS sectors. Reallocation between the two sector groups or backloading reductions into later years is not permitted
Gases covered	Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF6)	All GHGs, but main instruments refer to CO_2 because of centrality of fossil fuel combustion in energy-intensive sectors

Source: World Bank Staff based on UNFCCC and European Commission.

The EU climate change package was revised during the European Summit and approved by the European Parliament in December 2008. In response to political pressures, the final compromise contains numerous derogations designed to reduce compliance costs for fossil fuel-dependent power sectors and heavy industries.

The package includes five main elements, while the expansion of the cap and trade system from 2013 remains its critical, market-based component[2]. The elements are:

- Revision of the EU ETS in Phase III (2013-2020) and EU-wide rules to harmonize the allocation of emission allowances (AUs) across the Member States,
- Individual national emission reduction targets for non-ETS sectors (effort sharing), as compared to 2005 as a base year. The individual targets are based on incomes per capita. The targets range from +20 to -20 percent relative to 2005. Poland may increase its emissions in non-ETS sectors by 14 percent. All of the EU10 countries may increase their emissions in non-ETS sectors.
- Legally enforceable renewable energy targets for Member States,
- Carbon capture and storage (CCS) legal framework and environmental state aid.
- The regulation on CO_2 emissions from cars and the fuel quality directive.

I. EU ETS regulations

The EU ETS directive covers around 12.000 installations in Europe, and 838 installations are located in Poland. The major industrial emitters need to reach the 21 percent reduction of CO_2 emissions as compared to 2005 by 2020. Generally, the directive splits sectors covered by the auctioning system, which will be gradually phased in from 2013, into three categories:

- with significant risk of carbon leakage
- power sector
- industrial plants (including cogeneration and district heating producers).

During Phase II of EU ETS implementation (2008-2012), the EC sets allocation caps for EU ETS sectors based on the National Allocations Plans (NAPs)[3]. Currently, CO_2 allowances are allocated to emitters for free (grandfathering principle).

The distribution of total EU-wide number of the allowances to be auctioned will be based on formula 88/10/2 percent. First, 88 percent of allowances will be split between the Member States based on the higher of the following values: 2005 or the average over the period 2005-2007 verified emissions (general rule). Second, 10 percent of permits will be distributed on the basis of the GDP per capita and

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[2] On the design of CO_2 taxes at the domestic and international level and the choice of taxes versus a cap-and-trade system, see Aldy J.E., Ley E., and Parry I., A Tax-Based Approach to Slowing Global Climate Change, World Bank, PREMEconomics of Climate Change Discussion Paper No. 1, World Bank, August 2008.

[3] After the review of NAPs, submitted in 2006, the EC requested Poland and other EU10 countries to reduce the allocations proposed by around one-quarter. In response to this decision, Poland sued the EC in the European Court of Justice and received a favorable verdict in late 2009.

level of fossil fuels in energy mix. According to this rule, Poland will increase its number of allowances granted based on general rule by 39 percent. Third, the remaining 2 percent of allowances will be allocated between the Member States which had achieved in 2005 a reduction of at least 20 percent in GHG emissions compared with the Kyoto base year (1988 for Poland). Hence, 2 percent of EU-wide allowances will be distributed among the EU10 (except Slovenia), which are the Kyoto surplus countries. Out of this amount, 27 percent will be allocated to Poland. The exact number of EAs distributed between the EU countries will be specified in executive EC regulations by 2011. According to the estimates by Smol et al. (2010), presented in Table 20, Poland may be the second largest 'beneficiary' (after Germany) of the EAs in the EU in 2013[4].

Table 20. Allocation of emission allowances for ETS auctions among EU27 member states for 2013, in million tons of CO_2e

	Emissions in 2005 or 2005-2007 average	Country share in total emissions	88%	Percent-age increase by country (for 10% allocation)	10% * to be cor-rected	10%	Country share in 2% of allocation	2%	Total
Austria	19.61	1.55	17.26	0%	0.00	0.00	0.0%	0.00	17.26
Belgium	32.52	2.57	28.62	10%	2.86	2.80	0.0%	0.00	31.42
Bulgaria	23.03	1.82	20.27	53%	10.74	10.51	15.0%	3.80	34.58
Cyprus	3.04	0.24	2.68	20%	0.54	0.52	0.0%	0.00	3.20
Czech Rep.	49.73	3.93	43.76	31%	13.57	13.28	4.0%	1.01	58.06
Denmark	17.71	1.40	15.58	0%	0.00	0.00	0.0%	0.00	15.58
Estonia	7.84	0.62	6.90	42%	2.90	2.84	6.0%	1.52	11.25
Finland	23.53	1.86	20.71	0%	0.00	0.00	0.0%	0.00	20.71
France	77.06	6.09	67.81	0%	0.00	0.00	0.0%	0.00	67.81
Germany	281.91	22.28	248.08	0%	0.00	0.00	0.0%	0.00	248.08
Greece	41.88	3.31	36.85	17%	6.27	6.13	0.0%	0.00	42.99
Hungary	15.44	1.22	13.59	28%	3.80	3.72	5.0%	1.27	18.58
Ireland	13.16	1.04	11.58	0%	0.00	0.00	0.0%	0.00	11.58
Italy	133.11	10.52	117.14	2%	2.34	2.29	0.0%	0.00	119.43
Latvia	1.64	0.13	1.44	56%	0.81	0.79	4.0%	1.01	3.25
Lithuania	3.92	0.31	3.45	46%	1.59	1.55	7.0%	1.77	6.77
Luxembourg	1.52	0.12	1.34	10%	0.13	0.13	0.0%	0.00	1.47
Malta	1.14	0.09	1.00	23%	0.23	0.23	0.0%	0.00	1.23
Netherlands	47.20	3.73	41.54	0%	0.00	0.00	0.0%	0.00	41.54
Poland	121.85	9.63	107.23	39%	41.82	40.94	27.0%	6.83	155.00
Portugal	21.38	1.69	18.81	16%	3.01	2.95	0.0%	0.00	21.76
Romania	40.87	3.23	35.97	53%	19.06	18.66	29.0%	7.34	61.96
Slovak Republic	14.80	1.17	13.02	41%	5.34	5.23	3.0%	0.76	19.01
Slovenia	5.19	0.41	4.57	20%	0.91	0.89	0.0%	0.00	5.46
Spain	107.80	8.52	94.86	13%	12.33	12.07	0.0%	0.00	106.94
Sweden	11.39	0.90	10.02	10%	1.00	0.98	0.0%	0.00	11.00
UK	147.03	11.62	129.39	0%	0.00	0.00	0.0%	0.00	129.39
EU 27	1265.30	100.00	1113.46	--	129.25	126.53	100.0%	25.31	1265.30

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[4] The estimates by KASHUE-KOBIZE as of late 2010, suggest that Poland may get emission allowances for ETS auctions in 2013 for 160 million tons of CO_2e.

In addition, from 2013 onwards, overall, at least 50 percent of allowances will be auctioned in the EU, and the proportion will rise each year. However, there are many specific or transitory regulations, some of which are addressed to the new EU Member States. The major rules are following:

- Power sector
    - The general rule for EU power companies says that they have to buy all allowances on auctions from 2013. However, there are many exceptions. There is an option for transitional free allowances for modernization of electricity generation that will apply essentially for the new Member States, including Poland. The share of free allowances cannot be higher than 70 percent in 2013 and will decrease thereafter, resulting in no free allocation in 2020. However, there are quite demanding reporting requirements.
    - The Member State concerned shall submit to the EC a national plan that provides for investments in retrofitting and upgrading of the infrastructure and clean technologies and for the diversification of their energy mix and sources of supply for an amount to the extent possible equivalent to the market value of the free allocation with respect to the intended investments, while taking into account the need to limit as far as possible directly linked price rises. The application should contain the proposed allocation methodology and individual allocations. The deadline for the submission is 30 September 2011. The applicant country shall also submit to the EC, every year, a report on investments made in upgrading infrastructure and clean technologies. Investment undertaken from the entry into force of the ETS Directive may be counted for this purpose.
    - The 70 percent threshold is not an obligation and the cost of free of charge allowances has to be equal to the cost of all planned investments within the sector, so it depends on cost of allowances. The overall objective of this idea is to support installations under modernization: to let them avoid additional costs of purchasing allowances during construction time, and keeping the energy price at possible low level.
    - Until 2017, it is possible to postpone the 2020 deadline on the basis of the EC proposal, on request of the concerned Member State, that there is a need for an extension of that period for the derogations. The proposal may be submitted to the European Parliament and the Council, including the conditions that would have to be met in the case of an extension of that period. Free of charge emission allowances cannot be sold.
    - Only installations in operation on December 2008 and these new under construction which really started construction works not later than December 2008, can be covered by this regulation. There is a legal dispute between Poland and the EC on the interpretation of regulations concerning the starting point of the investments.
- Industry installations will be required to buy 20 percent of allowances in 2013, rising to 70 percent in 2020 and 100 percent (full auctioning) in 2027.
- The aviation sector will receive 85 percent of the allowances for free for the whole period 2013-2020.
- ETS sectors at significant risk of carbon leakage (the risk of reallocation of production to third countries with a less strict climate policy)
    - These sectors will receive allowances for free at the level of the benchmark of the best technology available until 2020, until an international climate change agreement is concluded.
    - The definition of significant risk of carbon leakage is complex and broad. It covers around 90 percent of European manufacturing industry. Sectors are exposed to significant risk of carbon leakage if "the sum of direct and indirect additional costs induced by the implementation of the [ETS] Directive would lead to an increase in production costs exceeding 5 percent of its gross value added and if the total value of its exports and imports divided by the total value of its turnover and imports exceeds 10 percent. Also, the sector is deemed to be exposed to a significant risk of carbon leakage if the sum of the direct and indirect additional costs induced by the implementation of the [ETS] Directive would lead to an increase in production costs exceeding 30 percent of its gross value added or if the total value of its exports and imports divided by the total value of its turnover and imports exceeds 30 percent"[5].
    - The list of these sectors and sub-sectors was published by the EC in December 2009 and will be determined every 5 years. In relation to these sectors, the public support will be excluded from EU public aid framework.
- Use of credits from outside the EU.
    - Member States may "offset" emissions, i.e. buy credits resulting from projects in third countries under the CDM. However, no more than 50 percent of the EU-wide reductions over the period from 2008 to 2020 may stem from such credits in order to ensure a sufficient level of emission reductions inside the EU.
    - All existing ETS operators shall be allowed to use credits (CER and ERU units from JI and CDM) during the period from 2008 to 2020 up to either the amount allowed to them during the period from 2008 to 2012, or to an amount corresponding to a percentage, which shall not be set below 11 %, of their allocation during the period from 2008 to 2012, whichever is the highest.
    - From 1 January 2013, measures may be applied to restrict the use of specific credits.

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[5] Council of European Union, 17215/08, Energy and climate change - Elements of the final compromise, Brussels, 12 December 2008.

- **Voluntary allocation of auctioning revenues on "green" projects.** Member States may pre-allocate on voluntary basis at least half of their auctioning revenues on measures to in the fight against climate change, including support for development of renewable energy sources, CCS (up to 15 percent of investment costs without risk against public aid regulations), increase energy efficiency, avoid deforestation and facilitate adaptation in developing countries, and introduce solutions against "energy poverty".
- **Small installations** could be excluded from the ETS system with a rated thermal input below 35 MW, and reported emissions of less than 25,000 tones of CO_2 equivalent. However, if excluded, there is a need for other instruments of emission reduction like environmental taxes.
- **Excess emissions penalty** under the ETS was set at 100 euro per ton of CO_2 emitted.

II. Non ETS sectors

While the EU is committed to reducing emissions in non-ETS sectors by 10 percent between 2005 and 2020, the catching-up EU countries were allowed to increase their emissions, of which Poland by 14 percent. Anyway, meeting this target will be challenging in the light of the expected expansion of non-ETS sectors, in particular transport in the BAU scenario. A linear adjustment trajectory for the period 2013-2020 is legally binding with annual monitoring and compliance checks.

Based on current regulations, a Member State which fails to meet its target will not pay an excess emissions penalty of 100 euro per ton of CO_2 emitted, as in case of ETS sectors, but will be required to undertake a corrective action. When a Member State exceeds its annual limits, it will have to compensate for this underachievement in the following year, while the excess emissions will be multiplied by an abatement factor of 1.08, reducing the emissions allowed for the following year.

The EU regulations allow for trading and transferring of over-performance of targets among Member States. The countries may transfer up to 5 percent of the annual emission allocation from the following year to the year in question (th is rate may higher in 2013 and 2014 in the event of extreme meteorological conditions). A Member State may also transfer up to 5 percent of its annual emission allocation of a given year to another Member State.

Member States may also offset emissions through CDM, but the annual use of such credits may not exceed 3 percent of the greenhouse gas emissions of that Member State in 2005. In addition, some Member States with stricter targets (which does not include Poland) will be able to use additional credits amounting up to 1 percent of their 2005 emissions.

III. Renewable energy sources

The EU27's shares of renewables in final energy demand are to increase en bloc from 8.7 percent in 2005 and reach the target of 20 percent in 2020. In Poland, the share is to double from the 7.3 percent level in 2005 to 15 percent in 2020. Also, the renewable energy sources directive sets the 10 percent target for renewables in all forms of transport (not only road transport). The 10 percent biofuels target will require significant progress, as they account for 0.5 percent in Poland of overall fuel consumption (2005 data).

The regulation fixes sustainability criteria to ensure that supported biofuels have no negative environmental impact. Its purpose is to promote "second generation" biofuels, which do not compete with food or feed production. They will be double credited towards the 10 percent target. Renewable electricity consumed by electric cars will be counted at 2.5 times its input. Also, to count towards the transport fuel target, the use of biofuels must save at least 35 percent of GHG emissions compared to fossil fuels. From 2017 onwards, the greenhouse gas emission savings of biofuels produced in existing production plants must be at least 50 percent compared to fossil fuels, while for new installations the percentage should be at least 60 percent. Also, the renewables directive creates cooperation mechanisms so that one can achieve the target in a cost effective way.

Member States may cooperate to achieve their renewables targets jointly. They may run joint projects on green electricity production, heating or cooling, or to transfer renewable energy "statistically" between each other. They may also coordinate their national support schemes so that renewable energy. Member States may count towards their national targets "green" electricity consumed in the EU but produced by newly constructed joint projects with third countries such as future solar thermal plants to be built in Northern Africa under the Mediterranean Solar Plan. Such renewable energy plants with a very long lead time may be accounted for in the calculation of a Member State's renewable energy share even if they will not e operational by 2020. Also, "green" electricity should be given priority or guaranteed electric grid access.

IV. Carbon Capture and Storage (CCS)

Carbon capture and storage, although still an emerging technology, is being promoted by the EU. The directive on geological storage of CO_2 provides a legal framework to manage possible environmental risks and liability issues. The CCS regulations are to equip power plants with CO_2 capture technology and establish conditions for safe transport and underground storage of the CO_2. Up to 300 million allowances in the New Entrant Reserve under the EU ETS will be made available to stimulate the construction and operation of up to 12 commercial demonstration projects by 2015. Moreover, the CCS demonstration constructions were also supported by €1,050 million from the European Economic Recovery Package (EERP), adopted in late 2008.

One of the EU demonstration CCS projects is located in Poland (Belchatow), the other one is a joint-venture with Germany. In the Bełchatów power plant, the CCS will cover 1/3 of a new block of 858 MW which is under construction. The EC already committed to €180 million for Bełchatów from the EERP. Together with additional funds from the New Entrant Reserve, the installation may be co-financed from the EU in 50 percent.

Based on the EU regulations, new large power plants with an output of more than 300 Megawatts (MW) need to be CCS-ready from 2015 onwards. In such circumstances, new market opportunities will arise for early adopters of implementable new technologies. Operators will need to assess whether storage sites are available, transport facilities are viable and if it is technically and economically feasible to retrofit the power station for CO_2 capture. Suitable space on the installation site should be guaranteed by the Member States' authorities. From 2015 onwards, new large power stations will have to store CO_2 underground.

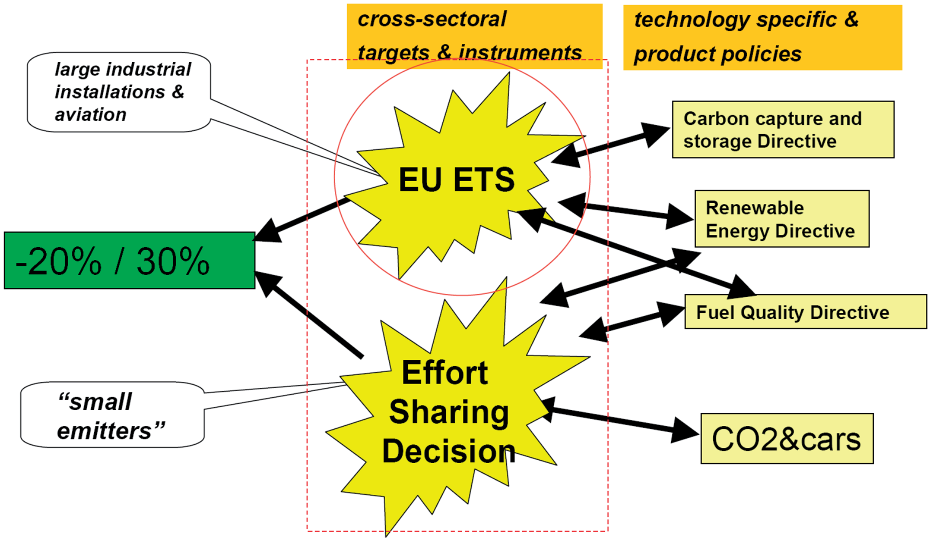
V. CO_2 emissions in transport and fuel quality

The EU legislation on reducing CO_2 emissions from cars set binding emissions targets for new passenger cars on an average level of 120g CO_2/km over the period 2012 to 2015, compared to current levels of 160 g/km. The car producers will be given interim targets in 2012-2015. Also, ultra low-carbon vehicles will be promoted in 2012-2015 (e.g. a car with CO_2 emissions of less than 50g CO_2/km will count as 3.5 cars in 2012-2013). The level of 130g CO_2/km is to be reached by improvements in vehicle motor technology, while a further 10g/km reduction through other technical improvements like better tires, for example. The long-term target is 95g CO_2/km by 2020 for the new car fleet. If emissions exceed the specific emission targets, they will have to pay fines, increasing progressively for every gram of excess CO_2 emission (flat fine of €95 for every gram will be introduced from 2019). (This regulation will contribute on average about one third of the reductions required from the non-ETS sectors. Small producers (below 10 thousand new cars per year) may apply to the EC for a derogation, while larger independent car producers (between 10-300 thousand new cars per year) may apply for an alternative target of reducing their average emissions by 25 percent as compared to 2007 levels.

Fuel quality directive places an obligation on suppliers to reduce greenhouse gases from the entire life cycle of transport fuels (from extraction or cultivation, including land-use changes, transport and distribution, processing and combustion) by 6 percent by 2020 from 2010 levels. The EC will prepare a review in 2012 and increasing the mandatory target will be considered. Additional reductions above the 6 percent target may be reached through the use of electric vehicles (excluding trains), the inclusion of CDM projects, and adoption of CCS technology in the production process.

The Member States should transpose the new directives into national law systems within two years. The implementation requires intensive organizational, legal and economical preparations of the authorities. No doubt the myriad of EU regulations will lead to a huge expansion of the bureaucratic and regulatory burden across Europe. Many of the instruments are overlapping (Figure 73). This is beyond the scope of this report, but the future doing business environment will be much complicated.

