McKinsey&Company

Assessment of Greenhouse Gas Emissions Abatement Potential in Poland by 2030

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Foreword

Climate change has become a business reality, as more and more countries around the world are adopting stringent greenhouse gas reduction targets.

For Poland to be able to assess what greenhouse gas reductions are achievable, when, and at what cost, a comprehensive analysis is required. McKinsey & Company, under the Honorary Patronage of the Polish Ministry of Economy, cooperated with over 40 institutions and companies to assess greenhouse gas reduction opportunities for Poland. All assumptions and results were discussed in numerous interviews with leading experts. Using a methodology proven in over 20 country studies worldwide, the research investigated over 100 individual abatement measures in all major areas of the economy.

This report[1] does not evaluate the science of climate change. It also avoids assessing policies, political implementation programs, and other governmental interventions. It is strictly intended to provide an objective fact base of the abatement potential and the costs of abatement measures in Poland. This data can serve as a starting point for further discussions and decisions.

We would like to thank all the participating experts, companies, and associations for their constructive cooperation and valuable inputs over the past few months.

Warsaw, December 2009

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[1] The report is published in Polish and in English. Please note that minor differences may occur between versions.

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Summary of Findings

Summary of Findings

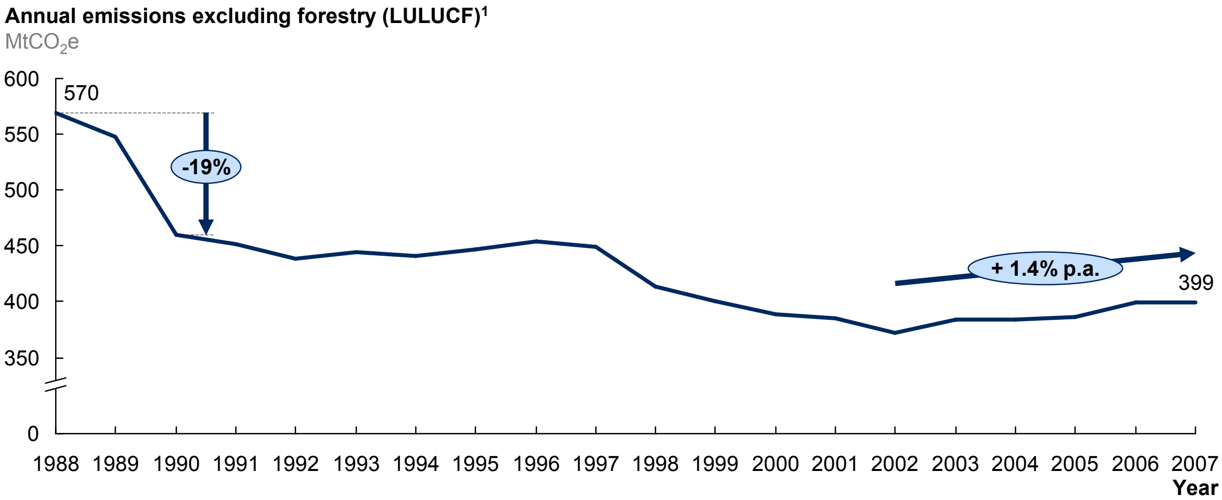
All countries are looking into how to reduce their greenhouse gas (GHG) emissions. Poland has significant emissions reduction potential, but seizing the opportunity will be a challenge. Fast, decisive action is required

Many scientists and policymakers believe that the rise in global average temperatures since pre-industrial times has been closely related to human activity, specifically the release of large amounts of carbon dioxide and other greenhouse gases (GHGs[2]) into the atmosphere. Many also believe that capping this increase at 2 degrees Celsius above pre-industrial levels – beyond which the implications of global warming could become very serious[3] – is an important goal, and that reducing GHG emissions would be a key step to ensure not only environmental stability but also long-term economic sustainability. To this end, the majority of governments ratified the Kyoto Protocol. Set to expire in 2012, the Protocol stipulates a 5% reduction target for the world's industrialized countries against 1990 emissions levels.

To account for the sharp decrease in industrial production levels following the collapse of communism, 1988 has been set as the base year from which emissions reductions for Poland will be calculated. The economic crisis at that time led to a significant decrease in GHG emissions (Exhibit 1).

Exhibit 1

Historical GHG emissions in Poland



1 Land use, land use change, and forestry; the forestry sector is not included in our calculations of total emissions

SOURCE: KASHUE; National Inventory Reports

[2] The main greenhouse gases, also analyzed here, are carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). To quantify the effect of all GHGs, values are expressed in CO_2e (carbon dioxide equivalent) – the unit of emissions that, for a given mixture and amount of GHGs, represents the amount of CO_2 that would have the same global warming potential.

[3] The primary source of the climate science in this report is "Climate Change 2007, Fourth IPCC Assessment Report", Intergovernmental Panel on Climate Change (IPCC).

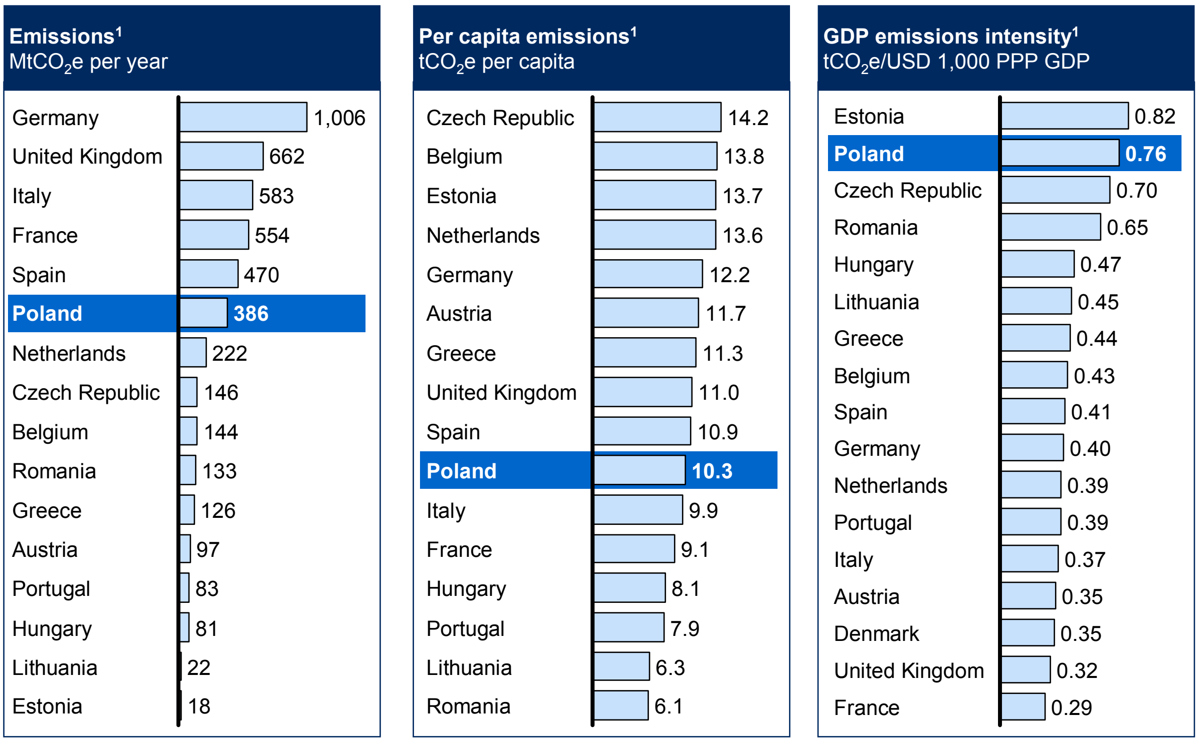
Continuing dependence on coal-generated power (~95% of the fuel mix) makes Poland a relatively carbon-intensive economy (Exhibit 2). Decisions taken now on the fuel mix will shape GHG emissions in Poland for decades to come. A key question for Poland will be how to fulfill its emissions reduction commitments while maintaining economic competitiveness and growth.

To inform the discussion on GHG abatement opportunities, McKinsey & Company has developed the GHG abatement cost curve for Poland. Providing a consistent view of available abatement measures and their related costs, the methodology allows for emissions reduction opportunities to be mapped across the major sectors of the economy (Exhibit 3)[4].