Figure 73. A myriad of policy instruments in the EU 2020 package



Source: Lock Alpine technical paper and European Commission.

Annex Table 21: EU ETS Phasing-in Process

	I Phase	II Phase	III Phase
Years covered	2005-2007	2008-2012	2013-2020
GHGs coverage	CO_2 only	CO_2 , N_2O, PFC	CO_2 , N_2O, PFC
Sectors covered	Power stations and other combustion installations, oil refineries, coke ovens, iron and steel, cement, glass, lime, bricks, ceramics, and pulp, paper and board. Sectors not covered in I Phase: petrochemicals, ammonia, aviation (2011 or 2012), aluminum, nitrous oxide (N_2O) from acid production, perfluorocarbon (PFC) from the aluminum sector.		
Emission Caps for ETS sectors	National target levels	National target levels	EU-wide, at 9 percent below 2005 level in 2013, declining linearly to 21 percent below 2005 levels in 2020
Auctions	Allowances allocated for free, a maximum of 5 percent of allowances on auctions	Allowances allocated for free, a maximum of 10 percent of allowances on auctions	At EU level, at least 50 percent of allowances on auctions, with transition option available for power sectors in the new EU Member States: maximum 70 percent of allowances can be allocated for free, but the sector will be covered by full auctioning in 2020. In other (heavy) ETS industries and EU wide, the phase out of free allowances will depend on risk of carbon leakage. Those exposed to significant risk of carbon leakage will be granted allowances for free until 2020 at the level of the benchmark of the best technology available. Those not subject to carbon leakage will be required to buy 20 percent of allowances in 2013, rising to 70 percent in 2020 and 100 percent in 2027.
Allocation of Allowances	By country, as specified in National Allocation Plans (NAPs), and approved by the European Commission		EU-wide. 90 percent of allowances to be auctioned with revenues distributed in proportion to 2005 emissions of the Member States, and 10 percent redistributed to MS with lower GDP per capita
Use of credits	Yes	Yes	Credits from the CDM and JI only from projects approved before 2012 and only through 2014. Additional use of credits if a new international agreement is reached
ETS reserve			5 percent of allowances for new market entrants, except in the electricity sector

Annex 2.

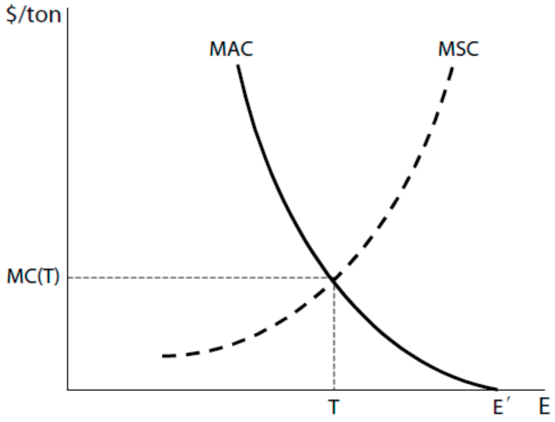
PRICES VERSUS QUANTITIES TO ACHIEVE A CARBON ABATEMENT GOAL

GHG emissions can be reduced either by applying a carbon tax, affecting the price of emission-producing goods and services, or by setting up a cap-and-trade system of emission allowances to control the quantity of emissions directly. Of course, both cannot be controlled at the same time. These instruments can be usefully compared on such characteristics as: transparency, operating (transaction) costs, public acceptability, dynamic efficiency, revenue and distributional issues, and international harmonization.[6] The case for the imposition of carbon pricing is strong and based upon the "polluter pays" principle first proposed by Pigou almost a hundred years ago. The list of economic arguments for the use of a price instrument for controlling carbon emissions is solid[7] and includes potential welfare gains. Nonetheless, the dominant policy choice seems to be the quantity instrument. For example, the European Commission made such a choice in the mid-2000s when it established the ETS. One driver of this decision was the political lesson learnt from the failure of the 1991 carbon tax proposals in the European Community (although carbon taxes were introduced successfully in Scandinavian countries in the early 1990s and some US states and Canadian provinces relatively recently).

Welfare implications of the choice between quantity and price targets under uncertainty can be analyzed using the following approach. In terms of economic efficiency, the choice between cap and trade and a carbon tax is important when the costs and benefits of emission controls are uncertain. Under certainty, the choice is indifferent because both instruments could lead to the same abatement at a given price. This is presented in graphical form in the Figure 74. However, under uncertainty the two instruments are not equivalent. Jacoby and Ellerman (2002)[8] argue that the better instrument is the one more likely to avoid a big mistake in the stringency of control imposed. For greenhouse gases, they claim, this is the price mechanism. This argumentation follows Weitzman (1974),[9] who argued that with uncertainty, the superior instrument depends on the relative sensitivity of the costs of emissions reduction, and of the benefits (i.e., cleaner air resulting from that reduction) as the level of emission control is varied.

The shapes of the curves in Annex 2 are as portrayed most frequently in the literature. Under certainty, the economically efficient abatement level is set by the intersection of MAC and MSC curves and it can be achieved equally by capping emissions at T or by a carbon tax equal to MC(T). The total cost of emissions abatement is the area between E' and T under the MAC curve.

Figure 74. Quantity target and price target under certainty



E	emissions
$/ton	cost per 1 ton CO_2 emissions
MAC	marginal abatement cost
MSC	marginal social cost (damages caused by E)
T	cap
MC(T)	carbon tax

Based on: Jacoby and Ellerman, 2002.

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[6] Pope and Owen claim that international harmonization provides the dominant reason why permits are more likely than taxes to succeed as a climate change regime. See more in: Pope, J., and A.D. Owen (2009), Emission trading schemes: potential revenue effects, compliance costs and overall tax policy issues, Energy Policy 37, 4595–4603.

[7] For example, J.E. Aldy and others discuss the design of carbon taxes at the domestic and international level and the choice of taxes versus a cap-and-trade system. There is a strong case for taxes on uncertainty, fiscal, and distributional grounds, though this critically hinges on policy specifics and how revenues are used (see more in: Aldy J.E., E. Ley, and I. Parry, A Tax-Based Approach to Slowing Global Climate Change, World Bank, PREMEconomics of Climate Change Discussion Paper No. 1, August 2008).

[8] Jacoby H.D., Ellerman A.D., The Safety Valve and Climate Policy, Report No.83, MIT Joint Program on the Science and Policy of Global Change, 2002.

[9] Weitzman, M.L., Prices vs. Quantities, Review of Economic Studies XLI, 477-91, October 1974.

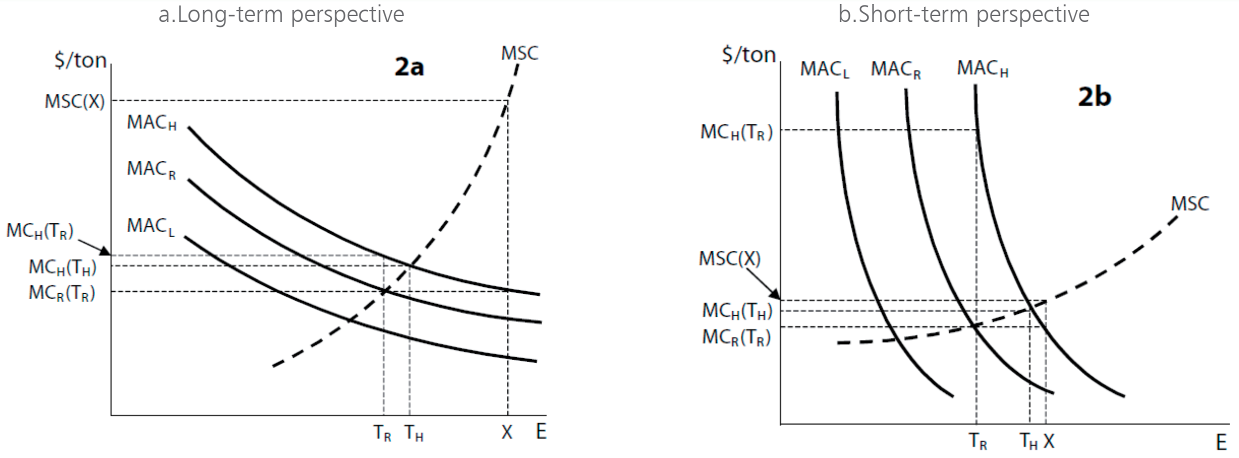
In practice, the shape and exact position of MAC and MSC curves is not known with certainty and they largely depend on the time perspective. While the cost curve or MAC can be estimated from the bottom up with engineering details on technologies captured through explicit step-functions of discrete abatement options, it remains sensitive to exogenous assumptions, for example, regarding fuel prices, and it is scenario dependent. The steepness of the MAC curve captures the ease of CO_2 abatement in production and consumption.

In case of the social cost (benefit) curve MSC, there is more uncertainty regarding its slope and position. One could argue that given the long-lasting impact of already accumulated carbon emissions in the atmosphere for future global temperature developments, or from the perspective of a small country, the social costs curve may be relatively flat. This would mean that any reduction in current emissions of such a country has no impact on social costs.

In the case of the MAC curve, moving along the curve from the right to the left, i.e., starting with smaller emissions reduction and opting for cheaper technologies in emission reduction, is less costly in the long term than the short term. In the long term, the MAC curve is relatively flat (laid out graphically in panel a. in Figure 75) compared to the short term (panel b. in Figure 75). In the longer term, it may be feasible to switch from a coal power plant to a nuclear power plant, for example, while such an option is not available in the short run. However, largely irrespective of the time horizon, some shocks may shift the MAC curve from its (true) reference position (MACR) downwards (to MACL)—for example, a positive technological shock in the energy sector. Or the curve may shift upwards (to MACH) if alternative technologies become more expensive compared to the reference technology, for example, if coal is the reference technology and its price falls.

Weizman (1974) proved that the rates at which the costs rise and benefits fall as emissions are reduced are critical in the instrument choice. If the cost-benefit relationship is as plotted in the left-hand panel (a), as emissions increase along the horizontal axis, the marginal cost of abatement falls relatively little compared to the marginal social costs which rise more rapidly. For example, this may be the case when the emissions are so high that they push significantly up the fat tail risk of catastrophic events. Suppose that the desired cap is TR and is aimed to be achieved by a tax of MCR(TR). Then, because of the ex ante uncertainty, it may turn out that the true MAC position is MACH. At price of MCR(TR), emissions will be X, far above the desired and optimal level of TH for MACH. In such a case, policymakers would be better off if they chose a quantity target of TR. Here a carbon tax is the inferior instrument because it translates into higher emissions than optimal (X rather than TH), while choosing a cap of a cap of TR would mean a small difference between the desired and achieved level (TH-TR). This happens because of the assumed slopes of the MSC and MAC curves. The rate of increase in MSC, as emissions rise, is greater than the rate at which MAC are falling.

Figure 75. Quantity target and price target under uncertai


a.Long-term perspective

b.Short-term perspective

Source: based on Jacoby and Ellerman, 2002.

In an alternative case, when the cost-benefit relationship is as plotted in the right-hand panel (b), the quantity would be an ineffective instrument in a welfare terms. A tax at MCR(TR) would be a better choice because emissions would remain close to the optimum level if it turns out that the MAC curve is different than MACR. If the cap TR were introduced and the true curve would be MACH, this would translate into a much higher marginal cost MCH(TR) than the corresponding marginal social cost.

The Macroeconomic Mitigation Options (MEMO) model, developed by the Warsaw-based Institute for Structural Research (IBS[10]) for this study, is a dynamic stochastic general equilibrium (DSGE) model specifically designed to analyze the effects of various GHG abatement policies on a small open economy. It is a large scale multisector DSGE model integrating typical DSGE features (real business cycle, imperfect competition) with typical CGE features (high disaggregation and sector detail). The model is innovative in its incorporation of energy and GHG emissions into a large scale DSGE model designed for country-level analysis. It includes the common assumptions of DSGE methodology, i.e., rationality of economic agents, homogeneity of households and firms in 11 sectors, as well as profit and utility maximization.

The economy, as described by the MEMO model, is presented in Figure 76. MEMO model block structure. It consists of several interrelated elements: households, private firms and the government. Households maximize their lifetime utility (welfare), and companies maximize profits. The government imposes taxes (CIT, PIT, VAT and wealth taxes) and spends money from the budget. Public expenditures include public consumption and investment. There are two countries in the model: Poland and the rest of the EU.

Model structure is divided into three main blocks: (1) households, (2) firms, and (3) government. Those blocks are interconnected one with another on three separate markets: (1) labor (2) capital, and (3) goods market. For the sake of simplicity, there is no banking sector and no money (therefore, no monetary policy) in the model. Households supply labor, decide on the level of their demand for consumption goods as well as for government bonds and firm stocks. Households communicate with producers on labor market where wages are negotiated and vacancies filled in the search and match process. This market is operated by a special intermediatory firm that buys labor from households and sells it to firms in eleven production sectors described later. In exchange for they work and savings they receive dividends and wages from firms and interest payments from government, paying at the same time taxes directly imposed on them by government. Firms produce final goods that are later consumed by households, re-invested by producers or utilized by government. Both production and consumption evoke CO_2 emission, that is modeled on sectoral and household level. In the production process, firms employ labor, capital, intermediate goods and energy. As they are owners of capital, and have some monopolistic power as well their profits are positive allowing them to pay dividend for their shareholders. Apart from it they also pay income and value added taxes to government. Government divides its tax income and EU funds subsidy into public investments, public consumption and social transfers to households for unemployed and retired.

Equilibrium in the goods market sets prices for consumption, investment and intermediate goods. Firms sell all types of goods (the production process is described broadly later on in the text). They also purchase materials and investment goods from other companies (both domestic and foreign) and utilize them as inputs in the production process. Furthermore, the latter may be bought by the government to improve economical environment for the firms and households. Companies' output and imported final goods are purchased by households as private consumption and by the government as public consumption.

The labor market is imperfectly competitive (or non-Walrasian), and wages are set by centralized negotiations between firms and unions somewhere above the market-clearing level. This generates unemployment. Moreover, there is a (costly) job search mechanism.

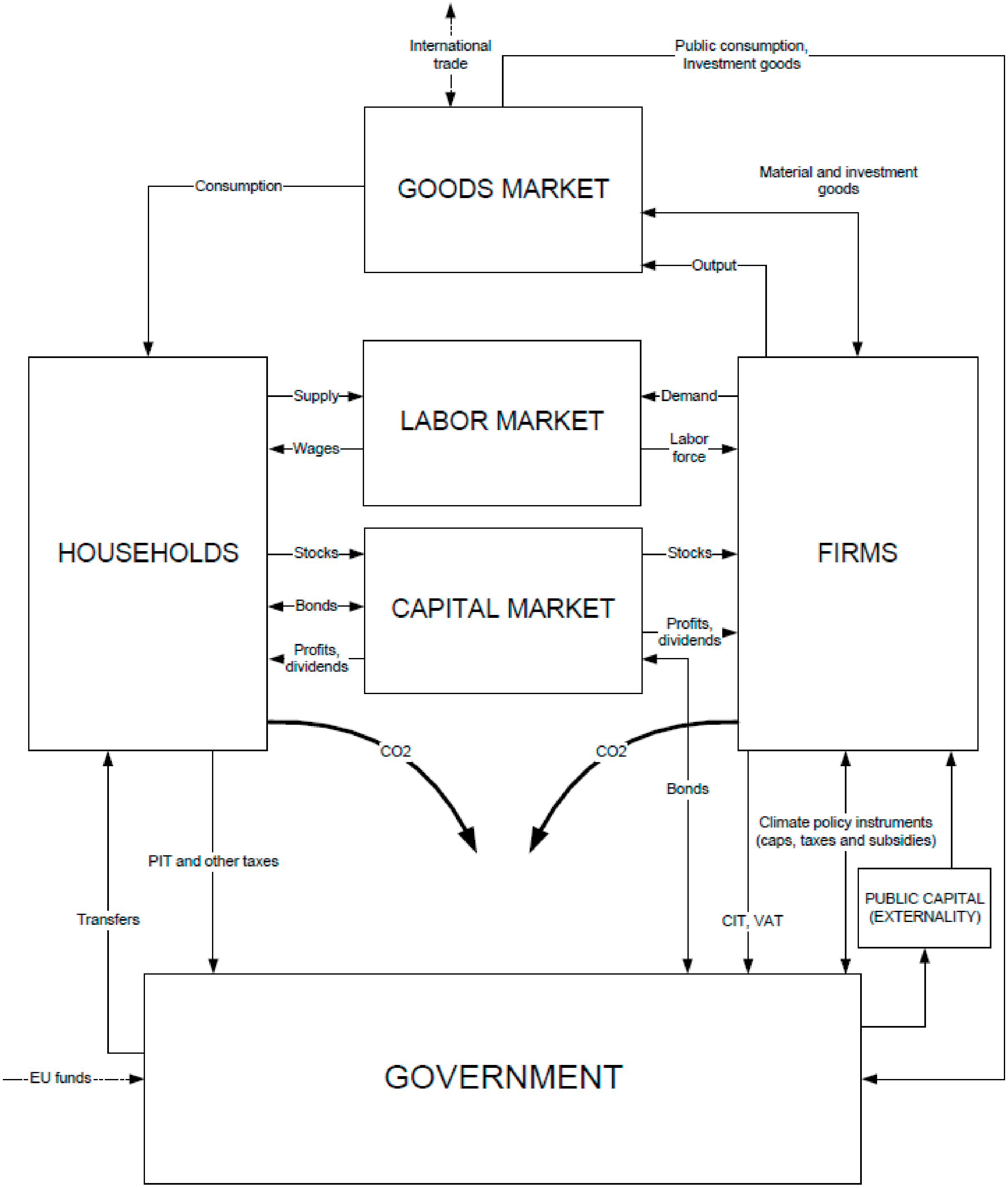
The capital market allows all types of economic agents to borrow through the issuance of bonds (debt). Furthermore, companies may share their profits with households by paying out dividends and raise capital by issuing stocks. Thus, the capital market allows for the flow of financing from households to firms and the smoothing of household consumption over time.

[10] IBS is Instytut Badan Strukturalnych, or the Institute for Structural Research, Warsaw, Poland.

Annex 3.

MEMO MODEL: DESCRIPTION OF THE MACROECONOMIC MITIGATIONS OPTIONS DSGE MODEL FOR POLAND

Figure 76. MEMO model block structure

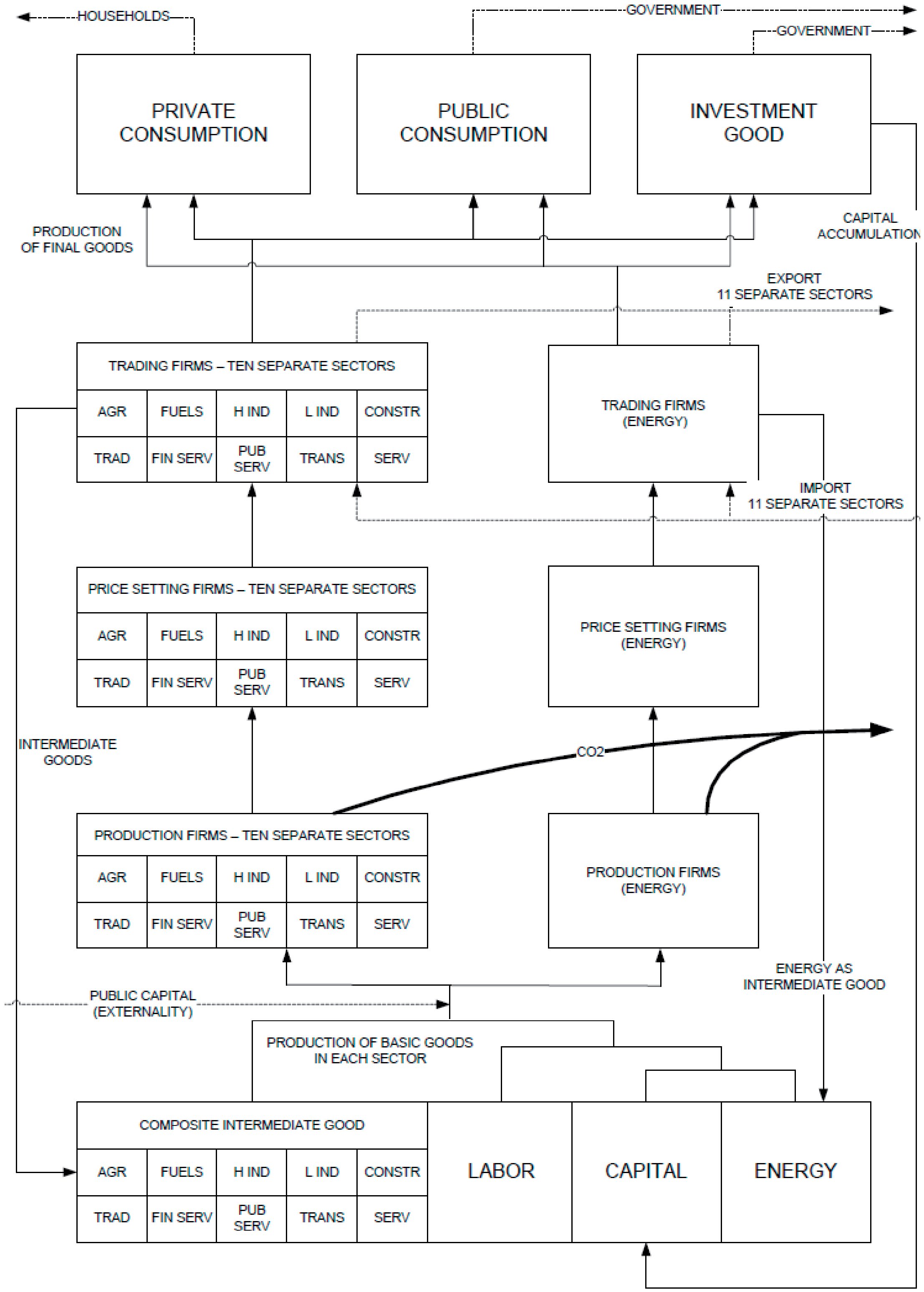


Source: *IBS technical paper.*

The economy is divided into eleven sectors: (1) agriculture and food, (2) light industry, (3) heavy industry, (4) mining and fuels, (5) energy, (6) construction, (7) trade, (8) transport, (9) financial services, (10) public services, and (11) other services. In each sector, firms produce goods using capital, labor and materials (including energy) as inputs. The structure of the production process is presented in Figure 77. MEMO model: production structure.

Production of basic goods is sequential, which means that inputs are combined (in mathematical terms) in a specific order: capital with energy first, then labor and, finally, other materials. Firms also benefit from external effects of investments in public capital undertaken by the government. Basic goods are then used in three subsequent stages of production (to produce final goods).

Figure 77. MEMO model: production structure



Source: IBS technical paper.

In the first stage, producing firms generate intermediate goods emitting GHGs to the atmosphere. The GHG emission level results from the amount of energy used by a firm and the energy intensity of the sector. The optimal levels of production and prices are set in line with the assumption of perfect competition among producers in this phase. Note that energy prices and GHG emission rights may be treated directly and indirectly (via incorporation into the prices of intermediate products) as a cost for the firm. Thus, negative externalities can be included in firms' profit-maximization.

In the second stage, prices are set under imperfect competition. Firms exert a degree of monopoly power, which is calibrated to achieve the actual domestic market prices of goods and services and the CIT revenues of the government.

In the third and last stage, trading firms purchase goods produced by domestic and foreign companies (where the foreign sector is the rest of the EU). Trading firms sell intermediate goods as: (1) intermediate goods used to produce basic goods, (2) private consumption to households, (3) public consumption to the government, (4) investment goods which are used by the government or by firms in production of basic goods, (5) export goods. The level of exports is determined by exogenous external demand and the current terms of trade.

The energy production process basically follows the same path as production in other sectors. The main difference results from not using energy as an intermediate good in production of basic goods. Instead, energy is combined with capital in the very beginning of the production process.

The MEMO model exhibits several specific features. Special focus has been put on issues concerning energy production and emission of GHGs. They are treated as a by-product of production and consumption. GHGs stemming from consumption are the result of demographic growth and households' energy intensity. Therefore, the model can consider changes in household preferences and the introduction of low-carbon facilities.

The model parameters are calibrated in accordance with the latest available macroeconomic data from EU KLEMS database.[11] These include a full input-output table for eleven economic sectors, labor market flows, detailed government accounts, emissions of GHGs, and other indicators. Of course, the exact method of calibration depends on the type of parameter. For instance, the level of employment is calculated directly from the data, while several elasticities are set on levels corresponding with results from available empirical surveys.

The details of the methodological strategy, modeling techniques, data, equations, and assumptions are available in the IBS technical paper.

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[11] The EU KLEMS database on productivity by industry for EU member states has a breakdown into contributions from capital (K), labor (L), energy (E), materials (M) and service inputs (S).

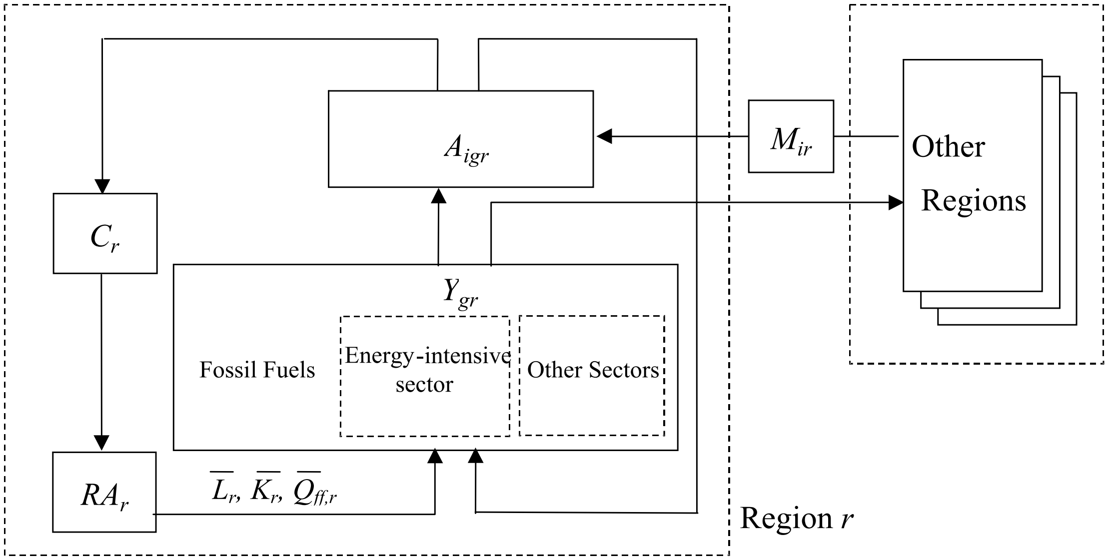
Annex 4.

ROCA MODEL: DESCRIPTION OF THE REGIONAL OPTIONS OF CARBON ABATEMENT MODEL FOR POLAND

The Regional Options of Carbon Abatement (ROCA) model, a country-level CGE model for energy and GHG mitigation policy assessment adapted to Poland, analyzes implementation of the EU 20-20-20 policy in the context of global policy scenarios, with an emphasis on spillover and feedback effects from international markets. The model has four countries/ regions; 8 sectors and 5 energy subsectors. It uses 2020 as the horizon. It includes market distortions such as existing taxes, and models hybrid energy production. Government spending (consumption) is held constant, with taxes adjusting to provide financing (or model closure). The base year is 2004.

Figure 78 provides a diagrammatic overview of the generic static multi-sector, multi-region CGE model framework. A representative agent RAr in each region r is endowed with three primary factors: labor $\overline{L}_r$, capital $\overline{K}_r$, and fossil-fuel resources $\overline{Q}_{ff,r}$ (used for fossil fuel production). Labor and capital are intersectorally mobile within regions but immobile between regions. Fossil-fuel resources are specific to fossil fuel production sectors in each region.

Figure 78. Diagrammatic overview of ROCA model framework



Source: Loch Alpine technical paper.

Domestic labor markets may exhibit frictions with equilibrium unemployment. Labor market rigidities are represented at the regional level through the specification of a wage curve. The wage curve reflects empirical evidence on the inverse relationship between real wages and the rate of unemployment (consistent with concepts of wage-bargaining as well as efficiency wage mechanisms). Since the equilibrium wage rate lies above the market clearing wage rate, unemployment results.

Production Ygr of commodity g, other than primary fossil fuels and electricity production, is captured by three-level nested constant elasticity of substitution (CES) cost functions that describe the price-dependent use of capital, labor, and energy in production (The index g comprises production outputs by sectors - indexed i - as well as the final demand components for private consumption, investment and public good provision). At the top level, a CES material composite trades off with an aggregate of energy, capital and labor subject to a constant elasticity of substitution. At the second level, a CES function describes the substitution possibilities between the energy aggregate and a value-added composite. At the third level, capital and labor substitution possibilities within the value-added composite are captured by a CES function, and different energy inputs enter the energy composite subject to a constant elasticity of substitution. In the production of fossil fuels, all inputs, except for the sector-specific fossil fuel resource, are aggregated in fixed proportions at the lower nest. At the top level, this aggregate trades off with the sector-specific fossil fuel resource at a constant elasticity of substitution. The latter is calibrated consistent with empirical estimates for the price elasticity of fossil fuel supply.

Given the paramount importance of the electricity sector with respect to CO_2 emission abatement, the standard representation of power production through a single CES production (cost) function is replaced by a bottom-up activity analysis characterization where several discrete generation technologies compete to supply electricity to regional markets. The price of electricity is then determined by the production costs of the marginal supplier. Power generation technologies respond to changes in electricity prices according to technology-specific supply elasticities. In addition, lower and upper bounds on production capacities can set explicit limits to the decline and the expansions of technologies.

Final consumption demand Cr in each region is determined by a representative agent who maximizes utility subject to a budget constraint with fixed investment (i.e., a given demand for the savings good). Consumption is given as a CES composite that combines consumption of an energy aggregate and a non-energy consumption bundle. Substitution patterns within the non-energy consumption bundle are reflected via a CES function; the energy aggregate in final demand consists of the various energy goods trading off at a constant elasticity of substitution.

Government provides a public good which is produced with commodities purchased at market prices. These expenditures are financed with tax revenues. The impact assessment of policy interference implicitly involves revenue-neutral tax reforms in order to provide a meaningful welfare comparison without the need to trade off private consumption and government consumption. This is done by keeping the amount of public good provision fixed and recycling any residual revenue lump-sum or through wage subsidies.

Bilateral trade is specified following the Armington approach of product heterogeneity, i.e., domestic and foreign goods are distinguished by origin.

CO_2 emissions are linked in fixed proportions to the use of fossil fuels with CO_2 coefficients differentiated by the specific carbon content of fuels. CO_2 emission abatement can take place by fuel switching (inter-fuel substitution) or energy savings (either by fuel-non-fuel substitution or a scale reduction of production and final demand activities). CO_2 emission abatement policies are introduced via an additional constraint that holds CO_2 emissions to a specified limit. Revenues from scarcity rents on CO_2 emission constraints accrue to the government in the respective region (or a collective agent such as the EU Commission which redistributes revenues according to some predefined formula).

Base-year data set

The model builds on the most recent GTAP dataset (version 7) with detailed accounts of regional production, regional consumption, bilateral trade flows as well as energy flows and CO_2 emissions for the base year 2004.[12] The dataset also features a variety of initial taxes. As is customary in applied general equilibrium analysis, base year data together with exogenous elasticities determine the free parameters of the functional forms. Elasticities in international trade and sectoral value-added are based on empirical estimates reported in the GTAP database. Substitution elasticities between production factors capital, labor, energy inputs and non-energy inputs (material) are taken from Okagawa and Ban (2008) who use most recent panel data across sectors and industries for the period 1995 to 2004.

Because of the availability of data in the GTAP dataset, this model tracks CO_2 emissions, which constitute around 80 percent of total GHG emissions in Poland. Since the EU energy and climate change policies focus in their application on CO_2 emissions stemming from fossil fuel combustion, this limitation of the ROCA model is not seen as a significant weakness.

The GTAP 7 database breaks down into 57 sectors and 113 regions or countries. The database can be flexibly aggregated towards a composite dataset. At the sectoral level, sufficient details on differences in factor intensities, degrees of factor substitutability and price elasticities of output demand must be incorporated in order to trace back the structural change in production triggered by policy interference. With respect to climate policy analysis, the composite database includes all major primary and secondary energy carriers: coal, crude oil, natural gas, refined oil products, and electricity. This disaggregation is essential in order to distinguish energy goods by CO_2 intensity and the degree of substitutability. In addition, the database allows the separation of CO_2 (energy) intensive industries which are generally most affected by emission control policies.

In order to capture international market responses to regional emission constraints and CDM supply options, analysis of international climate policy analysis requires the explicit representation of major industrialized regions as well as the developing world. Table 22 summarizes the sectors, commodities, and regions of the composite model database used for analysis of Poland.

[12] Badri and Walmsley (2008).

Table 22. ROCA model sectors and regions

Grouping of 57 Sectors and commodities	Grouping of 113 Countries and regions
Energy	Regions with Kyoto emission reduction pledges
Coal (COL) Crude oil (CRU) Natural gas (GAS) Refined oil products (OIL) Electricity (ELE)	Poland (PL) Rest of EU-27(EU-26) Remaining industrialized countries (A1)
Non-energy	Regions without emission pledges
Chemical industry (CRP) Air transport (ATP) Other transport (TRN) Non-metallic minerals (NMM) Iron and steel industry (I_S) Non-ferrous metals (NFM) Paper–pulp–print (PPP) Other manufactures and services (Y)	Developing countries (DC)

Source: Loch Alpine technical paper.

Forward calibration

The costs of complying with future emission constraints are directly linked to the structural characteristics of each particular economy exhibited in a hypothetical business-as-usual situation without such emission constraints.

A simple forward projection of the model from the 2004 base year to some target year with regional emission abatement pledges (e.g. 2020 in the case of the EU climate policy package) would involve calibration to a steady-state where all physical quantities (including CO_2 emissions) grow at an exogenous uniform rate while relative prices remain unchanged. The virtue of a steady-state baseline is that it provides a transparent reference path for the evaluation of policy interference. Any structural change in the counterfactual can be attributed to the new policy. Such a steady-state forward calibration, however, lacks policy appeal since it does not comply with official BAU projections.

In applied policy analysis, we are, however, typically confronted with projections for non-uniform growth rates and heterogeneous structural dynamics. Off-the-steady-state baseline projections may run against the high degree of endogeneity in economic variables that is one of the strengths of CGE models. The key challenge is to reconcile disparate and possibly contradicting values. For example, GDP growth estimates may be much higher than the projected increase in CO_2 emissions. A plausible reconciliation under business-as-usual then requires the assumption of 'autonomous' energy efficiency improvements triggered by baseline capital investments.

The ROCA model forward projection employs data from the US Energy Information Administration[13] which is complemented with more detailed information from the European Commission on Poland and the rest of the EU.[14] The business-as-usual scenario in 2020 is based on projected energy input demands across sectors, future GDP levels and the international price trajectory for crude oil.

Figure 79 illustrates the basic methodology along a CES production technology which is characterized by the continuous trade-off between energy (emission) inputs E and a composite non-energy input KLM. The CES technology is fully described by reference demand quantities E0 and KLM0, the reference price ratio p^0 and an exogenous elasticity of substitution σ. Along the baseline growth path, we take potential GDP and fossil fuel supply prices (denominated in terms of a consumption price index) as exogenous while computing all other variables as equilibrium values. This yields the energy/emission demand E* together with a consistent equilibrium price ratio p^*. However, the exogenous projections require baseline energy (emission) demand to match $\underline{E}$. We therefore impose $\underline{E}$ as re-calibrated reference demand at the new reference price ratio p^* and adjust reference demand quantities for KLM to be consistent

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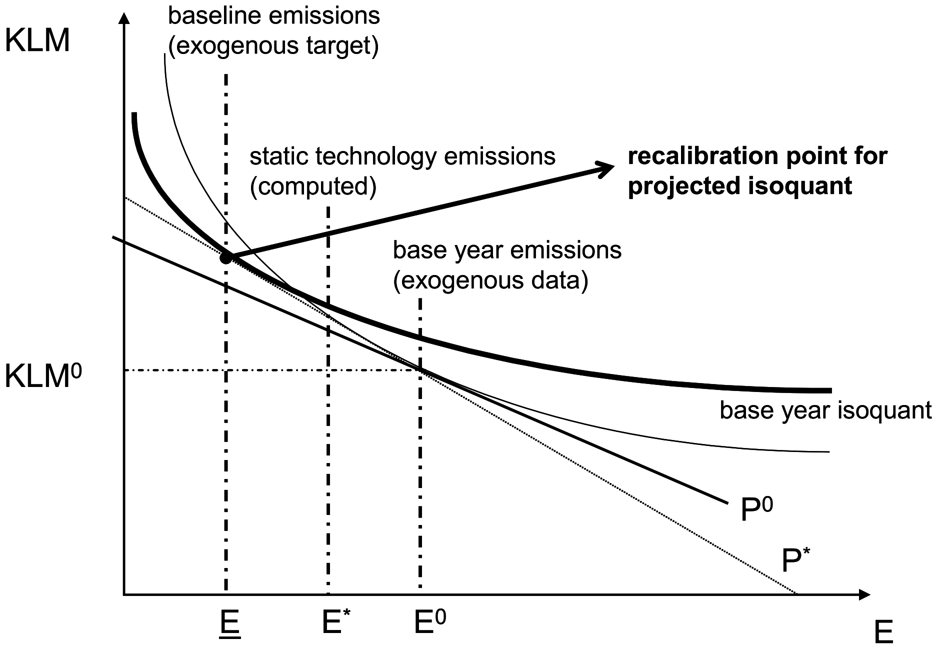
13 EIA (2009), International Energy Outlook, Energy Information Administration, US Department of Energy.

14 European Commission (2008), European Energy and Transport—Trends to 2030 (2007 update).

with the isocost-line. After a few iterations, this procedure yields a projected isoquant in exogenous energy/emission demands and residual other demands, thereby achieving a reasonable degree of micro-consistency of economic adjustments. At the recalibration point for the projected isoquant, the quantity of E is taken as exogenous whereas the quantities for KLM and the new reference prices are endogenously determined.

Figure 79. Calibration to exogenous emission projections



Source: Loch Alpine technical paper.

Annex 5.