Exhibit 2

Emissions and GDP emissions intensities of EU economies

2005



1 Excludes emissions associated with forestry and land-use changes

SOURCE: KASHUE; EUROSTAT

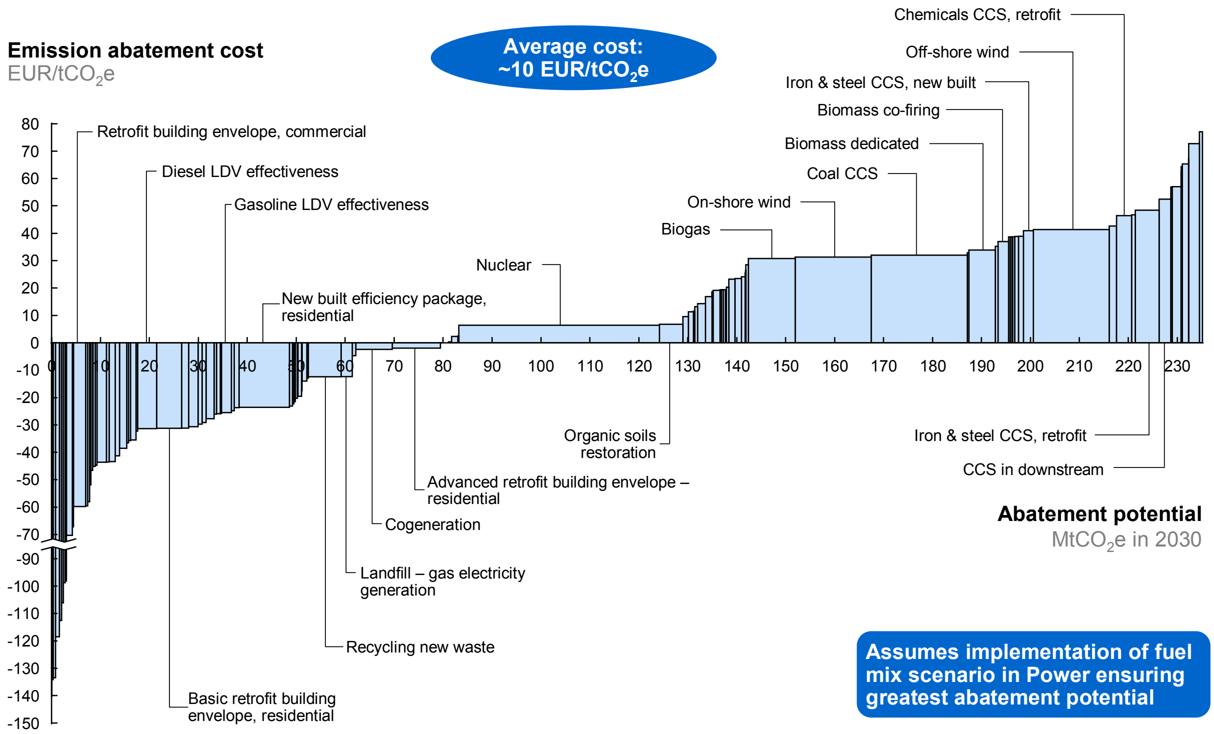
The report focuses on measures representing technical abatement opportunities without assuming any significant behavioral change among consumers (e.g., reduced driving or average home temperatures). Also excluded from consideration have been nascent abatement technologies, such as biodiesel from algae or tidal energy. Whereas such technologies could offer abatement potential in the future, their development remains uncertain, and it is unlikely they would have significant impact before 2030.

[4] We analyzed 10 sectors, which accounted for about 86% of Polish emissions in 2005, namely: power, buildings, transport, chemicals, iron and steel, petroleum and gas, cement, agriculture, waste management, and forestry.

Since fuel mix development in the power sector remains uncertain, we have modeled five potential scenarios (see Exhibit 8 for a summary). Unless stated otherwise, all summary analyses assume that the fuel mix scenario with the largest abatement potential would be implemented by 2030.

Exhibit 3

GHG abatement cost curve for Poland in 2030[1]



1 Only the most significant abatement opportunities are named

SOURCE: Poland GHG Abatement Cost Curve

How to read the GHG abatement cost curve for Poland

McKinsey's GHG abatement cost curve summarizes the technical opportunities (i.e., those without material impact on consumer lifestyle) to reduce emissions at a cost of up to EUR 80/tCO_2e[5]. The cost curve shows the range of reduction actions possible with available technologies or those whose potential can be estimated with a high degree of certainty up to the 2030 horizon.

The width of each column represents the GHG reduction potential of a specific opportunity in a specific year compared to business-as-usual (BAU) (Exhibit 4). The potential of each opportunity assumes aggressive action starting in 2010 but does not represent a forecast of how each opportunity will develop. The height of each column represents the average cost of abating 1 ton of CO_2e by 2030 through that opportunity. All costs are in 2005 real EUR. The graph is ordered from left to right from the net positive abatement opportunities to the highest cost ones. Uncertainty about volume and estimated costs can be significant for certain opportunities, especially emerging technologies.

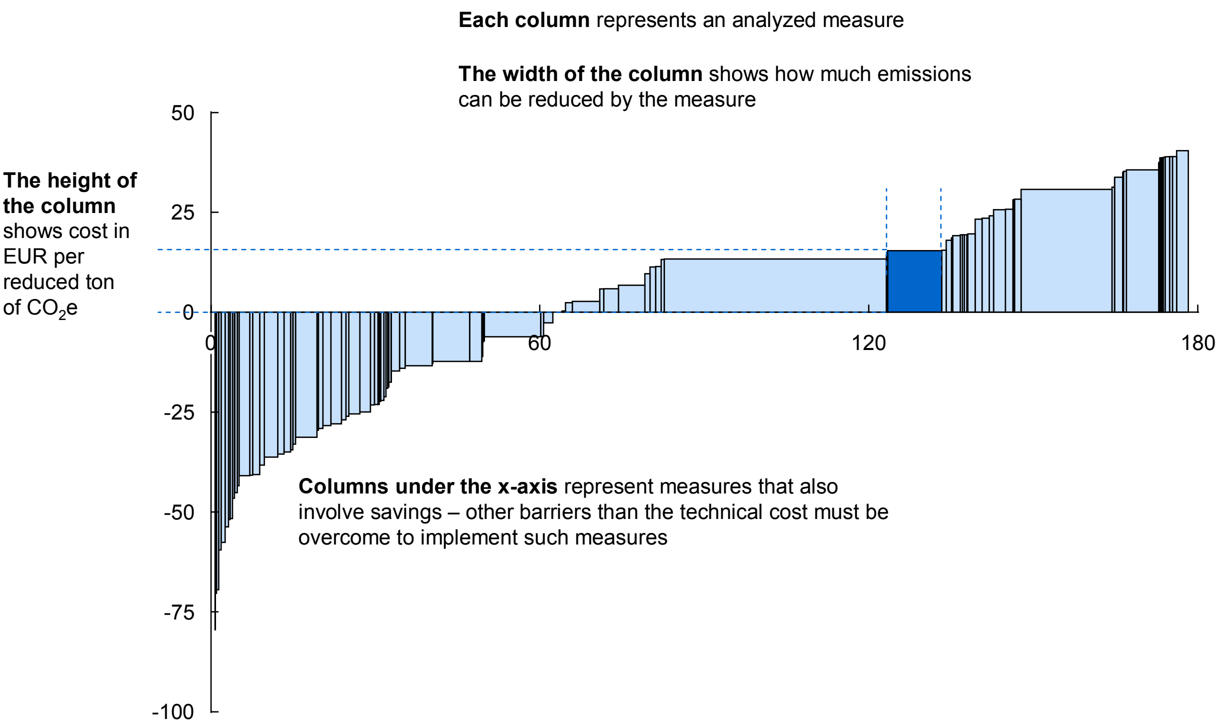
We have applied a consistent methodology to all emissions reduction opportunities considered in this report. Therefore, the curve can be used to compare the size and cost of opportunities, assess the relative importance of sectors, and estimate the overall size of the emissions reduction opportunity. It can also be used to test implementation scenarios, energy prices, interest rates, and technological developments. It should not, however, be used to try to predict any of these outcomes or developments.

The reader should bear in mind that abatement costs are calculated from a societal perspective (i.e., excluding taxes and subsidies, and with capital costs close to a real risk-free rate of 4%). This methodology allows comparison of abatement potentials and costs across countries, sectors, and opportunities. However, it means the calculated costs differ from the costs a company or consumer would incur, as the latter would factor taxes, subsidies, and different interest rates into their calculations. Therefore, the curve cannot be used to determine when it might be profitable to switch from one investment to another or to forecast CO_2 prices. The cost of each opportunity also excludes the transaction and program costs of implementing it on a large scale. The reason for this is that such costs reflect political choices about which policies and programs to implement and vary from case to case, making it impossible to incorporate these costs into the abatement curve in an objective way while maintaining the ability to compare abatement potentials across regions and sectors.

[5] Metric tons of CO_2e.