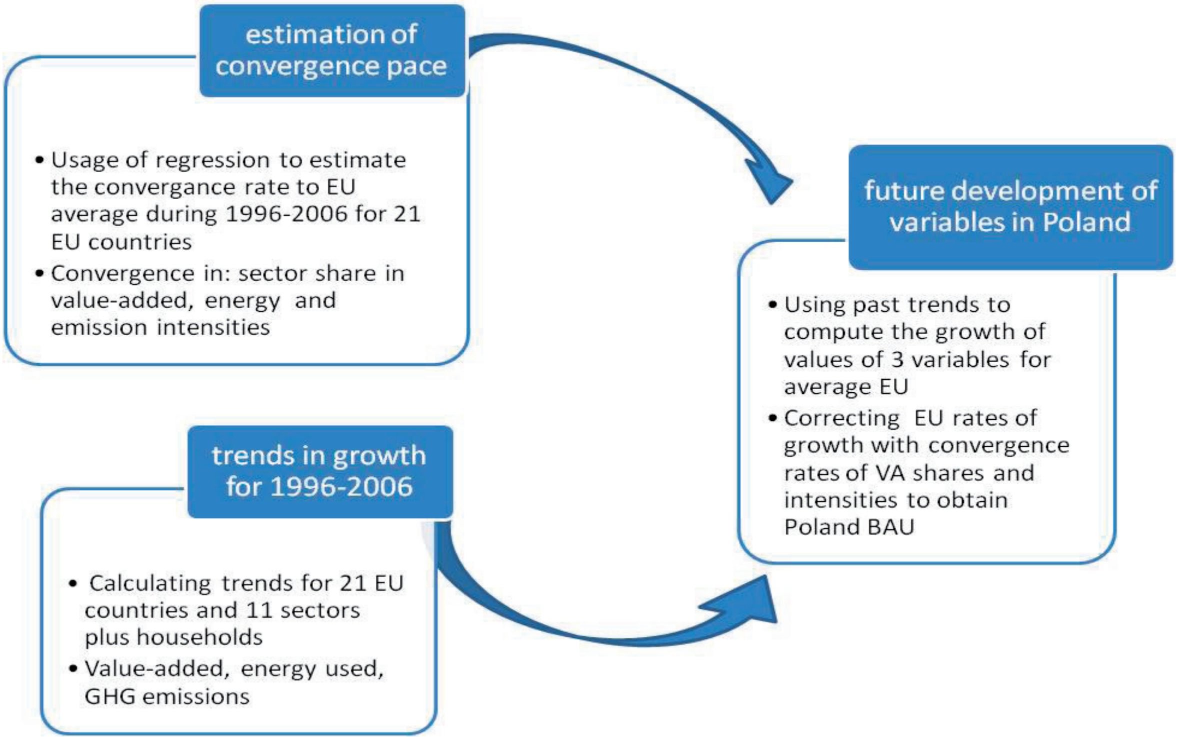
THE MEMO MODEL'S BUSINESS-AS-USUAL ESTIMATION TECHNIQUE

The reference scenario for the 11 sectors in the MEMO model for Poland and the rest of the EU were constructed using econometric convergence analysis.

A panel of annual data was extracted from the EUROSTAT database for 21 EU countries for 1996-2006. The countries were: Poland, Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Lithuania, Latvia, the Netherlands, Portugal, Slovakia, Slovenia, Spain, Sweden, and United Kingdom. The constructed database incorporates such variables as: value added expressed both in Purchasing Power Standard (PPS)[15] and volumes, energy consumption (in toe), energy intensity (in toe/GDP in PPS), GHG emission (in tCO_2e) and carbon intensity (in tCO_2e/GDP in PPS). The 11 sectors are: agriculture, heavy industry, light industry, energy, transportation, fuels, trade, construction, finance, public services and other services.

Standard regression techniques were applied to estimate the average convergence rates for all variables (see Figure 80 for a summary of this procedure). For example, the difference between each country and average EU shares of all sectors in total value added in 1996 and in 2006 is calculated. Next, for every sector, a regression is run of the 2006 shares on the 1996 shares to estimate the observed convergence rates in the sectoral structure between these two periods. Then, the average annual rate of growth of the every sector share is computed. A similar approach estimates the convergence rates of energy and emission intensities (although logarithms are used instead of shares). Then, the annual rates of growth of energy and emission intensities are calculated for all sectors.

Figure 80. MEMO model BAU estimation procedure



- Usage of regression to estimate the convergance rate to EU average during 1996-2006 for 21 EU countries
- Convergence in: sector share in value-added, energy and emission intensities

- Using past trends to compute the growth of values of 3 variables for average EU
- Correcting EU rates of growth with convergence rates of VA shares and intensities to obtain Poland BAU

- Calculating trends for 21 EU countries and 11 sectors plus households
- Value-added, energy used, GHG emissions

Source: IBS technical paper.

Table 23 presents the convergence rates calculated for the EU21. Agriculture's value-added share converged fastest in the dataset, while the transport, fuels and construction sectors also had high rates. Almost all of the energy intensities converge at similar rates, with the exceptions of light industry and the fuel sector. For these sectors, the 21 countries did not converge during 1996-2006, perhaps due to rising diversity in the energy-mix composition in the fuels sector (which includes hard coal, lignite, oil, and gas). The last category – emission intensity – is characterized by much higher dispersion of convergence rates between sectors, with the fastest convergence process in light industry and transport and the slowest in households, financial services, and public services.

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[15] The purchasing power standard (PPS) is the name given by EUROSTAT to the artificial currency unit in which the purchasing power parity of GDP is expressed for EU member states.

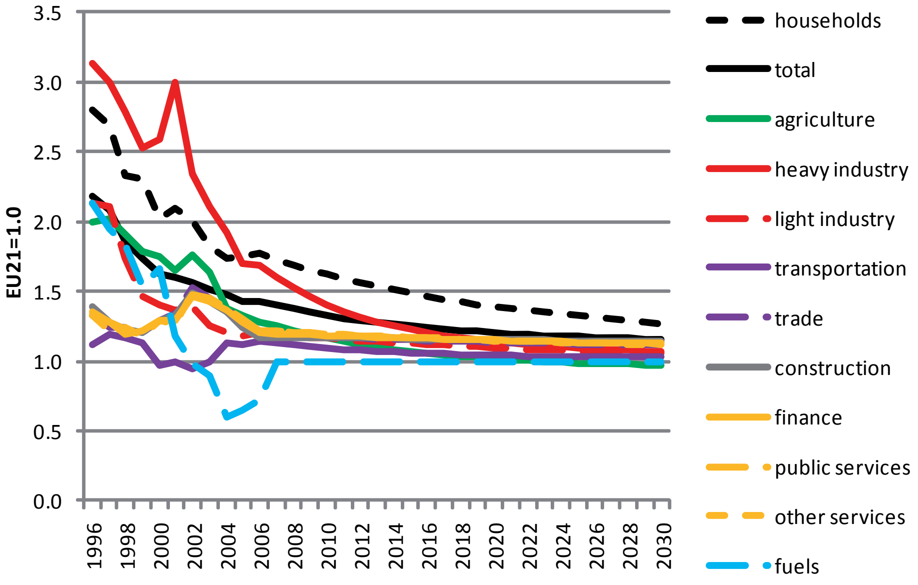
Table 23. MEMO BAU estimated convergence rates, EU21 during 1996-2006

	Value Added	Energy intensity	Emission intensity
Total	N/A	0.059	0.040
Agriculture	0.085	0.056	0.025
Heavy industry	0.015	0.075	0.029
Light industry	0.005	0.025	0.076
Energy	0.023	N/A (energy is not consumed)	0.021
Transportation	0.058	0.072	0.077
Fuels	0.025	-Inf (no convergence observed)	0.022
Trade	0.001	0.060	0.044
Construction	0.047	0.060	0.049
Finance	0.010	0.060	0.013
Public services	0.005	0.060	0.012
Other services	0.005	0.060	0.035
Households	N/A	0.049	0.007

Note: The values are annual averages of beta convergence coefficients in sectors for 21 EU countries. A higher value indicates faster convergence towards the average. For example, for value added, 8.5 percent convergence rate in agriculture means that agriculture's share of value-added was converging by 8.5 percent per year towards the EU21 average.
Source: IBS technical paper.

The same phenomenon of convergence described in the main text for value added can be observed in Figure 81 which depicts the projected time path of the ratio of energy intensity in 11 sectors in the Polish economy to the average energy intensity in the same sectors in EU.

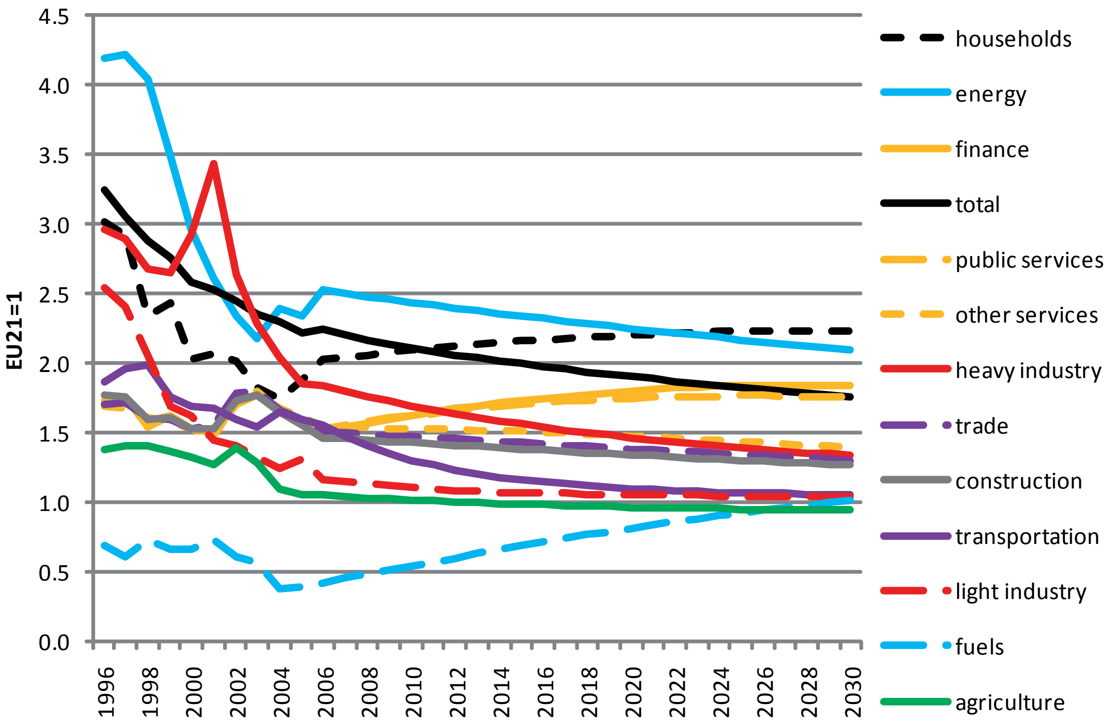
Figure 81. MEMO BAU projection of energy intensity in Poland



Source: IBS technical paper.

The last set of variables in the MEMO BAU scenario are GHG emissions in 11 sectors of the economy and households. Starting from the projection of emission intensities, which is a ratio of GHG emissions to value-added in a given sector, GHG emission levels depend on the energy consumption. Therefore, emission convergence is related to the catching-up process in the VA structure and energy intensity sector by sector (Figure 81 and Figure 82). While emission intensities are generally converging, for households, finance and public services it is not the case, because of the faster convergence in the VA structure than in the energy intensity. It does not violate or contradict the assumption on convergence in emission intensities. If the forecast window is extended to a much longer period of time these "untypical" behaviors would disappear, i.e., these sectors would approach the EU average despite their slower pace of energy intensity convergence.

Figure 82. MEMO BAU projection of GHG emission intensities in Poland



Source: IBS technical paper.

Annex 6.

THE ROCA MODEL: DETAILED SIMULATION RESULTS

Outcome indicator		BAU	Main scenario	Flexible emissions trading	Flexible trading & offsets	Renewables target	Wage subsidy	Unrestricted nuclear	Restricted gas	Free 30% allowances	Free 70% allowances	Top-down power sector	Small open economy
Real GDP (% change from BAU)													
Poland			-1.4	-1.16	-0.28	-1.02	-0.98	-1.12	-1.02	-1.46	-1.4	-1.4	-1.74
EU			-0.55	-0.41	-0.08	-0.37	-0.42	-0.45	-0.54	-0.56	-0.55	-0.54	
A1			-0.28	-0.28	-0.25	-0.27	-0.2	-0.28	-0.28	-0.28	-0.28	-0.28	
DC			-0.11	-0.09	-0.08	-0.09	-0.09	-0.1	-0.1	-0.11	-0.11	-0.11	
Welfare implications (% HEV)													
Poland			-0.94	-0.86	-0.18	-0.7	-0.31	-0.59	-1	-0.95	-0.96	-0.67	-1.47
EU			-0.29	-0.26	-0.03	-0.25	-0.05	-0.28	-0.3	-0.29	-0.28	-0.2	
A1			-0.2	-0.18	-0.16	-0.19	-0.07	-0.2	-0.2	-0.2	-0.2	-0.19	
DC			-0.14	-0.11	-0.08	-0.14	-0.11	-0.14	-0.14	-0.14	-0.14	-0.14	
Unemployment (change in percentage points, relative to BAU unemployment rate)													
Poland			0.53	0.41	0.1	0.35	-0.39	0.37	0.55	0.53	0.52	0.44	0.49
EU			0.17	0.12	0.03	0.04	-0.07	0.16	0.17	0.17	0.17	0.14	
Output of energy-intensive and trade-exposed sectors (% from BAU)													
Poland			-2.66	-2.82	-0.29	-1.13	-2.08	-1.86	-2.85	-2.4	-2.05	-1.94	-4.42
EU			-0.73	-0.78	0.2	0.14	-0.55	-0.66	-0.74	-0.64	-0.51	-0.37	
Electricity price (% change from BAU)													
Poland			20.1	26.2	5.5	3	20.1	9.2	22.4	20.2	20.3	13	21.5
EU			9.7	12.6	2.6	-7.1	9.8	8.7	9.9	9.7	9.8	3.9	
Technology shares (in % from total)													
Poland	coal	84.1	73.5	70.2	81.9	75.6	73.3	50.7	78.9	73.4	73.4		73.5
	gas	5.1	11.8	14	6.4	6.2	12	6.9	5.8	11.8	11.9		11.5
	oil	0.9	1.1	1.1	1	1	1.1	1	1.1	1.1	1.1		1.1
	nuclear	5.2	5.9	6	5.4	5.5	5.8	35.5	5.9	5.9	5.9		6
	renewable	4.5	7.8	8.7	5.3	11.7	7.8	5.9	8.2	7.8	7.8		7.9
EU	coal	20.1	12.1	10.6	18.2	11.6	12	12.8	12	12.1	12.1		20.1
	gas	29.7	31.2	30.9	30.2	24.8	31.3	31.2	31.3	31.3	31.3		29.7
	oil	3.6	3.7	3.7	3.6	3.4	3.7	3.7	3.7	3.7	3.7		3.6
	nuclear	25.5	26.3	26.6	25.6	20.2	26.2	26.2	26.3	26.3	26.3		25.5
	renewable	21.2	26.7	28.2	22.4	40	26.8	26.1	26.7	26.7	26.7		21.2

Outcome indicator		BAU	Main scenario	Flexible emissions trading	Flexible trading & offsets	Renewables target	Wage subsidy	Unrestricted nuclear	Restricted gas	Free 30% allowances	Free 70% allowances	Top-down power sector	Small open economy
CO$_2$ values (US$ per ton of CO$_2$)													
Poland	ETS		29.7	36.4	7.9	10.7	30.1	26.9	30.1	29.8	29.8	22	29.7
	non-ETS		87.2	36.4	7.9	86.6	91.3	88.3	87.4	87.3	87.3	87.8	67.6
EU	ETS		29.7	36.4	7.9	10.7	30.1	26.9	30.1	29.8	29.8	22	
	non-ETS		81.9	36.4	7.9	79.6	84	81.8	81.9	82	82.1	81	
A1			19.1	19.1	18.6	18.8	19.3	19	19.1	19.1	19.1	19	
DC			1.1	1.1	1.9	1	1.1	1.1	1.1	1.1	1.1	1.1	
CO$_2$ reduction (% from BAU)													
Poland			-20.1	-19.7	-4.9	-15.8	-19.9	-24.2	-23.3	-18.4	-20	-20	-21.2
EU			-14.7	-14.7	-2.8	-15.1	-14.7	-14.3	-14.4	-14.8	-14.7	-14.7	
A1			-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	-16.5	
DC			-0.8	-0.8	-3.3	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	

Note: CO$_2$, not GHG reduction. The central welfare indicator is the so-called Hicksian equivalent variation (HEV) in income which denotes the amount which is necessary to add to (or deduct from) the benchmark income of the representative consumer to enjoy a utility level equal to the one in the counterfactual policy scenario on the basis of ex-ante relative prices. Generally, the change in HEV can be interpreted as the change in real income and real consumption. For example, in the Main scenario, the HEV deviation from BAU of 0.94 percent for Poland indicates that the representative household in Poland loses roughly 1 percent of income as a consequence of GHG emission abatement. See Table 8 for definitions and description of scenario.

Source: Loch Alpine technical paper; ROCA model simulations; World Bank staff calculations.

Annex 7.