Exhibit 4

How to read the cost curve diagram



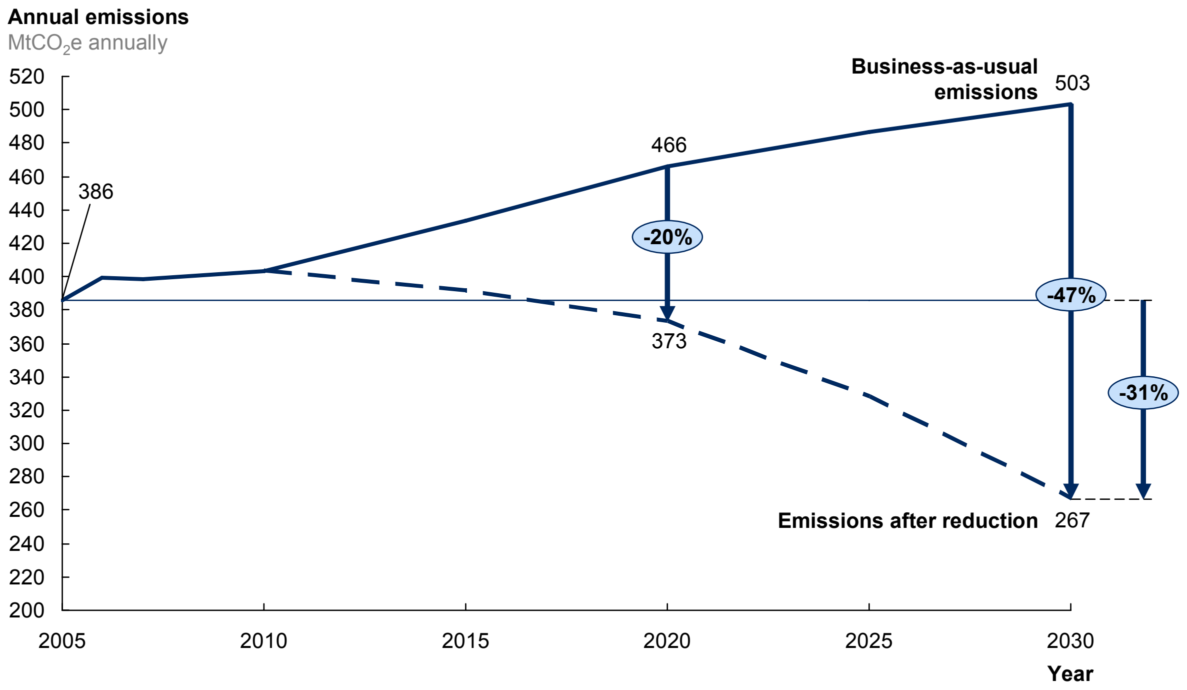
SOURCE: Poland GHG Abatement Cost Curve

Potential exists to significantly reduce emissions against the baseline, but capturing the full potential would be a major challenge

The cost curve identifies potential abatement of 236 $MtCO_2e$ by 2030 (Exhibit 5), which would represent a 31% reduction from 2005 levels, or 47% from estimated 2030 levels, assuming Poland made little attempt to curb current and future emissions (i.e., the BAU scenario)[6]. The pace of abatement would pick up significantly only after 2020, when major projects in the power sector (e.g., large-scale offshore wind generation, nuclear, or carbon capture and storage) became operational.

Exhibit 5

Emissions reduction potential relative to business-as-usual baseline



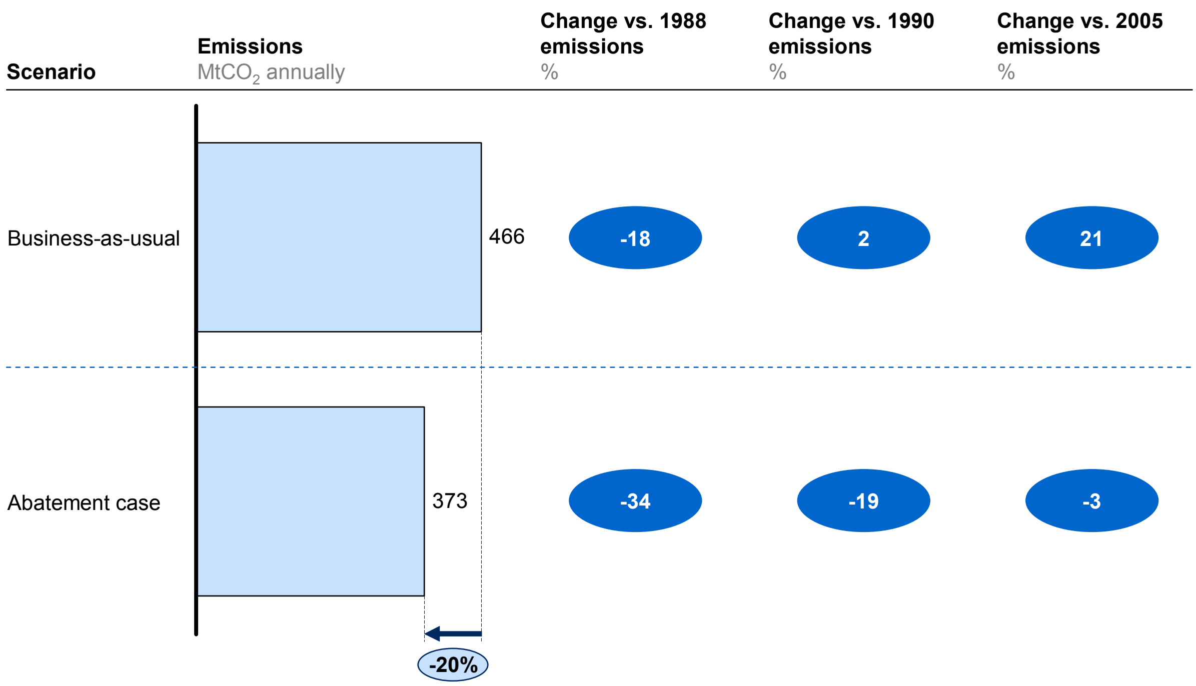
SOURCE: Poland GHG Abatement Cost Curve

An opportunity exists to reduce emissions by 20% against BAU by 2020. If the full technical potential were achieved, 2020 emissions in Poland would be 34% lower than in 1988 and 19% lower than in 1990 – the two potential baseline years for calculating emissions reduction targets. However, compared to 2005, even capturing the total 2020 technical potential would reduce emissions by only 3% (Exhibit 6). Greater abatement would require measures not included on the cost curve, such as consumer lifestyle changes or investments in more expensive technologies (e.g., electric cars).

[6] Our business-as-usual emissions projection represents the theoretical emissions trajectory that would occur under current trends, with little additional effort made to address climate change. It has been constructed from the bottom up, based on industry production levels and assuming natural improvements in technological efficiency. BAU emissions do not reflect current climate change regulations and targets.

Exhibit 6

Emissions reduction potential in 2020 vs. base year



SOURCE: Poland GHG Abatement Cost Curve; KASHUE; National Inventory Report

Capturing the full potential for deep cuts in GHG emissions in Poland would require concerted, targeted actions by government, business, and consumers. Significant gains would have to be made, for example, in the energy efficiency of buildings and transportation, and the share of low-carbon energy sources would have to rise to over 50% of the total electricity supply by 2030, up from less than 2% in 2005[7].

The analysis shows that such changes are feasible, but full implementation of all the measures would represent a major undertaking. Looking at GDP emissions intensity (i.e., the amount of carbon produced per EUR 1,000 of GDP), to achieve the total identified technical potential by 2030, Poland would have to decrease its GDP emissions intensity by almost 70% against current levels, and by over 40% against the BAU scenario level.