GHG ABATEMENT LEVERS IN POLAND GROUPED BY MICRO-PACKAGE

GHG ABATEMENT LEVERS IN POLAND
GROUPED BY MICRO-PACKAGE

Low-carbon energy supply	Chemical processes	Industry CCS and distribution maintenance
Biomass dedicated Biomass co-firing Coal integrated gasification combined cycle (IGCC) Gas CCS new built Gas CCS new built with enhanced oil recovery (EOR) Gas conventional Geothermal Nuclear On shore wind Off shore wind Small hydro Solar concentration Solar photovoltaic (PV)	Catalyst optimization, energy, level 1-3 Catalyst optimization, process, level 1-3 Ethylene cracking, new build and retrofit Process intensification, energy, level 1-3 Process intensification, process, level 1-3	Carbon capture and storage (CCS), iron and steel CCS ammonia, new build and retrofit CCS direct energy use in chemical plants, new build and retrofit CCS cement, petroleum and gas, new build and retrofit Distribution maintenance to reduce leakage,petroleum and gas Post combustion CCS-retrofit, cement
Agriculture interventions	Mixed energy/fuel efficiency	Fuel efficiency (1)
Improved agronomy practices (e.g. crop varieties and rotations) Improved cropland nutrient management (e.g. timing, fertilizers) Degraded land restoration Improved grassland management (e.g. irrigating, fire management) Grassland nutrient management (e.g. better fertilization) Livestock feed supplements Livestock - anti-methanogen vaccine Organic soils restoration (e.g. avoiding the drainage of soils) Reduced tillage of the ground and reduced residue removal/burning	Aggregated new build efficiency package, commercial Buildings (improved building design, orientation, insulation) Retrofit building envelope, commercial (improved air tightness and insulation) Retrofit Heating, Ventilation, Air Conditioning (HVAC) controls, commercial (adjustment for building occupancy) Retrofit HVAC, commercial (installing highest efficiency system)	Transport, Heavy-Duty Vehicles (HDVS), bundle D1-D4 (rolling resistance reduction, aerodynamics improvement) Transport, Light-Duty Vehicles (LDVS), bundle D1-D4, diesel, (downsizing, weight-reduction, improvements in AC and aerodynamics, low rolling resistance tires)
Fuel efficiency (2)		

Upstream oil and gas production, behavioral changes and improved maintenance & process control Downstream oil and gas production, behavioral and procedural changes Cement, clinker substitution by other mineral components Iron and steel, co-generation - new build and retrofit Iron and steel, coke substitution, new build and retrofit Waste, composting new waste More energy efficient new builds in upstream oil and gas production Chemicals, fuel shift from coal and oil to gas and Biomass, new build and retrofit Downstream oil and gas production, improved maintenance and process control Midstream gas transport and storage, improved maintenance on compressors	Chemicals, motor systems, new build and retrofit Midstream gas transport and storage, improved planning Midstream gas transport and storage, replace compressor seals Recycling new waste Residential buildings, retrofit HVAC - gas/oil heatingIron and steel, smelt reduction, new build and retrofit First generation biofuels Second generation biofuels Waste, landfill gas direct use	Transport, Light-Duty Vehicles (LDVS), internal combustion engine (ICE) fuel efficiency improvements – gasoline, bundle G1-G4 Transport, Medium-Duty Vehicles (MDVS), energy efficiency, bundle D4 Transport, Medium-Duty Vehicles (MDVS), bundle G1-G4(rolling resistance reduction, aerodynamics improvement, conventional ICE improvement) Transport, LDVS, compressed natural gas (CNG) vehicle Transport, LDVS, diesel – full hybrid Transport, LDVS, diesel – plug-in hybrid Transport, LDVS, gasoline – full hybrid Transport, LDVS, gasoline – plug-in hybrid Transport, LDVS, electric vehicle
Energy efficiency		
Residential buildings, aggregated new build efficiency package (improved building design, insulation, high efficiency HVAC) Appliances in commercial buildings Appliances in residential buildings Iron and steel: direct casting, new build Iron and steel, energy efficiency I&II (general): better maintenance, improved process flow, more efficient equipment Downstream oil and gas production, co-generation Downstream oil and gas production, efficiency measures (waste heat recovery, replacement of boilers, heaters, turbines, motors)	Residential and commercial buildings: switch compact fluorescent lights (CFLs) to light emitting diodes (LEDs) Residential and commercial buildings: switch incandescent bulbs to LEDs Commercial buildings: replace inefficient T12/T8 bulbs to super T8/T5 bulbs Commercial buildings: new build and retrofit lighting controls (dimmable ballasts, photo-sensors)	Residential buildings: insulation retrofit building package,level 1-2 Residential buildings: retrofit HVAC - electric resistance heating to electric heat pump; and retrofit HVAC maintenance Waste - landfill gas electricity generation Cement: waste heat recovery Chemicals, combined heat and power (CHP), new build and retrofit Residential buildings: water heating- replacement of gas and Electric heaters

Note: See Annex 10 for key assumptions for each lever.
Source: McKinsey technical paper, World Bank staff.

Annex 8.

THE MIND MODULE AND OPTIMIZATION OF ENERGY SECTOR COMPOSITION

The MIND algorithm is based on the assumption that a government intervenes on the market in order to achieve certain reduction target. This intervention can take a form of a new/higher tax on firms producing coal energy, or the cap on prices of emissions of CO_2 rights and transfers. The subsidies basically come from the addition tax and revenues from selling emission allowances. The target is set ambitiously and assumes 50 percent reduction of CO_2 emissions comparing to BAU in 2030.

The MIND module determines if an energy mix scenario is optimal if it allows the government minimizes its loss function which includes:

- the upward deviation of the reduction from the target value. As it is costly for government to finance reduction it does not want to achieve higher reduction than it is necessary
- the increase in costs relatively to the BAU scenario.

The loss function takes a following form:

$$\mathbf{L} = \mathbf{w}_{\mathbf{CO2}} * \left(\frac{\mathrm{CO2}_{\mathbf{optimal}}}{\mathrm{CO2}_{\mathbf{target}}} - \mathbf{1}\right)^{\mathbf{2}} + \mathbf{w}_{\mathbf{cost}} * \left(\frac{\mathrm{cost}_{\mathbf{optimal}}}{\mathrm{cost}_{\mathbf{BAU}}}\right)^{\mathbf{2}}$$

where $\mathbf{W}_{\mathbf{CO2}}$ and $\mathbf{W}_{\mathbf{COST}}$ are weights, and the weight attributed to the fulfillment of the abatement target is significantly higher than to the cost target. For example, it could be 10:1, which would suggest that the government is determined to meet the target at any cost

Individual scenarios are either set as the instances of alternative mitigation policies or as the shifts of optimal in a given direction (sensitivity analysis). Thus, in most of them we alter the government preferences with respect to abatement technologies. To assess them quantitatively we compute net present values (NPV) of all 17 types of energy plants under consideration. Doing this we draw from the engineering micro database which we summarize below. We made some changes in the original data in order to update it and make them comparable with EUROSTAT statistics. Specifically, we set gas prices at much lower level in line with the recent developments on the natural gas spot markets. The optimal scenario based on the historical high gas prices is specified as a separate case.

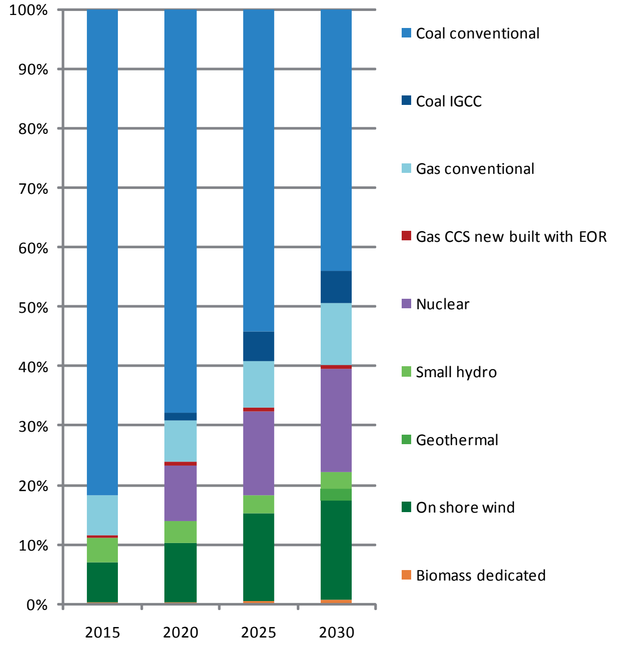
Apart from establishing the optimal scenario which is a low gas price scenario and serves later as a reference scenario, we also consider twelve alternative energy mix scenarios (see Table 24 and Annex 10): a low carbon scenario which meets the EU 2020 target for CO_2 emission reduction in 2020, and a 30 percent reduction by 2030 as compared to 1990; a more ambitious low carbon scenario of 30 percent reduction by 2020 in the EU; a "Delayed Action" scenario in which the Government follows the BAU for the next five years and then commits to a low carbon scenario; and several scenarios which assume an acceleration in the implementation of technologies like renewable energy, CCS, nuclear power, and natural gas by increasing their market penetration by 20 percent relative to the reference scenario.

In the following tables, we present short description of each of chosen scenarios together with a comparison of their key economic characteristics.

Table 24. MEMO model: sensitivity analysis of twenty percent deviation from optimal scenario

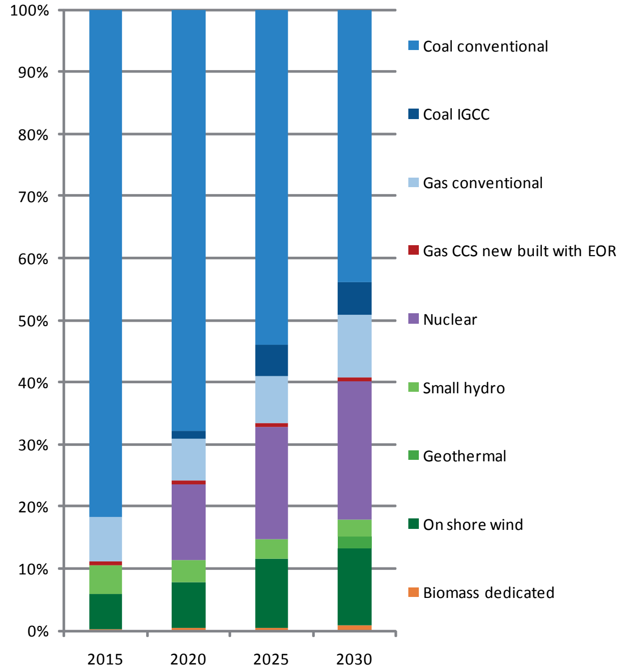
Simulation A: 20 percent shift to Wind + Solar / Wind + Biomass

This scenario is a variation of Wind + Solar scenario; however, very similar features are displayed by the variation of Wind + Biomass scenario. In both scenarios, the shares of energy produced from renewable sources is increased by 20 percent compared to the optimal scenario. Since the shares of solar and biomass in the optimal case are zero (because they are very expensive), the scenarios in which wind is combined with one of them are hardly distinguishable. As a consequence, the main difference between this scenario and optimal one is the slight increase in onshore wind capacities. To achieve it we had to violate our constraints as wind plants are used up to their constraints in the optimal case as they are relatively cheap and do not pollute. Therefore, this scenario is not fully comparable with the (constrained) optimal but still can serve as an illustration of the impact of the increased production from some renewable sources.



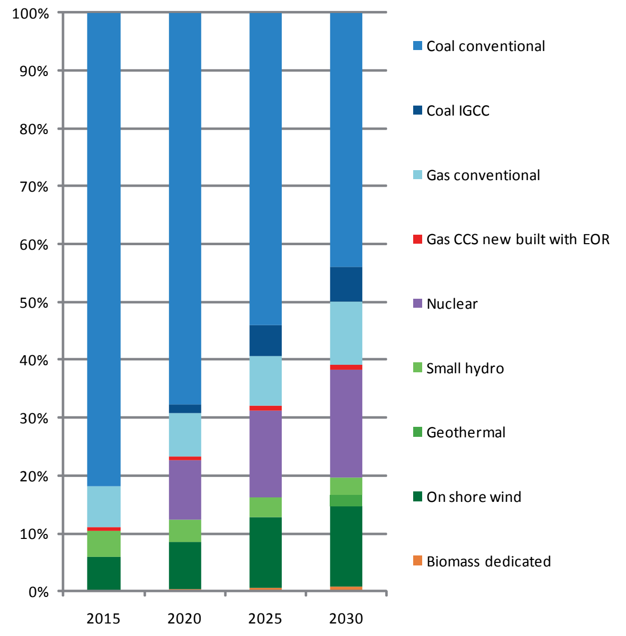
Simulation B: 20 percent shift to Nuclear

This scenario is variation of the reference scenario. In this case we relax the upper limit constraint on new nuclear plants capacity, assuming that the share of nuclear energy in total mix will be 20 percent higher than in the reference scenario.



Simulation C: 20 percent shift to CCS

In this scenario similarly to other "sensitivity analysis" scenarios we deviate by 20 percent from the reference optimal energy mix towards the CCS plants. It follows that small increase in the energy produced with CCS increases the average cost of government to 2 845 m PLN. ensuring the reduction of CO_2 emission at the level of 49,77 percent. These values are just a little bit different from those obtained in the optimal scenario. It is the result of the low base – CCS is hardly used in the optimal case.



Source: IBS technical paper, MIND module simulations

If we ignore the packages prepared within for the sensitivity exercise, it appears that only the unconstrained gas scenario performs better than the optimal (reference) scenario. It is, however, unable to deliver the desired level of CO_2 abatement both in 2020 and 2030 and therefore violates one of the important constraints. For 2030, the 20 percent shift to Wind-Biomass and 20 percent shift to Wind + Solar also perform slightly better than the reference case because they require lower government subsidy and investment. However this can be achieved if the original technology constraint is validated (see Table 25).

Table 25. Macroeconomic impact of alternative energy packages

Closure	Scenario	GDP change (in % vs BAU)				GDP elasticity vs GHG abatement			
		2015	2020	2025	2030	2015	2020	2025	2030
Public consumption	Reference (low gas price)	-0.15	-1.68	-1.31	-0.95	-0.04	-0.16	-0.08	-0.05
	Wind + Solar	-2.33	-3.66	-4.73	-3.42	-0.61	-0.37	-0.29	-0.17
	Wind + Biomass	-1.91	-5.03	-2.94	-2.43	-0.94	-0.58	-0.19	-0.14
	Gas (low gas price)	0.03	-0.45	-0.93	-0.13	0.01	-0.07	-0.07	-0.01
	CCS	-0.89	-3.53	-3.16	-2.52	-0.41	-0.39	-0.20	-0.13
	Nuclear	0.09	-2.07	-1.58	-1.37	0.05	-0.25	-0.10	-0.07
	Delayed action	0.12	-0.92	-1.91	-4.19	2.01	-0.36	-0.40	-0.30
	Ministry of Economy	-1.16	-1.78	-6.15	-2.78	-0.31	-0.18	-0.34	-0.13
	Optimal (high gas price)	-0.50	-2.08	-1.91	-1.29	-0.15	-0.20	-0.11	-0.06
Closure	Scenario	2015	2020	2025	2030	2015	2020	2025	2030
Social transfers	Reference (low gas price)	-0.06	-1.23	-0.89	-0.71	-0.02	-0.12	-0.06	-0.04
	Wind + Solar	-1.63	-2.53	-3.37	-2.42	-0.42	-0.26	-0.21	-0.12
	Wind + Biomass	-1.20	-3.34	-1.54	-1.79	-0.58	-0.38	-0.10	-0.10
	Gas (low gas price)	0.10	-0.26	-0.58	-0.02	0.04	-0.04	-0.05	0.00
	CCS	-0.75	-2.19	-1.91	-1.82	-0.34	-0.24	-0.12	-0.10
	Nuclear	0.10	-1.63	-0.99	-1.06	0.06	-0.20	-0.06	-0.05
	Delayed action	0.13	-0.72	-1.44	-3.18	1.77	-0.28	-0.30	-0.23
	Ministry of Economy	-0.68	-1.14	-4.55	-1.86	-0.18	-0.12	-0.25	-0.09
	Optimal (high gas price)	-0.37	-1.54	-1.33	-1.00	-0.11	-0.15	-0.08	-0.05
Closure	Scenario	2015	2020	2025	2030	2015	2020	2025	2030
VAT	Reference (low gas price)	-0.14	-1.13	-0.78	-0.73	-0.04	-0.11	-0.05	-0.04
	Wind + Solar	-1.63	-2.56	-3.14	-2.55	-0.40	-0.25	-0.19	-0.13
	Wind + Biomass	-1.20	-3.13	-1.66	-1.94	-0.52	-0.34	-0.11	-0.11
	Gas (low gas price)	0.07	-0.29	-0.39	-0.07	0.03	-0.04	-0.03	0.00
	CCS	-0.87	-1.98	-1.91	-1.99	-0.37	-0.21	-0.12	-0.10
	Nuclear	-0.02	-1.54	-0.90	-1.12	-0.01	-0.18	-0.06	-0.06
	Delayed action	0.06	-0.75	-1.37	-3.12	0.56	-0.28	-0.28	-0.22
	Ministry of Economy	-0.70	-1.16	-3.90	-2.12	-0.18	-0.12	-0.21	-0.10
	Optimal (high gas price)	-0.45	-1.49	-1.19	-1.08	-0.13	-0.14	-0.07	-0.05
Closure	Scenario	2015	2020	2025	2030	2015	2020	2025	2030
PIT	Reference (low gas price)	-0.16	-1.33	-0.92	-0.89	-0.05	-0.12	-0.06	-0.04
	Wind + Solar	-1.81	-2.98	-3.77	-2.92	-0.40	-0.28	-0.22	-0.14
	Wind + Biomass	-1.43	-4.31	-1.98	-2.25	-0.51	-0.42	-0.13	-0.12
	Gas (low gas price)	0.03	-0.37	-0.54	-0.19	0.01	-0.06	-0.04	-0.01
	CCS	-0.69	-2.64	-2.37	-2.34	-0.27	-0.27	-0.14	-0.12
	Nuclear	0.06	-1.80	-1.07	-1.34	0.03	-0.21	-0.07	-0.07
	Delayed action	0.08	-0.81	-1.44	-3.56	0.58	-0.29	-0.28	-0.25
	Ministry of Economy	-0.89	-1.37	-5.12	-2.43	-0.22	-0.14	-0.27	-0.11
	Optimal (high gas price)	-0.45	-1.66	-1.40	-1.27	-0.13	-0.15	-0.08	-0.06

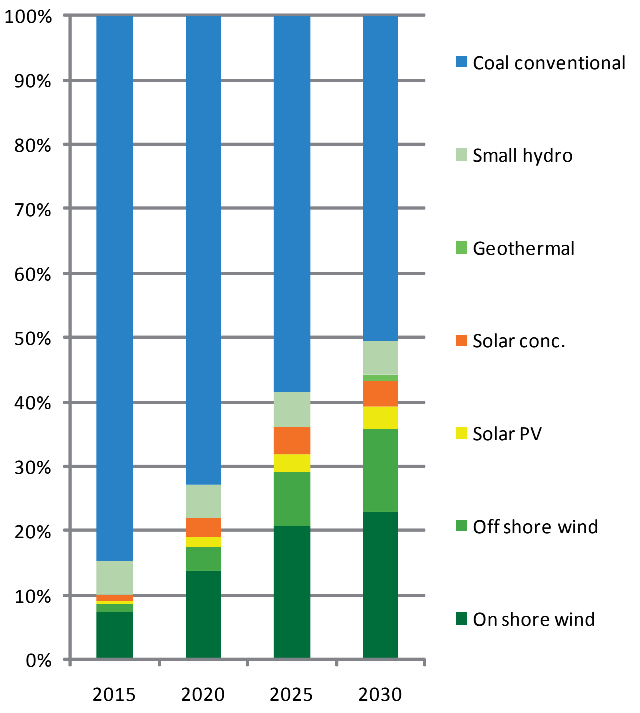
Source: IBS technical paper, MIND module simulations.

Annex 9.

THE MIND MODULE'S OPTIMIZATION: ALTERNATIVE ENERGY INVESTMENT SCENARIOS

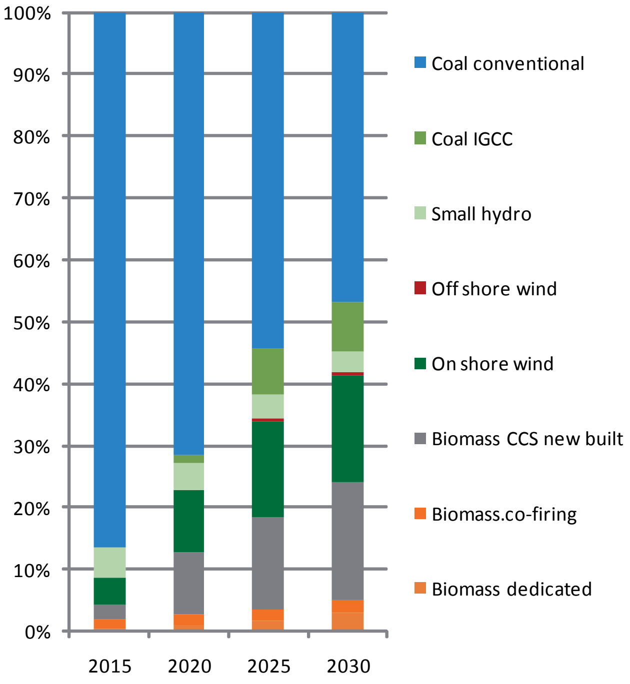
Scenario I: Wind + Solar

In the "Wind + Solar" scenario, we assume that government is interested in promoting some types of renewable sources of energy i.e. wind and solar. Although there are not as good conditions in Poland to use wind energy as in the Netherlands nor can the country use as much solar energy as countries in the south of Europe, according to our assumptions it is still possible to install more than 700 MW of solar plants and more than 6.7 GW of wind plants till 2030. Apart from renewable resources and coal there are no other sources of energy installed. On the other hand it must result in higher costs as both solar and wind plants are much less efficient than coal. Indeed it comes at the huge cost of PLN 9.989 million which is more than 4 times larger than cost in optimal scenario.