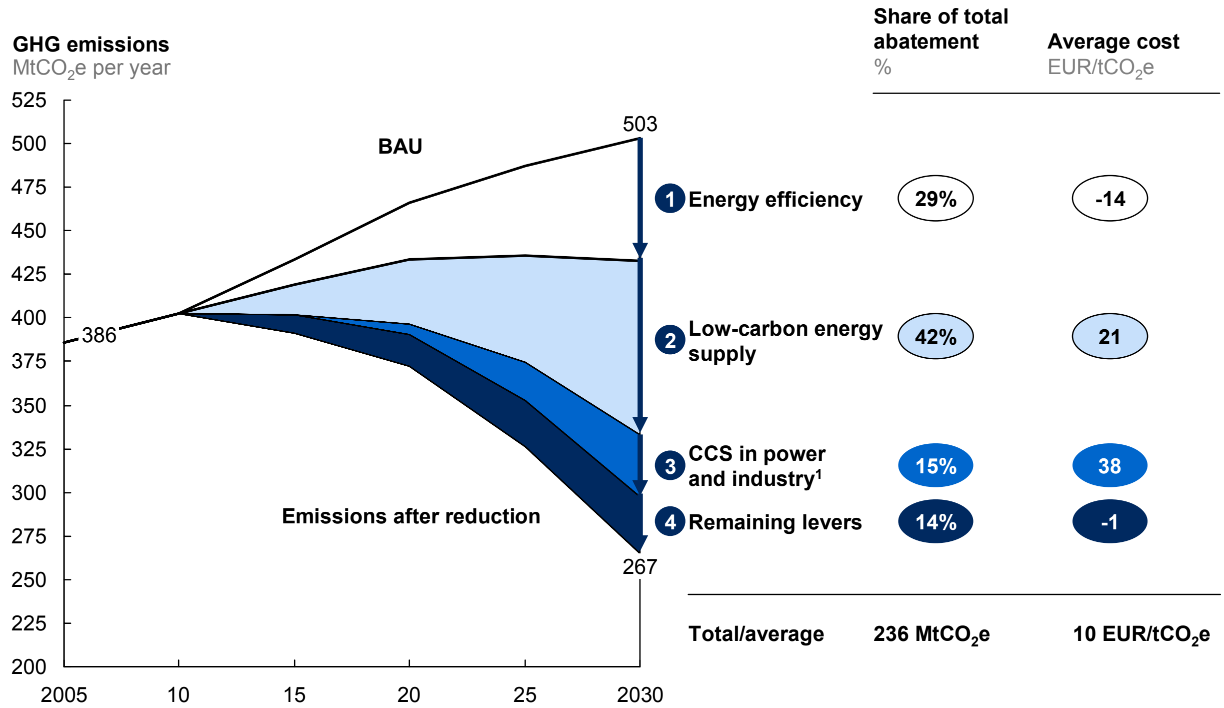
[7] The exact share of low-carbon technologies would depend on the fuel mix in the power sector. We have analyzed several potential fuel mix scenarios, described in more detail on page 16.

Approximately 70% of the total abatement potential is related to efficiency improvements and low-carbon energy supply opportunities

To address the emissions reduction challenge successfully, action needs to be taken between now and 2030 across four abatement categories: energy efficiency, low-carbon energy supply, carbon capture and storage (CCS), and other measures (industry, waste management, and agriculture) (Exhibit 7).

Exhibit 7

Reduction potential by category



1 CCS abatement opportunity in industry (chemicals, iron & steel, petroleum & gas, and cement) amounts to ~16 $MtCO_2e$ with an average cost of ~46 EUR/tCO_2e; in power the CCS abatement opportunity amounts to ~20 $MtCO_2e$ with an average cost of ~32 EUR/$MtCO_2$

SOURCE: Poland GHG Abatement Cost Curve; KASHUE; National Inventory Report

Energy efficiency (opportunity of 68 $MtCO_2e$ in abatement potential per year by 2030 – 29% of the total). Numerous opportunities exist to reduce power consumption by improving the energy efficiency of vehicles, buildings, and industrial equipment. More fuel-efficient cars, better building insulation, and tighter efficiency controls on manufacturing equipment are just a few of the possibilities. If all the energy efficiency opportunities we have identified were captured, annual growth in electricity demand in Poland from 2005 to 2030 would drop from 1.5% per year in the BAU scenario to ~0.9% per year – a difference of 29 TWh by 2030[8]. The most important opportunities in this category are in the buildings sector, where

[8] Gross electricity production in the BAU scenario is projected to grow from 157 TWh in 2005 to 227 TWh in 2030 (including industrial and commercial power plants). This growth would be driven by assumed annual GDP growth in Poland of 3.4% (Global Insight) and continued improvement in the energy intensity of the economy (e.g., it assumes a reduction in transmission loss). The potential energy efficiency improvement in our abatement case would reduce electricity demand by 29 TWh. Abatement in the power sector is calculated assuming electricity demand in 2030 of 198 TWh.

implementing stricter efficiency controls for new buildings and better insulating existing ones could abate almost 30 MtCO_2e by 2030 – roughly 13% of the total potential. Efficiency improvements in passenger cars could reduce fuel consumption by as much as 40% from current levels, representing an abatement opportunity of ~10 MtCO_2e by 2030[9]. This equals the approximate efficiency opportunity of the entire industry sector, with combined heat and power (CHP) (~3 Mt) and efficiency measures in the petroleum and gas industry (~3 Mt) offering the greatest potential.

Low-carbon energy supply – excluding CCS (opportunity of 100 MtCO_2e in abatement potential per year by 2030 – 42% of the total). Many opportunities exist to shift from coal to low-carbon alternatives. Examples include power generated from wind, nuclear, biomass, or biogas. The level of abatement would depend on fuel mix decisions and on the timeliness of implementation.

The coming years will be critical for determining the future fuel mix of the Polish power sector, as a sizeable share of currently operating coal plants are set to be retired. The chosen mix will have profound, lasting implications for CO_2 emissions. Balancing the multiple factors that influence the chosen fuel mix constitutes one of the biggest challenges facing Poland in the context of CO_2 abatement.

We have modeled five power sector scenarios to illustrate the options. Each entails different costs, benefits, and risks. Exhibit 8 summarizes the costs and the level of CO_2 reduction[10] in each scenario. The low emissions scenario offers the largest abatement opportunity (120 MtCO_2e)[11]. Others focusing on nuclear, renewables, and gas could abate 93, 81, or 68 MtCO_2e, respectively, by 2030[12]. The reduction potential of Poland's Energy Policy 2030 is 97 MtCO_2e.

We have summarized the technical abatement potential for Poland based on the low emissions scenario.

[9] In this report, we include only technical abatement measures and do not attempt to quantify the costs of behavioural changes in transport (e.g., increased use of public transport, reduced driving through better city and traffic design). While such changes are desirable, their costs and benefits are very difficult to quantify and depend on policy decisions and lifestyle changes, which makes their potential uncertain.

[10] Reduction potential is shown for the entire power sector, including CCS.

[11] In this scenario, we assumed that by 2030 installed capacity in Poland will reach 6 GW in nuclear, 10 GW in onshore wind, 6 GW in offshore wind, 1.7 GW in solar, 1.4 GW in biogas, 0.9 GW in dedicated biomass, and enlarged cogeneration capacity of 2.8 GW. Additionally, some coal-based plants will be equipped with CCS (3.2 GW) on top of 5.3 GW from co-fired biomass.

[12] There are key differences in installed capacity for nuclear, onshore wind, and offshore wind. In Focus on Nuclear scenario, capacity would reach 6 GW, 3 GW and 0 GW; in Focus on Renewables, 0 GW, 10 GW, and 6 GW; in Focus on Gas, 2 GW, 3 GW, and 0 GW; in gas, 7 GW; and in scenario E, 4.8 GW, 4.9 GW, and 3 GW.

Exhibit 8

Cost and abatement potential of different power scenarios

Scenario	Abatement potential $MtCO_2e$	Weighted average cost of abatement EUR/tCO_2e	Scenario description
A Low Emissions	120	22	▪ Natural retirement of coal power blocks (new blocks will still be required until 2020) ▪ Remaining power demand is met by wind and nuclear energy
B Focus on Nuclear	93	18	▪ Maintain current levels of coal-based production ▪ Remaining power demand is met by nuclear energy
C Focus on Renewables	81	32	▪ Maintain current levels of coal-based production ▪ Remaining power demand is met by wind energy
D Focus on Gas	68	24	▪ Maintain current levels of coal-based production ▪ Remaining power demand is met by gas plants
E Energy Policy 2030	97	21	▪ Assumptions from Poland's current official energy policy

SOURCE: Ministry of Economy; Poland GHG Abatement Cost Curve

Clearly, decisions about the future fuel mix will be shaped by factors outside the climate change debate, such as costs, execution risks, environmental concerns, safety issues, and energy security.

CCS (opportunity of ~36 $MtCO_2e$ in abatement potential per year by 2030 – 15% of the total). Just over a half the GHG abatement potential (20 $MtCO_2e$) is related to equipping coal power plants with CCS. The remaining 16 Mt could be achieved in industry sectors, with the largest potential in iron and steel (~7 Mt) and in chemicals (~6 Mt). Since CCS technology is still being tested, our analysis assumes that 30-40 Mt of annual storage capacity and transportation infrastructure would exist in 2030. However, if the technology matures faster and technical difficulties related to storage and transportation are resolved by then, storage potential in Poland could be much greater, resulting in a significant increase in abatement potential (36-76 Mt). Clearly, CCS could offer important emissions reduction opportunities in the future, but its large-scale deployment before 2030 remains uncertain.