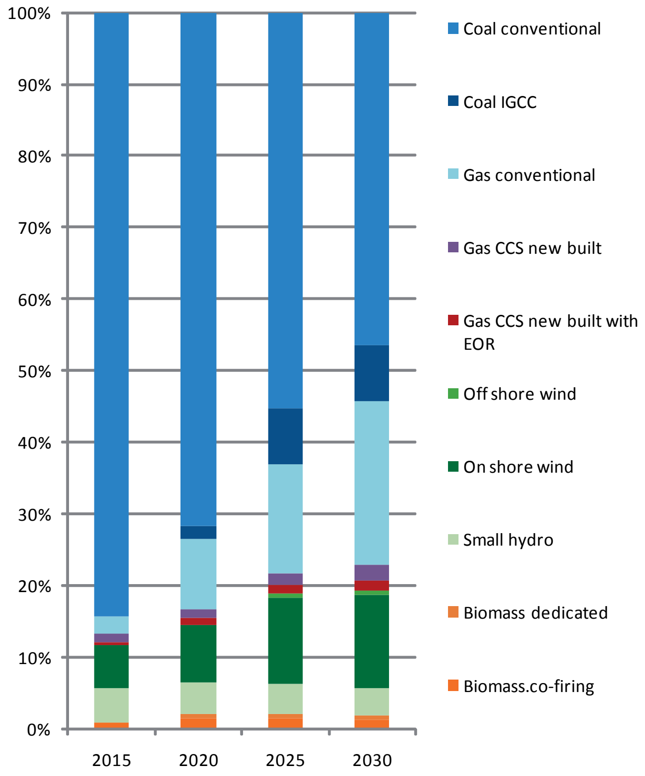
Scenario II: Wind + Biomass

In the "Wind + Biomass" scenario government aims at maximizing the production of energy from these two sources in a similar manner to Wind + Solar scenario. Biomass can be used in small power plants which may supply the energy to small towns or villages. It should be noted here, however, that due to a small efficiency of biomass and wind plants they cannot provide electricity to bigger cities. Therefore, the extent to which biomass can be used is limited and still some new large coal or nuclear plants will be needed. The latter ones are more likely because of their efficiency. The main component of biomass is biomass CCS plants which is desirable from CO_2 emission point of view. It is also the share of biomass CCS which mostly differentiates this scenario from the optimal one. Although biomass plants amount together to roughly 25 percent of whole energy production they cannot substitute for coal plants – some new coal IGCC will be needed.



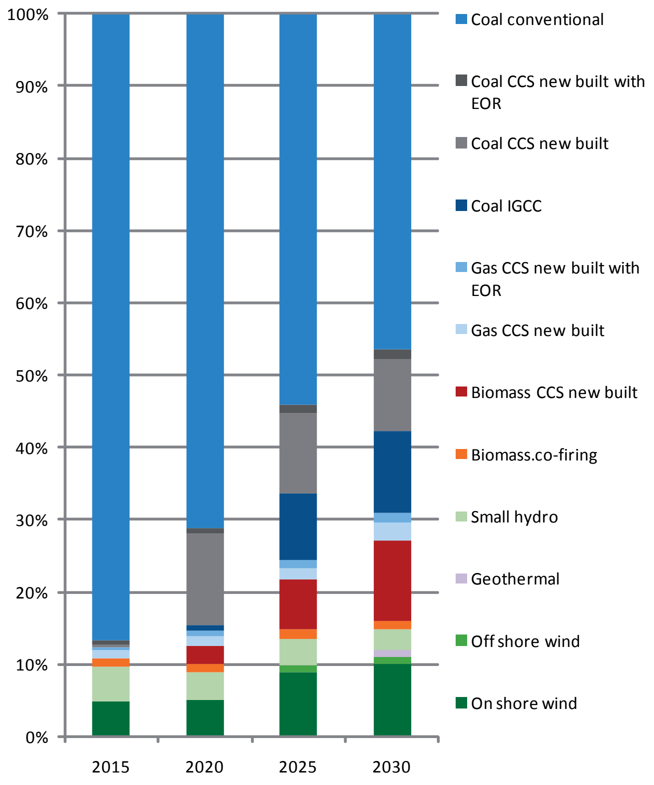
Scenario III: Natural Gas

The "Natural Gas" scenario takes a deeper dive into the policy in which government intervenes on the market in order to achieve a higher share of gas in the electric energy mix than in optimal scenario. Thus, constraints on the share of gas plants are eased. This exercise may be of interest due to recent decreases in gas prices and the possibility of unconventional gas exploitation in Poland in the future. In this scenario, coal, gas, and wind become the main sources of energy in Poland. It provides smaller CO_2 emission reduction (40 percent) but at a considerably smaller cost (by PLN 2.147 million annually between 2015 and 2030) which equals to 76 percent of the cost of the optimal scenario.



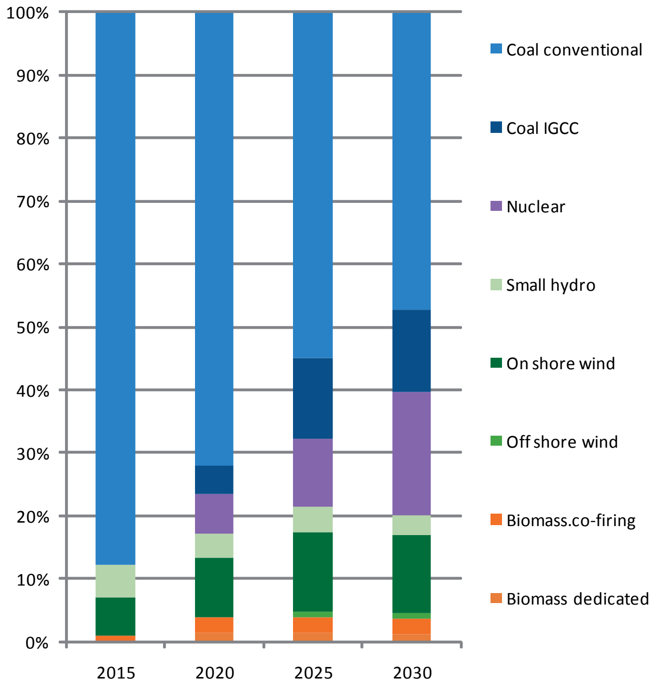
Scenario IV: Carbon Capture and Storage

Taking into account the strategic coal resources in Poland and the strength of coal lobby the government may be interested in implementing the technology which allows both high usage of coal as energetic resource and reduction of CO_2 emission. CCS scenario represents such an option. In this scenario not only CO_2 produced by coal plant is captured and stored but also from biomass and gas (however from the latter to much less extent). As it can be seen from the table CCS can be used as important source of reducing the CO_2 emissions (48 percent comparing to BAU) though it comes at a considerable cost – government has to spend PLN 8.874 million which is more than 3 times more than in the optimal scenario. It means that concentrating mainly on CCS is expensive; however, it is still less costly than the scenario based on renewable energy sources.



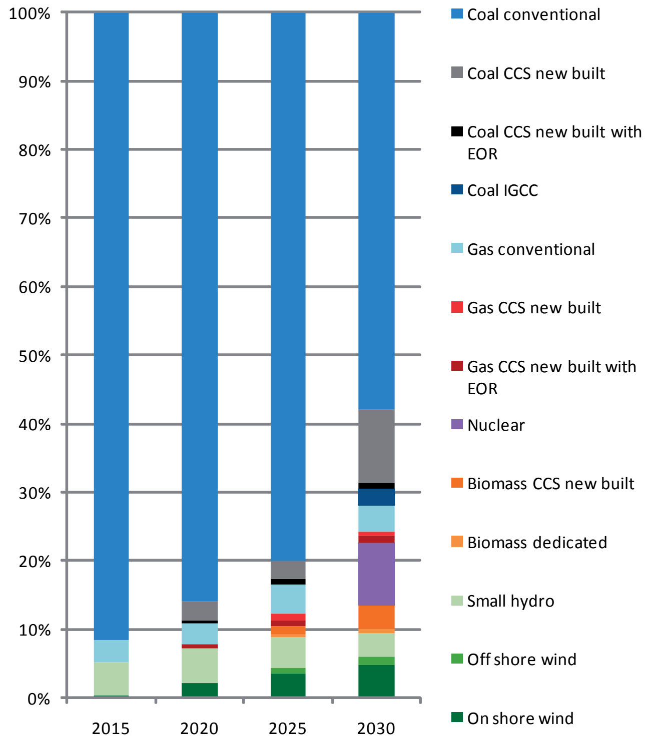
Scenario V: Nuclear Power

The "Nuclear Power" scenario investigates the impact of higher usage of nuclear plants. As a result of this simulation other alternative to coal sources of energy are used to less extent and nuclear contributes to 20 percent of total energy production in 2030. It comes at the annual cost of PLN 3.341 million with the reduction of CO_2 emission equaling to around 49 percent.



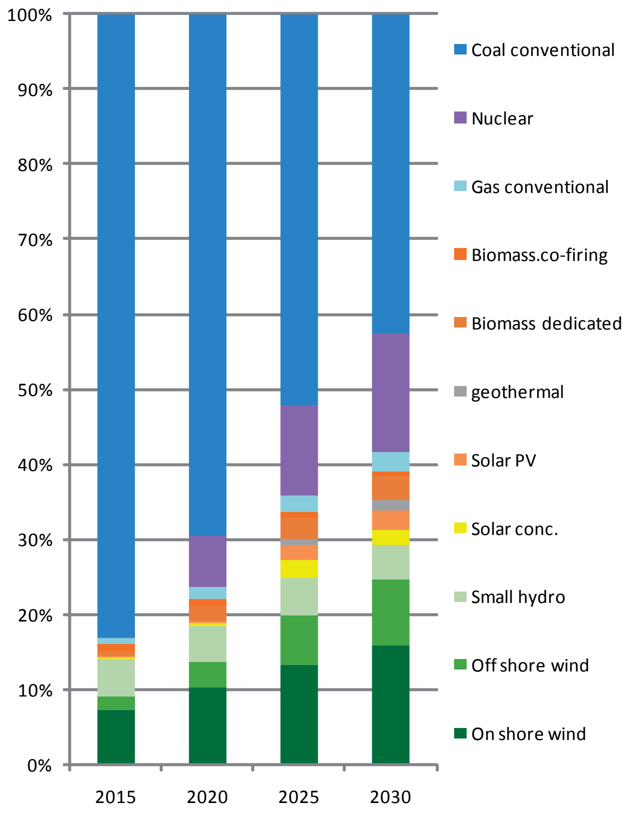
Scenario VI: Delayed Action

In the "Delayed Action" scenario, we assume that the government postpones its actions till 2015. After that it decides to reach the same goals as described earlier and undertakes optimal policy to reach them. It turns out that in this case average costs of participation of the government in new power plants rise to PLN 3.932 million whereas the emission reduction shrinks to 37 percent only. It is caused by the fact that the government has to influence the market to invest in less efficient (and more costly) technologies (like coal CCS) which are necessary to approach the reduction target.



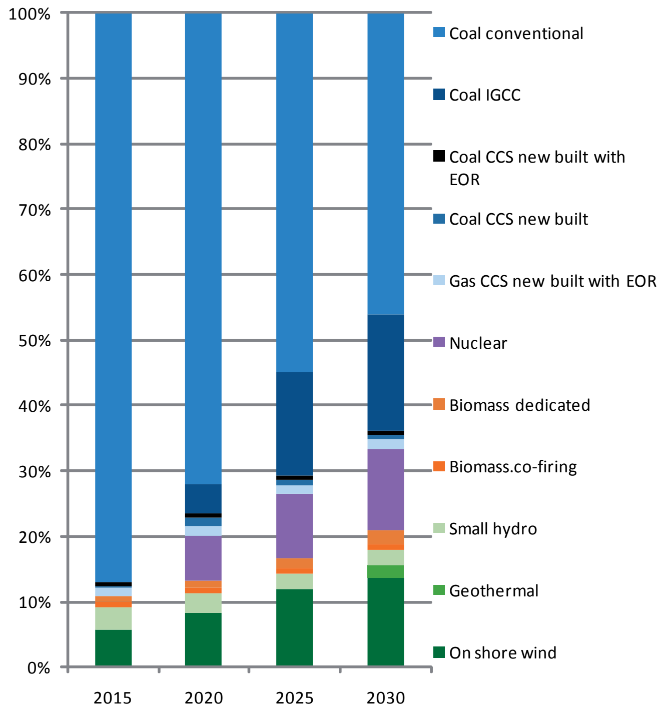
Scenario VII: Ministry of Economy 2030 (Balanced Mix)

In the scenario of "Balanced Mix", we assume a structure of energy mix as envisioned by the Polish Ministry of Economy targets in the "Energy Policy 2030". If these targets are to be achieved, it would cost PLN 8.362 million and lead to a reduction of CO$_2$ emissions by 53 percent which is the highest abatement in all scenarios.



Scenario VIII: Optimal at high gas prices

The high volatility of energy prices is observable in recent years. For example, gas prices fell dramatically in 2009. In the scenario of gas prices from the beginning of 2009, we investigate the optimal structure of energy mix. It turns out that the new optimal solution is by 20 percent more expensive for the government than the optimal reference scenario and the average annual cost amounts to PLN 3.398 million. The emission reduction remains at 49 percent. As expected, the main difference between high gas price scenario and the optimal one is no gas in energy mix. In this scenario, gas was replaced mainly by higher coal IGCC share.



Source: Institute for Structural Research (MIND module simulations).

Annex 10.

DESCRIPTION OF MITIGATION LEVERS

Lever	Description	Key volume assumptions	Key cost assumptions
Power			
Wind		- Volume growth constrained by two factors - Maximum wind production growth rate capped at 20% per year - Intermittent power sources (wind, solar PV) capped at 25% of production (wind 17–20%, solar 5–8%) - Wind energy natural potential assumed to not be a constraining factor - Installed capacity capped at 16 GW in 2030 due to grid safety	- Average 2005 capex of € 1,800 per kW of on-shore wind capacity and € 2,800 per kW of off-shore wind capacity - Overall cost per unit of electricity produced projected to decrease by ~5% with every doubling of cumulative installed capacity; these costs reductions reflect technology improvements but also decreasing resource quality with increasing penetration levels - On-shore: grid extension costs of € 3 per MWh throughout 2005-2030; back-up capacity cost of € 4 per MWh throughout 2005-2030; variable maintenance costs of € 16 per MWh in 2005 and € 9 per MWh in 2030 - Off-shore: grid extension costs of € 4 per MWh throughout 2005-2030; back-up capacity cost of € 4 per MWh throughout 2005-2030; variable maintenance costs of € 27 per MWh in 2005 and € 18 per MWh in 2030
Solar PV		- Intermittent power sources (wind, solar PV) capped at 25% of production (wind 17–20%, solar 5 8%)	- 2005 capex: € 3,500 per kW - Capacity driven learning rate at 18% for every doubling of cumulative installed capacity - Variable maintenance costs modeled at € 16 - € 5 per MWh in the period of 2005-2030 - Back-up capacity cost of € 0.6 per MWh throughout 2005-2030 - Grid extension cost of € 1.4 per MWh throughout 2030
Solar Conc		- Installed capacities assumed at the same level as in Energy Policy 2030;	- Total capex at € 2,500 per kW in 2005 and decreasing to 2000 per kW in 2020 - Variable maintenance cost + fuel: € 48 per MWh in 2005 decreasing to € 41 per MWh in 2030 - Fixed maintenance cost of € 93 per kW in 2005 decreasing to € 88 per kW in 2030
Nuclear		- Maximum installed base capped at 6 GW in 2030, based on estimates by Ministry of Economy, power sector companies and McKinsey; growth limited by engineering, construction and supply chain capacity constraints	- Due to limited experience with new construction and cost overruns in current projects, there is much uncertainty around capital costs for nuclear plants. We assume a cost of € 3,500 per kW throughout the forecast period due to little evidence of learning curve in the past - Operating costs at around € 22/MWh in 2005 and around € 21/MWh, including fuel costs and waste disposal, maintenance costs, insurance, liabilities and decommissioning costs

Lever	Description	Key volume assumptions	Key cost assumptions
Co-generation		- Due to lack of appropriate analysis of the volume of heat plants suitable to CHP (combined heat and power) retrofit all existing heat plants are assumed to be CHP by 2030	- Total capex of € 2,600 per kW in 2005 decreasing to €2,240 per kW by 2030 - Variable maintenance costs + fuel costs amounting to € 13 per MWh in 2005 and € 14 per MWh in 2030 - Fixed maintenance costs assumed at € 20 per kW throughout period of 2005-2030
CCS		- 0 plants assumed by 2020 - After 2020, assumption that CCS technology has been proven on a large scale and that it will "take off": CCS in power industry is assumed to account for 85 percent of all new-built coal-fired plants between 2020 and 2030 - The power sector shows the largest CCS potential due to large point sources, availability of cheap fuel/electricity and suitable infrastructure	- High uncertainty on the cost side, as the technology has not yet been employed on such a large scale - Base capex for new-build coal-fired power plants equipped with CCS is € 3,400–4,500/kW in 2005 decreasing to € 1,800-2,000/kW in 2030 (depending on technology) - Storage capacity assumed to be capped at 30-40 $MtCO_2e$ by 2030 - Variable maintenance costs + fuel assumed at € 29 per MWh throughout the period of 2005-2030 - Fixed maintenance costs decreasing from € 79 per kW in 2005 to € 35 per kW in 2030 - Sequestration cost of € 17 per tCO_2 in 2005 increasing to € 19 per tCO_2 in 2030
Biomass		- 10% biomass co-firing is assumed on majority of coal plants - Volume of dedicated biomass plants in our model limited 0.89 GW in 2030	- Dedicated capex: € 2,200 per kW in 2005 decreasing to € 1,500 per kW in 2030 - Dedicated opex: fuel + variable maintenance cost at € 59 per MWh in 2005 and € 51 per MWh in 2030 - Co-firing capex: € 6 per kW in additional capex compared to conventional coal for minor modifications of fuel feed system - Co-firing opex: fuel + variable maintenance cost at € 26 per MWh in 2005 and € 24 per MWh in 2030 - Fixed maintenance costs assumed at the level of coal conventional
Small hydro		Potential largely exploited but still able to reach 1.69 GW of capacity by 2030	- Capex of € 2,500 per kW in 2005 with assumed learning rate of 5% with every doubling of capacity - Fixed maintenance costs at € 8 per kW throughout 2005-2030