Other measures (opportunity of 33 $MtCO_2e$ in abatement potential per year by 2030 – 14% of the total). In addition, we have identified major opportunities to reduce nitrous oxide and methane in waste management and agriculture, together accounting for over half the abatement potential, as well as industry-specific measures. The largest opportunities in the waste sector include intensified recycling (~7 Mt) and capture and use of methane from landfills (~4 Mt). In agriculture, improving agronomic practices and reflooding peat lands offer the greatest potential (~2 and ~5 Mt, respectively). Estimates should be considered with caution, as abatement in agriculture could vary considerably depending on the soil type, exploitation history, and climate. The remaining potential is split between transport and industry. In the former, biofuel blends could reduce emissions by ~2 $MtCO_2e$ by 2030. In industry the biggest opportunity is in chemical plants, where process optimization (e.g., of catalyst use or process intensification) could reduce emissions by ~4 $MtCO_2e$. Finally, increasing the share of fuels such as biomass, waste, or gas in industry could abate ~3 $MtCO_2e$.

The size of abatement opportunities in energy efficiency and in the power sector suggests that these two areas could be the focus of future abatement measures in Poland. A promising but as yet unproven new technology, CCS, could have major impact on the country's future emissions. Among other opportunities, waste management and agriculture offer considerable abatement potential, and should not be overlooked.

A different way of looking at potential is the sector abatement split (Exhibit 9). Approximately 53% of the total reduction potential is in energy supply sectors (power, petroleum and gas), 12% in the industry sector, 31% in sectors with significant consumer influence (transport, buildings, waste management), and the remaining 4% in land use related sectors (forestry and agriculture).

Exhibit 9

Split of abatement potential among different sectors

	Sector	Abatement potential 2030, $MtCO_2e$	Emissions reduction relative to BAU 2030, %	Average abatement cost EUR/tCO_2e
Power and industry	Power	120	-66	22
	Chemicals	15	-47	22
	Iron & steel	12	-39	31
	Petroleum & gas	6	-38	13
	Cement	2	-13	-2
Consumer	Buildings	44	-34	-18
	Transport	17	-22	-5
	Waste	11	-141	-18
Land use	Agriculture	9	-30	1
	Forestry	1	-3	13
	Total	236		

SOURCE: Poland GHG Abatement Cost Curve

Required additional investment by 2030 is estimated at 0.9% of annual GDP, with an average cost of EUR ~10/tCO_2e and significant differences between sectors

If Poland were to implement all the measures on the cost curve, the theoretical average abatement cost would be EUR ~10/tCO_2e by 2030. Transaction and program costs, which have not been factored into the curve, are estimated at EUR 1-5/tCO_2e, on average, and would have to be added to the cost of some measures.

This estimate should be considered with caution for two reasons: firstly, the assumption that all opportunities would be seized is highly optimistic; secondly, significant dynamics would affect the economy with a program of this magnitude. Such effects, which could either increase or decrease costs depending on how measures were implemented, have not been factored into the analysis.

Many of the abatement opportunities involve investing additional resources upfront to make existing or new infrastructure more carbon efficient and recouping that investment in part or in full through lower energy or fuel spending. Although it makes economic sense to pursue such opportunities, unlocking the potential could be challenging. The required additional upfront investment could discourage consumers from opting for the more efficient product, even if it saved them time or money.

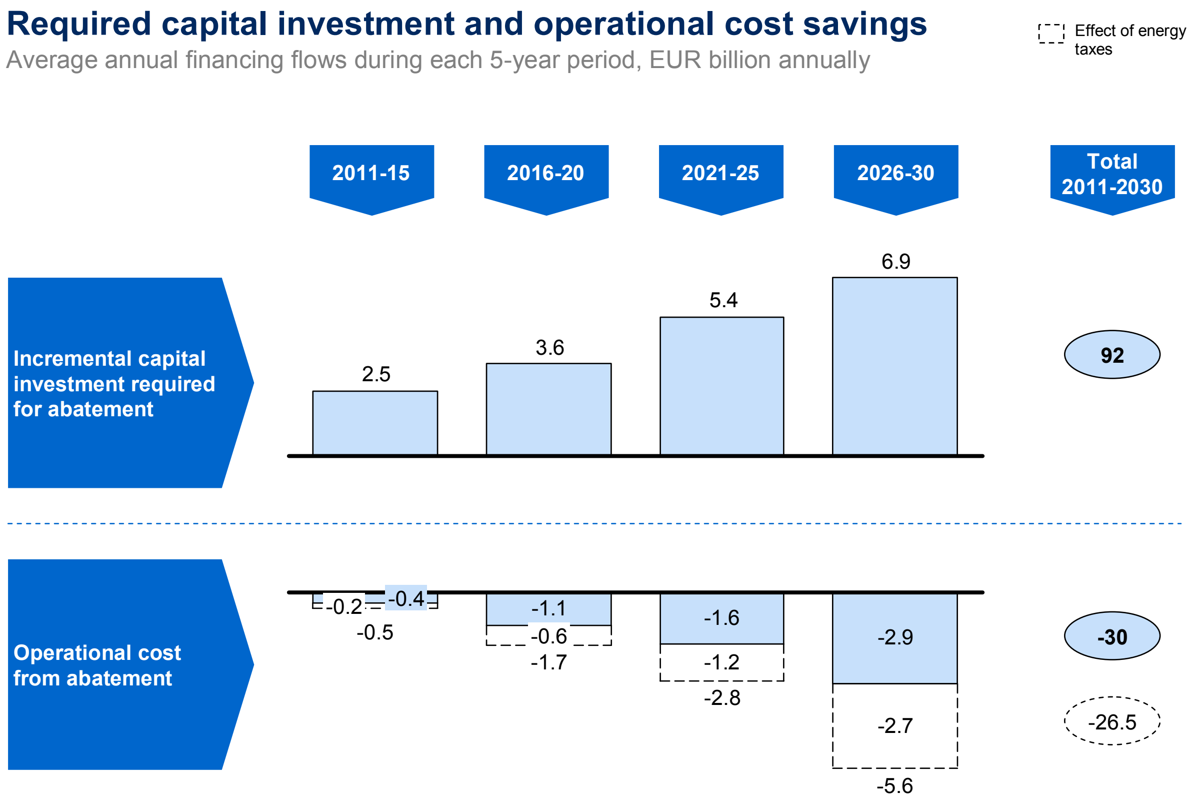
Analysis of the capex and the opex savings (Exhibit 10) reveals that the required annual incremental investment would grow as more abatement opportunities were implemented. Similarly, the operational cost savings would increase as the energy efficiency potential was captured[13]. The total additional investment required from 2011 to 2030 is estimated at EUR 92 billion. On an annual basis, the additional investment is estimated at ~1% of GDP[14]. By comparison, total direct investment in Poland in 2008 was 22% of GDP. These costs and the required capital would be split somewhat unevenly among sectors and vary over time.

It should be kept in mind that for every MWh saved, investors also save in terms of the energy taxes they would otherwise have to pay. Meanwhile, since these taxes represent government revenue, a reduction in energy demand lowers government income. Thus, whereas the total savings for consumers would be EUR 5.6 billion per year from 2026 to 2030, savings for the entire economy would be EUR 2.9 billion per year.

[13] The value of savings is highly dependent on assumed fuel prices. We assume that prices (currently paid by power companies in Poland) would develop in line with IEA "Global Energy Outlook 2007" trends. Thus, fuel prices in 2030 would reach the following levels: hard coal – 101 USD/t; oil – 62 USD/bbl; gas 13 USD/mbtu.

[14] Throughout the period we have assumed a fixed exchange rate of USD 1.50 per EUR 1.

Exhibit 10



SOURCE: Poland GHG Abatement Cost Curve

Financing costs, fuel prices, and technology costs affect the cost of abatement

In addition to the uncertainties surrounding the costs of fuels and the costs and feasibility of technologies in early stages of development (e.g., CCS, offshore wind), financing costs also significantly influence the cost of abatement.

Higher energy prices primarily affect the cost of energy efficiency measures. Assuming a 50% rise in the price of oil (and a proportionate rise in other fuel prices), the average cost of abatement would be reduced from EUR 10 to 4/tCO_2e (as a rule of thumb, an increase in the price of oil of USD ~10 per barrel decreases the average cost of abatement by EUR 2/tCO_2e).

The assumptions on the capital investment required to implement various technologies also influence the cost of abatement. For example, increasing the total capital investment required to install 1 GW of nuclear capacity by EUR 500 million increases the abatement cost of nuclear by about EUR 4/tCO_2e. For offshore wind, this change leads to a EUR 15/tCO_2e increase.