DESCRIPTION OF MITIGATION LEVERS

Lever	Description	Key volume assumptions	Key cost assumptions
Petroleum and gas: upstream production and processing			
Energy efficiency from improved behavior, maintenance and process control on retrofits	Energy conservation awareness programs Additional/improved maintenance that ensures equipment stays in optimal condition; i.e., monitoring and reduction of fouling (deposit build-up in the pipes) Improved process control that reduces suboptimal performance i.e., due to undesired pressure drops across gas turbine air filters, an undesired turbine washout frequency, suboptimal well and separator pressures	Due to low priority historically given to efficiency in upstream, abatement potential assumed equal to max. abatement in downstream (levers 1 & 2 combined) – EU: 9.0% – US: 10.6% – ROW: 9.4%	Capex assumed equal to downstream in terms of cost per tCO_2e abated (16 M€ per $MtCO_2e$) Savings based on (for all efficiency levers) – Reduced fuel consumption (natural gas and fuel oil) – Projected prices of fuels consumed
Energy efficiency from improved maintenance and process control	Efficiency measures that involve replacement/ upgrades/additions that do not alter the process flow of an upstream production site More efficient pump impeller Replacement of boilers/ heaters/turbines/ motors	Abatement potential assumed equal to minimum in downstream for lever 3 because of little opportunity for heat integration and more simple operations – EU: 4.1% – US: 6.5% – ROW: 5.9%	– Capex assumed equal to downstream in terms of M€ per $MtCO_2e$ abated (€495 million per $MtCO_2e$) – Opex estimated at 5% of total required Capex
More energy efficient new builds	Program that ensures new built production sites use both process units with best-in-class energy efficiency as well as maintenance procedures and process controls that uphold the best-in-class energy efficiency	Based on Energy Star Program and expert estimates, volume savings are estimated at – EU: 13.1% – US: 17.1% – ROW: 15.3%	Capex assumed equal to 80% of total costs for levers 1 & 2 as improvements can be implemented 'first time right' (€ ~409 million per $MtCO_2e$) Opex estimated at 5% of total required Capex
Petroleum and gas: midstream gas transport and storage			
Replace compressor seals	Replacing traditional wet seals, which use high-pressure oil as a barrier against natural gas escaping from the compressor casing, with dry seals reduces methane leakage from compressors	Based on Energy Star Program, Oil & Gas Journal and expert estimates, volume savings as percentage of total emissions are estimated at 82% of emissions from all dry seals which is – ~7% of ransmission leakage emissions or – 2% of total emissions	Capex – € 160,000/ compressor for dry seals – € 40,000/ compressor for wet seals Opex – € 7,000/ compressor for dry seals – € 49,000/ compressor for wet seals
Improved maintenance on compressors	A directed inspection and maintenance (DI&M) program is a means to detect, measure, prioritize, and repair equipment leaks to reduce methane emissions from compressors, valves, etc. – A DI&M program begins with a baseline survey to identify and quantify leaks. Repairs that are cost-effective to fix are then made to the leaking components – Subsequent surveys are based on data from previous surveys, allowing operators to concentrate on the components that are most likely to leak and are profitable to repair	Also based on Energy Star – 15% leakage (not due to seals) worldwide is abated – This represents 3% of total emissions	No Capex Opex: € 133/ compressor

Lever	Description	Key volume assumptions	Key cost assumptions
Directed inspection and maintenance (DIM) on distribution network	DIM program on the distribution network reduces leakage in a similar way as a DIM program on compressors but focuses on surface and metering stations	Based on Energy Star Program and expert estimates – 80% of the gap between current practice and technical best practice can be reduced – Technical best practice is a 10% reduction of emissions in the region with current best practice – This represents 5% of total emissions	Capex assumed equal to 80% of total costs for levers 1 & 2 as improvements can be implemented 'first time right' (€ ~409 million per $MtCO_2e$) Opex estimated at 5% of total required Capex
Improved planning	Planning decreases emissions due to transmission combustion – Planning reduces unnecessary (de-) pressurization by actively matching compression needs with natural gas demand – In addition, emphasis is placed on running compressors at their most efficient point, called the working point	Based on expert opinion – Assume 7% reduction in fuel consumption – This represents 2% of total emissions	Capex: € 100,000/bcm Opex: 15% of Capex

Petroleum and gas: downstream refining

Lever	Description	Key volume assumptions	Key cost assumptions
Energy efficiency from behavioral changes	Energy conservation awareness programs including – Energy and GHG awareness of personnel – A review energy and GHG management system including monitoring KPIs vs. targets – An energy management focus in all processes	Based on Energy Star Program and expert estimates, abatement volume* is estimated at – EU: 2.5–3.0% – US: 2.9–3.5% – ROW: 2.6–3.1%	No Opex or Capex required Savings based on (for all efficiency levers) – Reduced fuel consumption – Projected prices of fuels consumed
Energy efficiency from improved maintenance and process control	Additional/improved maintenance that ensures equipment stays in optimal condition; i.e., maintenance and monitoring of steam traps/steam distribution or monitoring and reduction of fouling (deposit build up in the pipes) Improved process control that reduces suboptimal performance i.e., due to undesired pressure drops across gas turbine air filters, an undesired turbine washout frequency, suboptimal well and separator pressures	Different abatement volume estimates depending on whether refineries have implemented major energy efficiency programs – EU: with 0.5–1.2%; without 2.5–6.0% – US: with 0.6–1.4%; without 2.9–7.1% – ROW: with 0.5–1.2%; without 2.6–6.2%	Capex investment of USD 1 million required for a reference refinery (capacity of 180 MBBL/ day) in a reference region (EU) Capex scaled by volume and regional factors Opex estimated at 15% of total required Capex
Energy efficiency requiring Capex at process unit level	Efficiency measures that involve replacement/ upgrades/additions that do not alter the process flow of a refinery – Waste heat recovery via heat integration – Replacement of boilers/heaters/ turbines/motors	Based on Energy Star Program and expert estimates, abatement volume* is estimated at – EU: 4.1–4.3% – US: 6.5–9.5% – ROW: 5.9%-9.7%	Capex investment of USD 50 million required for a reference refinery (capacity of 180 MBBL/ day) in a reference region (EU) Capex scaled by volume and regional factors Opex delta estimated at 5% of total required Capex

Lever	Description	Key volume assumptions	Key cost assumptions
Co-generation	Efficiency measure using Combined Heat and Power generation in which waste heat from power production is used in the refinery	Co-generation capacity replaces 30% of thermal energy 60% of refineries technically capable of installing cogeneration Volume determined by the delta in carbon intensity between the of the power sector and co-generation	Capex of 1 M€ per MW Opex estimated at 5% of total required Capex Co-generation assumed to run on natural gas Savings result from reduced indirect electricity and reduced fuel consumption of standard fuels (e.g., fuel oil)
Carbon Capture and Storage (CCS)	Applying Carbon Capture and Storage to – The exhaust emissions coming from direct energy use in the downstream refineries – The emissions coming from the hydrogen generation unit	Refineries processing >100 MBBL per day are large enough 80% of refineries assumed to be close enough to storage CCS technically feasible in 80% of refineries 90% capture rate	Capex € ~600 per tCO_2e annual abatement capacity decreasing to ~200 in 2030 Energy cost dependent on fuel mix and electricity prices Transport average 100 km @ 0.14 € per km decreasing to 0.10 by 2030 € 11 per t storage cost increasing to 12 by 2030 Overhead cost € 15 per ton CO_2 abated, decreasing to € 6 per tonne in 2030

Cement

Clinker replacement with other mineral components (MIC)	As above	Max share of clinker replacement with other MIC assumed 8% Unlimited availability assumed	Capex of 60 € per tonne other MIC grinding capacity and 12 € per tonne handling capacity Material costs of 1.5 € per tonne Minus avoided clinker opex and capex
Increased share of waste as kiln fuel	Burning alternative fuels, such as municipal or industrial fossil waste, or biomass instead of fossil fuels in the cement kiln to reduce average fuel combustion emissions of the clinker making process	RC share set at 40%, increased to 55% of energy required for clinker production in 2030 Combustion reduces CO_2e of alternative power use in incineration	Capex of 200 € per tonne waste handling capacity Fuel costs of 5 € per tonne waste & 7 € per tonne OH Minus avoided costs for fossil fuels (differs by region based on fuel mix)
Increased share of biomass as kiln fuel	Biomass fuel is assumed CO_2e neutral, based on a life-cycle perspective for biomass	2005 share assumed as reference scenario Increased to 8% of energy required for clinker production in 2030 globally	Capex of 200 € per tonne waste handling capacity Fuel costs of 51 € per tonne biomass & 7 € per tonne OH Minus avoided costs for fossil fuels
Carbon Capture and Storage – retrofits	Carbon Capture and Storage (CCS) is the sequestration of CO_2 after it has been emitted due to fuel combustion and the clinker calcination process	Implementation commencing in 2026 Share of retrofitted capacity assumed 3% on average between 2026–2030	Overhead cost € 15 per ton CO_2 abated, decreasing to € 6 per tonne in 2030 Energy cost dependent on fuel mix and electricity prices CO_2 transport cost of 7 € per tonne CO_2 in 2030 € 11 per tonne storage cost, increasing to € 12 per tonne in 2030 Capex € ~600 per tonne new build CO_2 annual abatement capacity decreasing to € ~200 in 2030
Waste heat recovery	Usage of excess heat from the clinker burning process for electricity generation using steam turbines driven by the flue gas exhaust stream	33% of clinker production capacity assumed to be equipped with waste heat recovery 15 KWh electricity generated per tonne clinker	Capex of 12.9 € per tonne annual clinker capacity equipped Opex savings based on electricity cost

Iron and steel

Lever	Description	Key volume assumptions	Key cost assumptions
Co-generation	Blast Furnace/Basic Oxygen Furnace (BF/ BOF) steel-manufacturing process generates gas as a by-product This gas can be recovered, cleaned and used for power generation Cogeneration can be integrated in the BF/ BOF steel-manufacturing process to reduce the total energy demand	All indirect energy in BF/BOF plants can be generated internally, allowing them to literally cut the power cord 10% implementation co-generation in BAU, 100% implementation in abatement scenario by 2030	Capex of € ∼70 per tonne steel production capacity 4 % interest rate (all levers) No opex cost delta Savings based on indirect energy prices (Power)
Direct casting	Direct casting is a technique that integrates the casting and hot rolling of steel into one step, thereby reducing the need for reheat before rolling Near net-shape casting and strip casting are two newly developed direct casting techniques	∼18% reduction in after treatment energy intensity Only applicable to new build 10% implementation direct casting in BAU 100% implementation by 2030 Only applicable to new build	Capex of € ∼80 per tonne steel annual after treatment capacity, no opex cost delta Savings based on direct energy prices for fuel mix used in steel after treatment
Smelt reduction	Smelt reduction is a technique that avoids the coking process by combining upstream hot metal production processes in one step The emission savings are achieved as less direct fuel is used when integrating preparation of coke with iron-ore reduction	∼8% reduction of BF/BOF direct energy intensity 10% implementation smelt reduction in BAU 100% implementation by 2030	Capex of € ∼100 per tonne steel annual production capacity, no opex cost delta Savings based on direct energy cost for fuel mix used in direct BF/BOF plants
Energy efficiency	Annual improvement in direct energy efficiency above reference case, caused by a number of individual levers: Structural shift from BF/ BOF to EAF production, better preventative maintenance, Improved process flow (management, logistics, IT-systems), motor systems, New efficient burners, Pumping systems, Capacity utilization management, Heat recovery, Sinter plant heat recovery, Coal moisture control, Pulverized coal injection	0.2–0.4% p.a. general energy efficiency increase above reference case (EE I), 0.2 % efficiency increase (EE II) Different improvement rates in EE I due to converging energy efficiencies globally	Modeled as a net capex delta of € 25 or € 45 per tonne, respectively, abated CO_2e, no opex cost
CCS	Carbon capture and storage (CCS) is the sequestration of CO_2 from large emission point sources Capture is modeled as post combustion, with chemical reactions “cleaning” the exhaust gases of CO_2	90% capture rate, 90% of plants reaching enough scale 80% within reach of storage sites 0.24 MWh energy increase per tonne CO_2 separated in 2030 80% of old plants retrofittable due to technical constraints Global cap of CCS supply limits theoretical potential Implementation commencing in 2021	Overhead cost € 15 per tonne CO_2 abated, decreasing to € 6/tonne in 2030 (€ 19 and € 8 per tonne for retrofit) Transport average € 7 per tonne in 2030 € 11 per tonne storage cost, increasing to € 12 per tonne 2030 Capex € ∼600 per tonne new build CO_2 annual abatement capacity decreasing to € ∼200 in 2030
Coke substitution	Substituting coke used in BF/BOF furnaces with fuel based on biomass, with zero carbon intensity	∼10% of coke possible to substitute ∼100% carbon intensity decrease from carbon neutral biomass No substitution in reference case 100 % implementation by 2030	No capex required for fuel shift Savings based on indirect fuel price deltas for BF/BOF mills

Lever	Description	Key volume assumptions	Key cost assumptions
Chemicals			
Motor systems	Introduction of energy saving measures in motor systems, such as adjustable speed drive, more energy efficient motors, and mechanical system optimization	~25% savings in indirect energy compared to standard systems 30 % implementation in RC, 100 % in AS by 2030	Capex of € ~50 per MWh installed base* No overhead cost delta Opex based on energy savings
Fuel shift	Shifting direct energy use from coal powered systems to biomass powered systems, and oil powered systems to gas power, thereby lowering the carbon intensity per MWh energy produced given the lower carbon intensity of gas and biomass	Biomass not part of RC, 80 % in AS new build, 50 % retrofit Gas not part of RC, 80% in AS new build, 50% retrofit CO_2e abatement based on combustion emissions by fuel	Capex of € ~5 per MWh installed Opex based on difference of fuel prices No significant overhead costs assumed
CCS Ammonia	Introduction of Carbon Capture and Storage to the CO_2 emitted as a process emission from Ammonia production	90% capture rate, 90% of plants reaching enough scale 80% within reach of storage sites 0.24 MWh energy increase per ton CO_2 separated in 2030 (0.15 for ammonia separation) 80% of old plants retrofittable Global cap of CCS storage might limit theoretical potential Implementation commencing in 2021	Overhead cost € 15 per ton CO_2 abated, Energy cost ~ € 15 per ton Transport average in 2030 € 11 per tonne € 11 per tonne storage cost, Capex € ~600 per tonne new build CO_2 annual abatement capacity decreasing to € ~200 in 2030
CCS Direct	Applying Carbon Capture and Storage to the exhaust emissions coming from direct energy use in the chemical plants		
Process intensification	Process intensification in chemical processes, leading to an annual emission decrease. The improvements are caused by a number of individual levers, including continuous processes, improved process control, preventative maintenance, more efficient burners and heaters and logistical improvements	0.1-0.25% p.a. process intensification and catalyst optimization above RC Different improvement rates regionally due to converging energy efficiencies globally Modeled in three steps, with increasing costs Both levers split in two buckets: “process “and “energy”, affecting the corresponding emission type in baseline	Capex modeled as the net delta per tCO_2e annual abatement potential in three steps, € 0, € 200, and € 400 per tonne Opex modeled as net opex delta per abated tCO_2e in similar steps @ € 0, € 10, and € 20 per tCO_2e
Catalyst optimization	Catalyst optimization in chemical processes, leading to an annual process and direct energy emissions decrease above the reference case. The improvements are caused by a number of individual levers, including improved chemical structure of catalysts, design to lower reaction temperatures, and chain reaction improvements		
Combined heat and power (CHP)	CHP, combined heat and power, is a technique to involve the energy losses in power production to generate heat for processes, in order to increase system efficiency and decrease the amount of fuel needed for power generation	15% savings in direct power (regional) compared to heating systems without CHP 0% implementation in RC, 100 % in abatement case by 2030	Capex of ~€ 55 per MWh existing direct power in a given plant Opex based on fuel savingsv
Ethylene cracking	Ethylene Cracking improvement includes furnace upgrades, better cracking tube materials and improved separation and compression techniques that lowers the direct energy used in the cracking process	~1.1 MWh savings per ton Ethylene compared to standard cracking processes 0% implementation in RC, 100 % in abatement case by 2030	Capex of € ~50 per tonne Ethylene production Overhead cost of € ~25 per tonne Ethylene Opex largely driven by energy savings (1.1 MWh per tonne)

Lever		Description	Key volume assumptions	Key cost assumptions	
				Initial cost	Reduced cost 2030
Transport: LDVs gasoline, diesel					
ICE fuel efficiency improvements – gasoline	Bundle G1	Variable valve control Engine friction reduction (mild) Low rolling resistance tires Tire pressure monitoring system Mild weight reduction	ICE World scenario: 27% in 2011-2015, 25% in 2016-2020 Mixed Tech scenario: 25% in 2011-2015, 24% in 2016-2020 Hybrid/Electric World scenario: 26% in 2011-2015, 24% in 2016-2020	€ 307 (2010)	€ 185
	Bundle G2	Bundle G1+ Medium displacement reduction ("downsizing") Medium weight reduction Electrification (steering, pumps) Optimized gearbox ratio Improved aerodynamic efficiency Start-stop	ICE World scenario: 2% in 2011-2015, 14% in 2016-2020, 13% 2021-2025 Mixed Tech scenario: 13% in 2011-2015, 12% in 2016-2020 Hybrid/Electric World scenario: 13% in 2011-2015, 12% in 2016-2020	€ 1,116 (2010)	€ 673
	Bundle G3	Bundle G2+ Strong displacement reduction ("downsizing") Air conditioning modification Improved aerodynamic efficiency Start-stop system with regenerative braking	ICE World scenario: 8% in 2011-2015, 38% in 2016-2020, 30% 2021-2025 Mixed Tech scenario: 7% in 2011-2015, 32% in 2016-2020,35% 2021-2025 Hybrid/Electric scenario: 7% in 2011-2015, 29% in 2016-2020, 22% 2021-2025	€ 1,794 (2010)	€ 1,081
	Bundle G4	Bundle G3+ Direct injection (homogeneous) Strong weight reduction (9%) Optimized transmission (including dual clutch, piloted gearbox)	ICE World scenario: 0% in 2011-2015, 20% in 2016-2020, 70% 2021-2025, 100% 2026-2030 Mixed Tech scenario: 0% in 2011-2015, 17% in 2016-2020, 44% 2021-2025, 53% 2026-2030 Hybrid/Electric scenario: 0% in 2011-2015, 15% in 2016-2020, 32% 2021-2025, 33% 2026-2030	€ 2,593 (2010)	€ 1,563
Gasoline – Full hybrid		Bundle G4 + Full hybrid	ICE World scenario: no penetration Mixed Tech scenario: 3% in 2011-2015, 8% in 2016-2020, 18% 2021-2025, 25% 2026-2030 Hybrid/Electric scenario: 0% in 2011-2015, 10% in 2016-2020, 23% 2021-2025, 28% 2026-2030	€ 3,498 (2010)	€ 1,848
Gasoline – Plug-in hybrid		60 km range - 66% electric share; Energy demand electric drive 250 Wh per km	ICE World scenario: 0% in 2011-2030 Mixed Tech scenario: 0% in 2011-2015, 3% in 2016-2020, 13% 2021-2025, 20% 2026-2030 Hybrid/Electric scenario: 1% in 2011-2015, 4% in 2016-2020, 18% 2021-2025, 30% 2026 - 2030	€ 12,217 (2010)	€ 3,530
Electric vehicle		200 km range Energy demand 250 Wh/km	ICE World scenario: 0% in 2011–2030 Mixed Tech scenario: 0% in 2011–2015, 1% in 2016–2020, 1% 2021–2025, 2% 2026–2030 Hybrid/Electric scenario: 1% in 2011–2015, 2% in 2016–2020, 6% 2021–2025, 10% 2026 - 2030	€ 26,336 (2010)	€ 5,764

Lever		Description	Key volume assumptions	Key cost assumptions	
				Initial cost	Reduced cost 2030
ICE fuel efficiency improvement – Diesel	Bundle D1	Medium downsizing Engine friction reduction Low rolling resistance tires Tire pressure monitoring system Mild weight reduction (1.0%)	ICE World scenario: 12% in 2011-2015, 31% in 2016-2020, 25% 2021-2025 Mixed Tech scenario: 30% in 2011-2015, 24% in 2016-2020 Hybrid/Electric World scenario: 31% in 2011-2015, 25% in 2016-2020	€ 1,084 (2006)	€ 899
	Bundle D2	Bundle D1 + Piezo injectors Medium downsizing Medium weight reduction Electrification (steering, pumps) Optimized gearbox ratio Improved aerodynamic efficiency	ICE World scenario: 4% in 2011-2015, 15% in 2016-2020, 13% in 2021-2025 Mixed Tech scenario: 15% in 2011-2015, 13% in 2016-2020 Hybrid/Electric World scenario: 14% in 2011-2015, 12% in 2016-2020	€ 1,396 (2006)	€ 1,087
	Bundle D3	Bundle D2 + Torque oriented boost Air conditioning modification Improved aerodynamic efficiency Start-stop system with regenerative braking	ICE World scenario: 8% in 2011-2015, 23% in 2016-2020, 15% in 2021-2025 Mixed Tech scenario: 7% in 2011-2015, 20% in 2016-2020, 13% in 2021-2025 Hybrid/Electric scenario: 7% in 2011-2015, 19% in 2016-2020, 12% 2021-2025	€ 1,984 (2006)	€ 1,441
	Bundle D4	Bundle D3 + Increase injection pressure Strong downsizing (instead of medium downsizing) Strong weight reduction	ICE World scenario: 0% in 2011-2015, 35% in 2016-2020, 84% 2021-2025, 99% in 2026-2030 Mixed Tech scenario: 0% in 2011-2015, 29% in 2016-2020, 64% in 2021-2025, 68% in 2026-2030 Hybrid/Electric scenario: 0% in 2011-2015, 25% 2016-2020, 56% 2021-2025, 56% in 2026-2030	€ 2,349 (2006)	€ 1,661
Diesel – Full hybrid		Bundle D4 + Full hybrid	ICE World scenario: 0% in 2011-2030 Mixed Tech scenario: 3% in 2011-2015, 8% in 2016-2020, 15% in 2021-2025, 20% in 2025-2030 Hybrid/Electric scenario: 0% in 2011-2015, 8% 2016-2020, 18% in 2021-2025, 23% 2026-	€ 4,962 (2010)	€ 2,512
Diesel – Plug-in hybrid		60 km range – 66% electric share Energy demand electric drive 250 Wh per km	ICE World scenario: 0% in 2011-2030 Mixed Tech scenario: 0% in 2011-2015, 3% in 2016-2020, 8% 2021-2025, 10% 2025-2030 Hybrid/Electric scenario: 0% in 2011-2015, 5% in 2016-2020, 13% 2021-2025, 18% 2026-2030	€ 12,217 (2010)	€ 3,530
CNG vehicle		Fuel economy 2.92-4.43 litres natural gas per 100 km Combustion emissions 1,740 g CO_2e per l natural gas Energy content 31.6 MJ per l natural gas	ICE World scenario: 1% in 2011-2030 Mixed Tech scenario: 1% in 2011 – 2025, 2% in 2026 - 2030 Hybrid/Electric scenario: 0% in 2011-2015, 0% 2016-2020, 3% in 2021-2025, 4% 2026-2030	€ 4,274 (2010)	€ 2,576

	Lever	Description	Key volume assumptions	Key cost assumptions	
				Initial cost	Reduced cost 2030

Transport: MDVs

	Lever	Description	Key volume assumptions	Initial cost	Reduced cost 2030
MDV ICE fuel efficiency improvements	Bundle 1	Rolling resistance reduction	30% in 2011–2015 10% in 2016–2020 0% in 2021 – 2030	€ 637 (2008)	€ 637
	Bundle 2	Rolling resistance reduction Aerodynamics improvement	30% in 2011-2015 10% in 2016-2020 0% in 2021-2030	€ 637 (2008)	€ 1,273
	Bundle 3	Rolling resistance reduction Conventional ICE improvement incl. mild hybrid	20% in 2011–2015 40% in 2016–2020 50% in 2021–2030	€ 5,943 (2008)	€ 2,759
	Bundle 4	Rolling resistance reduction Aerodynamics improvement Conventional ICE improvement incl. mild hybrid	20% in 2011–2015 40% in 2016–2020 50% in 2021–2030	€ 5,943 (2008)	€ 3,396

Transport: HDVs

	Lever	Description	Key volume assumptions	Initial cost	Reduced cost 2030
HDV ICE fuel efficiency improvements	Bundle 1	Rolling resistance reduction	30% in 2011–2015 6% in 2016–2020 0% in 2021 – 2030	€ 2,122 (2010)	€ 2,122
	Bundle 2	Rolling resistance reduction Aerodynamics improvement	30% in 2011-2015 14% in 2016-2020 0% in 2021-2030	€ 2,441 (2010)	€ 3,714
	Bundle 3	Rolling resistance reduction Conventional ICE improvement incl. mild hybrid	20% in 2011-2015 24% in 2016-2020 25% in 2021-2025 20% in 2026-2030	€ 12,734 (2010)	€ 7,428
	Bundle 4	Rolling resistance reduction Aerodynamics improvement Conventional ICE improvement incl. mild hybrid	20% in 2011–2015 56% in 2016–2020 75% in 2021–2025 80% in 2026–2030	€ 13,053 (2010)	€ 9,020

Transport: biofuels

Lever	Description	Key volume assumptions	Initial cost	Reduced cost 2030
1st generation biofuels	Modeled as sugarcane ethanol (26 gCO_2e per MJ)	Gasoline biofuel content: 22.85% in BAU, 34.27% in abatement case (26.27% 1st generation biofuels (16.3% corn/maize, 10.0% sugarcane), 8% 2nd generation biofuels (lignocellulosic)) Diesel: 6.13% in BAU, 6.13% in abatement case	Ethanol - $ 1.60 per gallon Biodiesel – $ 2.63 per gallon	$ 1.60 per gallon Biodiesel – $ 2.63 per gallon
2nd generation biofuels	Modeled as lignocellulosic ethanol (25 gCO_2e per MJ)		–	$ 1.38 per gallon

Building: residential

Lever	Description	Key volume assumptions	Key cost assumptions
New build efficiency package (incl. insulation)	Achieve energy consumption levels comparable to passive housing Reduce demand for energy consumption through improved building design and orientation Improve building insulation and air tightness; improve materials and construction of walls, roof, floor, and windows Ensure usage of high efficiency HVAC and water heating systems	Assume that maximum site energy consumption for HVAC and water heating in new builds is 132 kWh per m2 New technology results in average consumption of 30 kWh per m2 in 2005 down to ~27 kWh in 2030 (SITE energy)	In 2005, 6-7% cost premium on new builds By 2020: 4% premium US initial construction costs validated with experts, and scaled for Poland, based on expert interviews
Insulation retrofit building package, level 1 and level 2	Level 1 retrofit - "basic retrofit" package Improve building air tightness by sealing baseboards and other areas of air leakage Weather strip doors and windows Insulate attic and wall cavities Add basic mechanical ventilation system to ensure air quality Level 2 retrofit Retrofit to "passive" standard, in conjunction with regular building renovations Install high efficiency windows and doors; increase outer wall, roof, and basement ceiling insulation; mechanical ventilation with heat recovery, basic passive solar principles	Level 1 retrofit based on 25% heating savings potential and 5% cooling savings potential, adjusted by income and climate Level 2 retrofit can reach heating/cooling consumption of 30 kWh per m2 (SITE energy)	Level 1 retrofit based on 6.26 € per m2 in W. Europe / Japan. Scaled down to 3.66 EUR / m^2 for Poland based on GDP Cost of level 2 retrofit is 39 € per m2 in 2005 and 25 € per m2 in 2030 in Poland
Retrofit HVAC, residential	When current gas/ oil furnaces or boilers expire, replace with the highest efficiency model, with AFUE (annual fuel utilization efficiency) rating above 95 When current air conditioning unit expires, replace with highest efficiency model (16 SEER or above) Reduce energy consumption from HVAC and AC through improved maintenance Improve duct insulation to reduce air leakage and proper channeling of heated and cooled air Ensure HVAC system is properly maintained, with correct level of refrigerant and new air filters	For standard gas/ oil heaters, assume up to 19% savings potential from improved technology and proper sizing For electric heat pump, assume up to 50% savings potential compared to electric resistance heating. Savings is slightly lower in extreme climates For HVAC maintenance, assume total 15% savings from proper duct insulation and proper maintenance	Assume 500 € premium for high efficiency gas/ oil model that covers 150 m2 house; assume 2000 € premium for HE heat pump model that covers 150 m2 house Assume 500 € premium for HE AC system Assume duct insulation/ maintenance job costs 635 € (aggressive cost estimate) to cover 150 m2 house
Retrofit water heating systems	When existing standard gas water heaters expire, replace with solar water heater, or with tankless / condensing models When existing electric water heater expires, replace with solar water heater or electric heat pumps	Aim for 10% solar penetration, with remainder using most efficient technology (heat pump or HE gas)	Solar water prices drop at 2.3% CAGR, based on historic improvement from 1984-2004

Lever	Description	Key volume assumptions	Key cost assumptions
New and retrofit lighting systems	Replace incandescent bulbs with LEDs Replace CFLs with LEDs	lumen/W varies by technology: Incandescent: 12 CFL: 60 LED: 75 in 2010; 150 by 2015 In abatement case, assume full remaining share of incandescents switch to LEDs, and full remaining share of CFLs switch to LEDs	Learning rate for LEDs based on historic 18% improvement in solar cell technology
New and "retrofit" appliances and electronics	Purchase high-efficiency consumer electronics (e.g., PC, TV, VCR/ DVD, home audio, set-top box, external power, charging supplies) instead of standard items When refrigerator/ freezer, washer / dryer, dishwasher, and fan expires, replace with high efficiency model	HE consumer electronics use up to 37% less energy Package of certified appliances consume ~35% less energy	Electronics: 34 € price premium for small devices Appliances: price differential is 3-10% for HE devices

Buildings: commercial

Lever	Description	Key volume assumptions	Key cost assumptions
New build efficiency package (incl. insulation)	Reduce demand for energy consumption through improved building design and orientation Improve building insulation and air tightness; improve materials and construction of walls, roof, floor, and windows Ensure usage of high efficiency HVAC and water heating systems	61% savings potential on HVAC and water heating for new builds using „maximum technology"	In developing regions, 5% cost premium on new builds with „high efficiency package." 4% premium in developed regions
Insulation retrofit building envelope	Level 1 retrofit - "basic retrofit" package Improve building air tightness by sealing areas of potential air leakage Weather strip doors and windows insulation; mechanical ventilation with heat recovery, basic passive solar principles	Assume 48% savings potential	Level 1 retrofit is 4.10 € per m2 in W. Europe/ Japan. Scaled down to EUR 1.71 for Poland based on GDP
Retrofit HVAC and HVAC controls	When HVAC system expires, install highest efficiency system Improve HVAC control systems to adjust for building occupancy and minimize re-cooling of air	HVAC system retrofit: assume similar savings potential compared to residential (~15%) HVAC controls: ~15% savings potential	500 € premium for every 5 tonnes (~17,000 W) of capacity installed 5,000 € cost for retrofit control system in 1,700 m2 building in developed countries
New and retrofit lighting systems	Replace incandescent bulbs with LEDs Replace CFLs with LEDs Replace inefficient T12s/ T8s with new super T8s and T5s New build - install lighting control systems (dimmable ballasts, photo-sensors to optimize light for occupants in room) Retrofit - install lighting control systems (dimmable ballasts, photo-sensors to optimize light for occupants in room)	In abatement case, assume full remaining share of incandescents switch to LEDS, and full remaining share of CFLs switch to LEDs Assume maximum switch from old T12 and T8s to new T8/T5s For lighting control systems Achieve 50% savings potential in new build Assume 29% savings potential in retrofit	Learning rate for LEDs based on historic 18% improvement in solar cell technology Cost of labor and materials for new build 3.42 € per m2. Cost for retrofit is 10.93 € per m2
New and "retrofit" appliances and electronics	When existing standard gas water heaters expire, replace with tankless gas, condensing gas, or solar water heater When existing electric water heater expires, replace with heat pump or solar water heater	48% savings potential in office electronics 17% savings potential in commercial refrigerators	1.5 € price premium per item for high efficiency charging devices and reduction in standby loss 19 € premium for every 0.65 m2 of high efficiency refrigeration area

Lever	Description	Key volume assumptions	Key cost assumptions
Waste			
Electricity generation from landfill gas	Capture landfill gas to generate electricity	LFG electricity generation is limited to a technical potential of 80% of all sites Capture rates over the lifetime of the landfill is assumed to be 75%	Capex: € 361 (2005) to 381 (2030) per tCO$_2$e of abatement capacity Opex: € 2 per tCO$_2$e Revenues from energy sales: € 42 per tCO$_2$e
Direct gas use of landfill gas	Capture landfill gas and sell to a captive player	LFG direct use is limited to a technical potential of 30% of all sites Capture rates over the lifetime of the landfill is assumed to be 75%	Capex: € 108 to 114 per tCO$_2$e of abatement capacity Opex: range from € 0.8 per tCO$_2$e Revenues from energy sales: range from € 37 (2005) to 46 (2030) per tCO$_2$e
Composting	Produce compost through biological process where organic waste biodegrades	Food: 1.0 tCO$_2$e per ton Yard trimming: 1.3 CO$_2$e per ton Paper: 1.9 CO$_2$e per ton Wood: 1.5 CO$_2$e per ton Textiles: 1.2 CO$_2$e per ton	Capex for composting per tonne of organic waste processed: € 44 to 47 per tCO$_2$e Opex for composting per tonne of organic waste : € 13 per tCO$_2$e Revenue from composting per tonne of organic waste : € 16 per tCO$_2$e
Recycling	Recycle raw materials (e.g., metals, paper) for use as inputs in new production	Paper: 2.9 tCO$_2$e per ton Cardboard: 3.7 tCO$_2$e per ton Plastic: 1.8 tCO$_2$e per ton Glass: 0.4 tCO$_2$e per ton Steel: 1.8 tCO$_2$e per ton Aluminum: 13.6 tCO$_2$e per ton	Capex for Recycling per tonne of waste processed: € 12 per tCO$_2$e Opex for recycling per tonne of waste : € 5 per tCO$_2$e Revenues from recycling : Paper: € 33 per tCO$_2$e Cardboard: € 67 per tCO$_2$e Plastic: € 67 per tCO$_2$e Glass: € 7 per tCO$_2$e Steel: € 13 per tCO$_2$e Aluminum: € 133 per tCO$_2$e
Forestry			
Aforestation of marginal croplands and pastureland	Plantation of forest carbon sinks over marginal pastureland and marginal cropland Carbon is sequestered in the forest carbon pools Based on a „carbon graveyard" forest case, where forests are not harvested	Available area excludes released or fallow croplands allocated to bioenergy Sequestration rates per ha are based on Moulton and Richards US estimates scaled on regional MAI for long range forestation	Annual rental for crop and pasture lands is based on regional averages - degraded land is assumed not needing rental One-time capex and annual management costs are based on US estimates Payments are matched to carbon flux assuming full repayment of capex and PV of annual expenditure over 50 years of constant sequestration
Forest management	Increase of the carbon stock of existing forests based on active or passive management options such as fertilization, fencing to restrict grazing, fire suppression, and improved forest regeneration	Total opportunity is based on new afforested land only, because all forest in Poland is managed as National Park, Protective Forest, or Commercial Forest Sequestration rates per ha are based on Moulton and Richards U.S. estimates scaled on regional MAI for long range forestation	One-time and annual costs based on US estimates (except that for Canada, where it is based on volume estimates from Chen et al. and IPCC estimates of fertilization costs at $ 20 per tCO$_2$).

Agriculture

	Lever	Description	Key volume assumptions	Key cost assumptions
Cropland management	1. Conservation tillage/residue management	Reduced tillage of the ground and reduced residue removal/ burning	0.3 tCO_2e/ha/yr for reduced till 0.5 tCO_2e/ha/yr for reduced till	€ -15 to -13/ ha/yr (costs increase over time with labour costs)
	2. Improved agronomy practices	Improved productivity and crop varieties; extended crop rotations and reduced unplanted fallow; less intensive cropping systems; extended use of cover crops	1.0 tCO_2e/ha/yr	€ 10/ ha/yr
	3. Improved nutrient management	Adjusting application rates, using slow-release fertilizer forms or nitrification inhibitors, improved timing, placing the nitrogen more precisely	0.6 tCO_2e/ha/yr	€ -28/ha/yr
Grassland	4. Improved grassland management practices	Increased grazing intensity, increased productivity (excluding fertilization), irrigating grasslands, fire management and species introduction	0.8 tCO_2e/ha/yr	€ 2 / ha/yr
	5. Improved grassland nutrient management practices	More accurate nutrient additions: practices that tailor nutrient additions to plant uptake, such as for croplands Increased productivity (through better fertilization) For instance, alleviating nutrient deficiencies by fertilizer or organic amendments increases plant litter returns and, hence, soil carbon storage	0.6 tCO_2e/ha/yr	€ -28/ha/yr
Land restoration	6. Organic soils restoration	To be used for agriculture, these soils with high organic content are drained, which favors decomposition and therefore, high CO_2 and N2O fluxes. The most important mitigation practice is to avoid the drainage of these soils or to re-establish a high water table\	33.5 tCO_2e/ha/yr	€ 227/ha/yr
Livestock management	7. Increased use of livestock feed supplements	Livestock are important sources of methane, accounting for about one-third of emissions mostly through enteric fermentation	14% of emissions from beef livestock	€ 64 per tCO_2e
	8. Use of livestock enteric fermentation vaccines	The key lever is the potential use of wide range of specific agents or dietary additives, mostly aimed at suppressing methanogenesis. The ones modeled are Propionate precursors which reduce methane formation by acting as alternative hydrogen acceptors. But as response is elicited only at high doses, propionate precursors are, therefore, quite expensive Vaccines against methanogenic bacteria which are being developed although not yet available commercially	11% of emissions from dairy and beef livestock	€ -26 per tCO_2e

Source: McKinsey & Company.

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This study poses the question of how Poland can transition to a low emissions economy as successfully as it underwent transition to a market economy in the early 1990s. With the EU policies on climate change and 2020 targets already in place, Poland faces immediate policy challenges. What are the implications for Poland of implementing EU policies on energy and climate change? Could the country commit to more ambitious overall greenhouse gas mitigation targets for the longer term—to 2030 and beyond? What technological options are available, and how expensive are they? Would there be high costs in lost growth and employment? The report addresses these questions while advancing the methodological approach of the World Bank's low carbon studies by integrating 'bottom-up' engineering analysis with 'top-down' economy-wide modeling. The economic impact is presented using a unique macroeconomic version of the well-known marginal abatement cost curve.

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