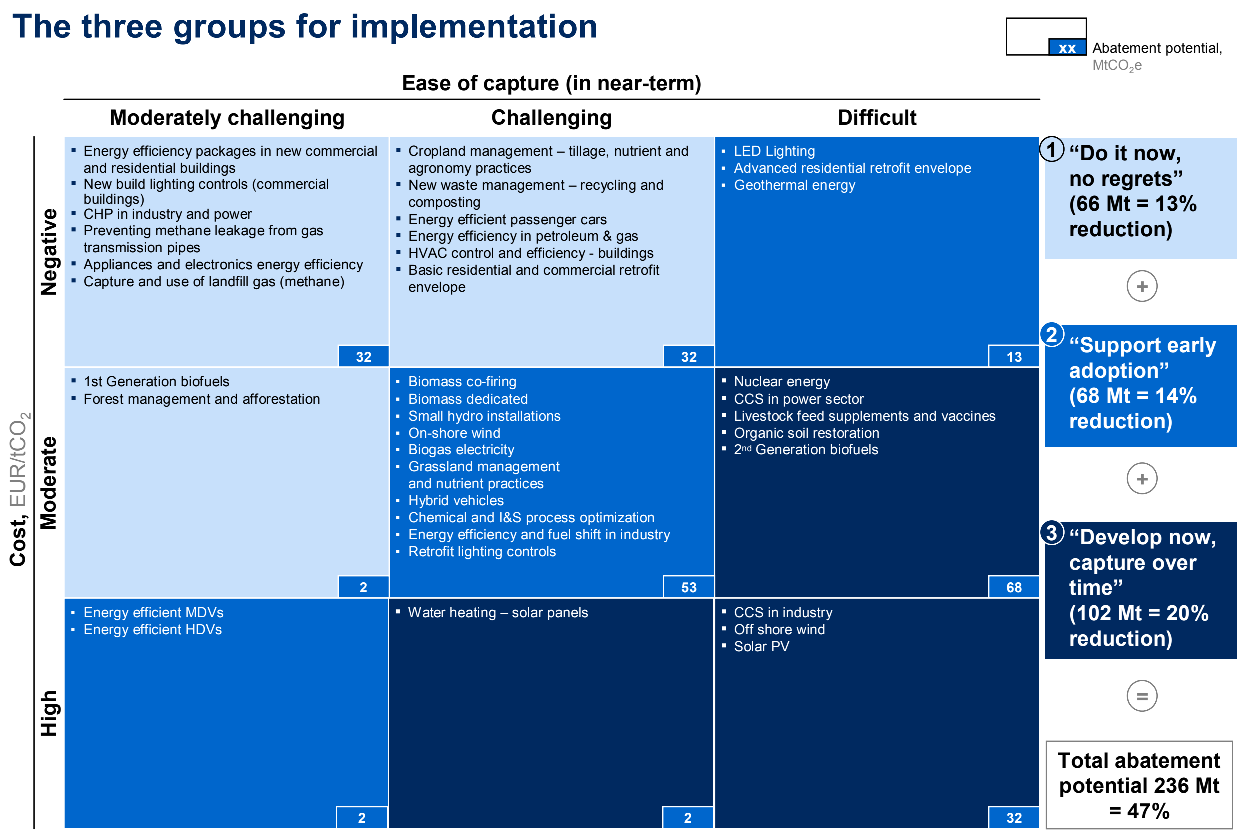
So far, we have assumed a risk-free financial rate of 4% for the required investments, excluding the mechanisms government has at its disposal to influence investment decisions: energy taxes and subsidies, feed-in tariffs, and free market mechanisms such as certificates and carbon allowances. Such mechanisms could be applied to favor abatement investments and reduce some of the investment risk. A higher interest rate of 8% would increases the cost of capital-intensive technologies with relatively short lifetimes, such as wind turbines and hybrid vehicles, increasing the total abatement cost from EUR 10 to 19/tCO_2e.

To maximize emissions reductions, urgent action is needed in Poland

Steering the Polish economy towards low-carbon growth path, would require policymakers, businesses, and consumers to start thinking about implementing abatement measures now. Two types of considerations would influence the sequencing and effectiveness of abatement actions.

The first consideration involves the practical timing of capturing each opportunity, which is influenced by the current cost of the measure and its ease of capture. With this in mind, each group of measures has been assigned to one of three implementation groups (Exhibit 11) – a means of classification necessarily simplifying the abatement process. The purpose of the matrix is to map the opportunities and the costs on a timescale.

Exhibit 11



SOURCE: Poland GHG Abatement Cost Curve

The first group consists of measures which are relatively easy to implement and result in net economic benefit or have moderate abatement cost (up to EUR 40/tCO_2e). For example, increasing the share of recycled waste would reduce both emissions and the cost to society. Moreover, proven mechanisms to achieve it exist. Measures in the second group either have higher abatement costs or would require some build-up of regulatory or institutional capabilities. These would entail adopting innovative technologies, such as hybrid vehicles, or innovative processes and techniques, especially in agriculture, as well as efficiency opportunities in industry. Opportunities in this group should be addressed by measures which support early adoption and create a favorable environment for scaling up implementation in the future. Finally, the third group consists of measures with significant implementation barriers in terms of cost and existing mechanisms for effective capture. They require either technologies to mature significantly (e.g., CCS, offshore wind) or very high capital expenditures and the overcoming of regulatory challenges, as for nuclear. For Poland, measures in the third group not only represent a significant part of the abatement potential but also determine the country's future carbon development path. These opportunities could be seized over time by taking the necessary steps today.

The second consideration involves issues related to the timing and scope of implementing opportunities. While implementing all the opportunities from 2010 onwards would be ideal from the standpoint of GHG abatement, we have analyzed the impact of delay and incomplete implementation. Exhibit 12 summarizes the four theoretical scenarios we have analyzed to illustrate what is at stake.

Exhibit 12

Potential implementation scenarios

	Description	Assumptions
A Full Implementation	▪ **Climate change mitigation becomes a top priority** ▪ Timely and decisive action is taken to capture abatement	▪ Full abatement potential is captured in time
B Implementation Difficulties	▪ **Steps are taken to tackle climate change** ▪ Implementation difficulties prevent full capture of the potential	▪ Most measures in Group 1 are successfully implemented ▪ More difficult opportunities in industry and power (efficiency, CCS, offshore wind) are not fully captured
C Delayed Action	▪ **"Wait and see" attitude** ▪ As pressure to reduce emissions grows, action is taken	▪ Abatement actions do not start until 2015 ▪ After that, the full abatement potential is captured in all three horizons
D Delayed Difficult Decisions	▪ Climate change is treated with some urgency, but other matters get higher priority ▪ **Difficult measures are avoided**	▪ Abatement action begins in 2010 ▪ Abatement measures in Group 1 and Group 2 are captured in full, but nuclear and offshore wind power, and CCS, are not implemented

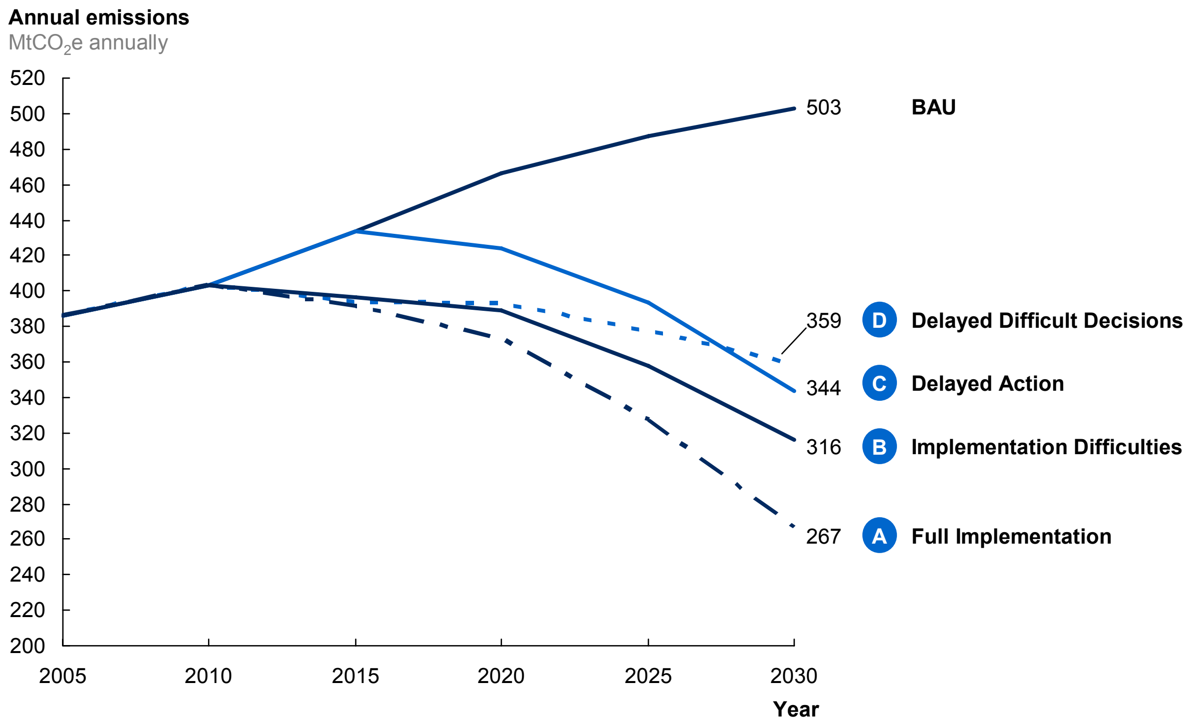
SOURCE: Poland GHG Abatement Cost Curve

Our analysis shows that if Poland delays crucial decisions about the power supply by five years, its ability to realize the full abatement potential would be significantly inhibited (Exhibit 13).

Delaying decisions on CCS, nuclear, and offshore wind power would considerably limit the abatement potential in 2020 and 2030 (Exhibit 14), and would likely lock Poland into carbon-intensive infrastructure for years to come. Delaying action by only five years could reduce abatement potential by over 30%.

Exhibit 13

Scenarios' impact on abatement potential



SOURCE: Poland GHG Abatement Cost Curve

Without suggesting what specific measures policymakers should take, we highlight three main policy areas where we believe actions are required to reduce emissions while maximizing the economic benefit for Poland:

1. Addressing market imperfections (e.g., subpar technical norms and standards) that limit energy efficiency and prevent other measures which have net economic benefits (e.g., waste recycling) from being implemented.

2. Establishing stable long-term incentives (e.g., CO_2 prices or taxes) to encourage power producers and industrial companies to develop and deploy GHG-efficient technologies.

3. Providing support, including sufficient incentives, for the adoption of relatively new technologies, such as hybrid vehicles, second generation biofuels, and LED lighting.

Exhibit 14

Scenarios' impact on overall reduction potential in 2020

Scenario	Annual emissions, 2020 $MtCO_2e$	Change vs. 1988 %	Change vs. 1990 %	Change vs. 2005 %
BAU	466	-18	2	21
Delayed Difficult Decisions	393	-31	-14	2
Delayed Action	424	-25	-8	10
Implementation Difficulties	389	-32	-15	1
Full Implementation	373	-34	-19	-3

SOURCE: Poland GHG Abatement Cost Curve; KASHUE; National Inventory Report

* * *

This report does not take a viewpoint on scientific explanations of the causes of climate change. Rather, it focuses on providing objective, consistent data on opportunities to reduce GHG emissions and on their expected costs. It is intended to serve as a starting point for discussions among companies, policymakers, academics, and other stakeholders on how best to manage Poland's transition to a low-carbon economy.

The Global Context

The Global Context

Most scientists agree that global warming is caused by human-produced greenhouse gases and could severely impact the environment

According to the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report, "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations"[15]. By trapping heat that would otherwise escape into space, GHGs help to keep the planet warm. Adding GHGs to the atmosphere traps more heat, thus increasing the equilibrium temperature of the earth's climate. The IPCC report argues that to limit the increase in temperatures compared to pre-industrial levels, deep emissions cuts are required.

From 1990 to 2005, emissions have grown from 36 to 46 $GtCO_2e$ and are forecast to grow to 70 $GtCO_2e$ by 2030

Most of the current research forecasts that, in the absence of major global policy action, global emissions will continue to grow at a similar pace as they have grown historically, driven by world population growth and rising wealth. Drawing on external sources widely acknowledged to contain some of the most comprehensive projections of GHG emissions, we see BAU global anthropogenic GHG emissions increasing by around 55% from 2005 to 2030, going from 46 to 70 $GtCO_2e$ per year – or annual growth of 1.7%[16]. The emissions baseline is subject to substantial uncertainty, mainly due to unclear GDP and population growth assumptions as well as questions regarding how carbon-intense countries' chosen development paths will be. If the economic crisis lasts longer than currently assumed, BAU emissions might grow more slowly. The abatement potential and, consequently, the achievable emissions development over time are strongly linked to the baseline.

Our analysis splits emissions by region (Exhibit 15). In 2005, the developed world contributed about 40% of total global emissions and the developing world roughly 56%, with the remaining 4% coming from global air and sea transport, which, in line with international agreements, is not attributed to a specific region. Under the BAU scenario, the developed world will contribute 32% of the total by 2030, the developing world 63%, and global air and sea transport 5%.

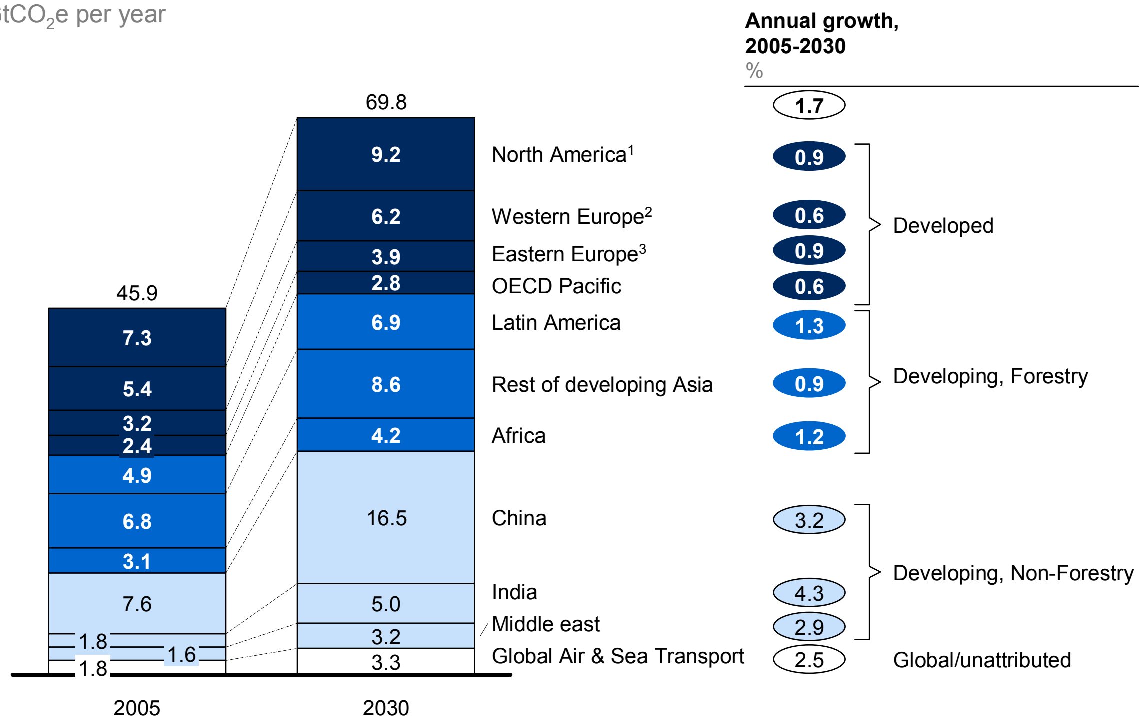
[15] The key document summarizing the scientific rationale for the link between greenhouse gas concentrations and climate change is the 2007 Intergovernmental Panel on Climate Change (IPCC) report, created by over 2,000 scientists who cooperated on an international effort sponsored by the United Nations. A much-discussed report by a team of economists from the UK Treasury (Stern, 2006) examines the economic impact of climate change as well as the economics of stabilizing GHGs.

[16] McKinsey & Company, "Pathways to a Low-Carbon Economy", 2009: For our BAU analysis, we have drawn directly from a range of expert sources: the International Energy Agency (IEA) for CO_2 emissions from fossil-fuel combustion; Houghton 2003 revised, the UNFCCC, and the IPCC for land-use, land-use change and forestry (LULUCF) emissions including peat; and the US Environmental Protection Agency (EPA) for emissions of non-CO_2 GHGs. For industry sectors, we have constructed emissions baselines leveraging IEA data wherever possible.

Exhibit 15

Business-as-usual emissions split by region in 2005 and 2030

$GtCO_2e$ per year



1 US and Canada
2 EU-27, Andorra, Iceland, Lichtenstein, Monaco, Norway, San Marino and Switzerland
3 Non-OECD Easter Europe and Russia

SOURCE: Houghton; IEA; IPCC; UNFCCC; US EPA; McKinsey Global GHG Abatement Cost Curve v2.0

In per capita terms, 2005 emissions were approximately 14 tCO_2e per year in the developed world and 5 tCO_2e per year in the developing world. By 2030, per capita emissions in the developed world are expected to remain more than twice as high as those in the developing world (16 and 7 tCO_2e per year, respectively), despite the fact that expected annual growth in developed countries of 0.7% is only one third of the 2.2% growth rate expected in developing countries.

Objectives and Methodology

Objectives and Methodology

The GHG abatement cost curve represents the combined potential of over 100 emissions reduction levers, ranked according to their costs and determined using a proven methodology tailored to local conditions

To evaluate the potential for GHG reductions in Poland, we analyzed the costs and abatement potential of more than 200 levers across 10 sectors of the economy. Our analysis focused on the 10 largest sectors, which together accounted for over 85% of GHG emissions in 2005. Specifically, we constructed detailed bottom-up estimates for power, chemicals, iron and steel, petroleum and gas, cement, buildings, transport, agriculture, waste management, and forestry. Abatement potential was analyzed using a three-step process (Exhibit 16). First, a BAU case was constructed to serve as the baseline for future emissions reductions. Second, a range of reduction opportunities were identified, and estimates were made of the costs and potential abatement volume of each. Third, these levers were ranked according to their costs to create the GHG abatement cost curve for Poland, which represents the total economic abatement potential under a cost threshold of 80 EUR/tCO_2e and the related costs per lever, calculated as incremental to the baseline.

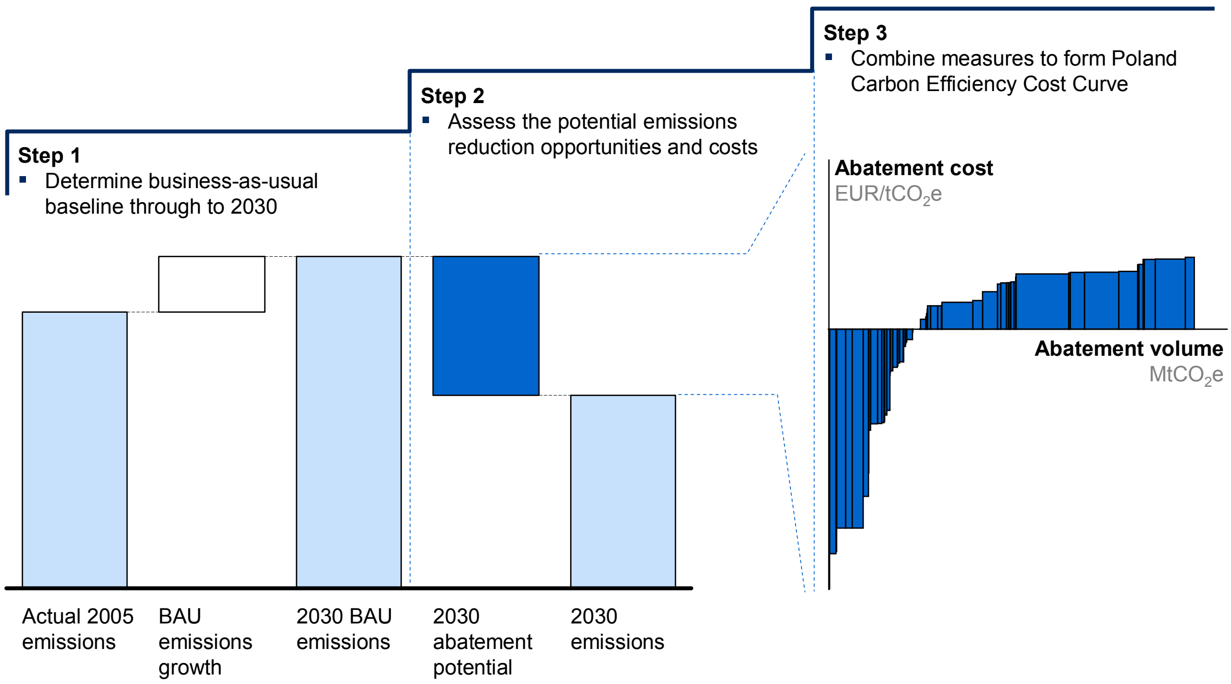
Step 1: BAU case baseline for emissions through 2030 was constructed, drawing on a number of governmental and other public sources

These forecasts represent the emissions trajectory that would occur under current trends, assuming few additional efforts were made to address climate change. Estimates of emissions levels were constructed from the bottom up, based on future production levels for industry and future activity levels in transport and buildings. 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.

Exhibit 16

Three-step process of quantifying GHG abatement opportunities

$MtCO_2e$



SOURCE: Poland GHG Abatement Cost Curve

Step 2: Potential emissions reduction opportunities and costs were assessed

We first identified potential actions that could reduce GHG emissions in Poland, and then we quantified the amount of reduction possible and the cost per ton of eliminated GHG emissions.

When considering abatement opportunities, we drew on a catalogue of options compiled by McKinsey & Company globally in cooperation with leading external climate change experts. Potential options include a broad range of technologies and measures – such as renewable energy, alternative fuels, energy efficiency measures, and new technologies – which allow GHG-generating activities to be replaced by low-emission or carbon-neutral alternatives.

Two groups of levers were not included. First, speculative technologies were excluded. Although we analyzed a range of abatement opportunities, we concentrated on measures with a cost of less than EUR $80/tCO_2e$[17].

[17] Using IPCC terminology, we studied the economic potential below EUR $80/tCO_2e$ of technical emissions reduction opportunities. We chose an economic cutoff to enable us to compare the size of opportunities within different sectors and regions in an objective way. We chose EUR $80/tCO_2e$ because higher-cost measures tend to be early-stage technologies with development paths that are difficult to project.

Secondly, we did not consider levers that would require significant consumer lifestyle changes. For example, while fuel substitution and improved vehicle efficiency were within the research scope, public transport and bicycle riding to replace private vehicles were not[18]. Similarly, increasing the efficiency of residential heating was considered, but reducing average home temperatures was not. Opportunities involving lifestyle and behavioral shifts were kept out of the scope because their costs or benefits are largely nonfinancial and therefore difficult to quantify. In fact, many of these out-of-scope shifts may be attractive, and some are likely to occur automatically in response to carbon price signals in the economy. We believe that, on balance, our projections are conservative, since they do not include behavioral shifts and technological developments that might take place in the future.

For each lever, the abatement cost[19] was taken to be the additional cost of implementing the opportunity compared to the cost of the activity that would otherwise have been incurred (i.e., in the BAU). Thus, for example, the abatement cost of wind power was calculated as the additional generation cost over and above the average generation cost of power assets in the reference case, while also taking the quantity of emissions avoided by each produced unit of wind energy into consideration. Our analysis of costs did not take into account transactional costs, taxes, subsidies, feed-in tariffs, and other governmental measures, which depend on policy decisions and could serve as levers to encourage or discourage climate change actions. In keeping with our view of abatement from a societal or governmental perspective, we used a risk-free financing rate of 4%. This approach allowed us to compare results across countries and over time while discounting the differences in government policies. For Poland, we also developed a unique investor perspective, testing the cost curve's sensitivity to a higher interest rate of 8%. It is important to note, however, that we did not make any assumptions about who would bear the incremental costs of abatement. We assumed that whether subsidized by the government, passed on to consumers, or paid for by businesses, the underlying economic costs would remain the same.

We kept in mind that volumes are sensitive to the order of implementation. For example, since power demand reduction initiatives reduce the total amount of energy produced, they reduce the additional abatement potential of the power sector as well. To avoid double counting, we attributed the emissions associated with implementing a given lever to the relevant industry producing those emissions (e.g., the GHGs emitted during production of photovoltaic solar panels were not attributed to this lever itself, but to the manufacturing industry).

Step 3: Measures were combined to form the cost curve for Poland

The various GHG abatement measures were ranked from lowest to highest in terms of cost, and adjusted to eliminate double counting. Their costs and volumes were then plotted to create a GHG abatement cost curve for Poland. This cost curve represents the economic potential under 80 EUR/tCO_2e for emissions reductions in Poland by 2030. The adoption rate of new technologies depends strongly on energy prices[20] as well as on cost and performance improvements, neither of which can be predicted with precision. We used the cost curve to calculate the abatement levers achievable and the associated costs. We also modeled the investment costs related to the implementation of different levers in order to provide a clearer view of the capital requirements related to abatement.

18 A discussion of the measures which can support behavioral change in transport is included appendix.

19 The abatement cost is the weighted average across sub-opportunities and years, and is calculated as the sum of incremental capital expenditures (annualized as a repayment at an interest rate of 4%) and incremental operational expenditures or savings.

20 We assume that current prices (paid by power companies in Poland) would develop in line with the IEA's energy outlook trends. Thus, fuel prices in 2030 reach the following levels: hard coal – 101 USD/ton; oil – 62 USD/bbl; gas 13 USD/mbtu.

GHG Abatement Potential in Poland

GHG Abatement Potential in Poland

In 2030, emissions could be reduced by 47% against the baseline by capturing energy efficiency potential, adjusting the fuel mix in the power sector, implementing Carbon Capture and Storage, and pursuing a variety of other measures. Many measures would pay off over time, but major barriers need to be removed to unlock the abatement potential

BUSINESS-AS-USUAL EMISSIONS TRAJECTORY IN POLAND

If little is done in Poland to address climate change, GHG emissions are forecast to grow 30% above 2005 levels by 2030

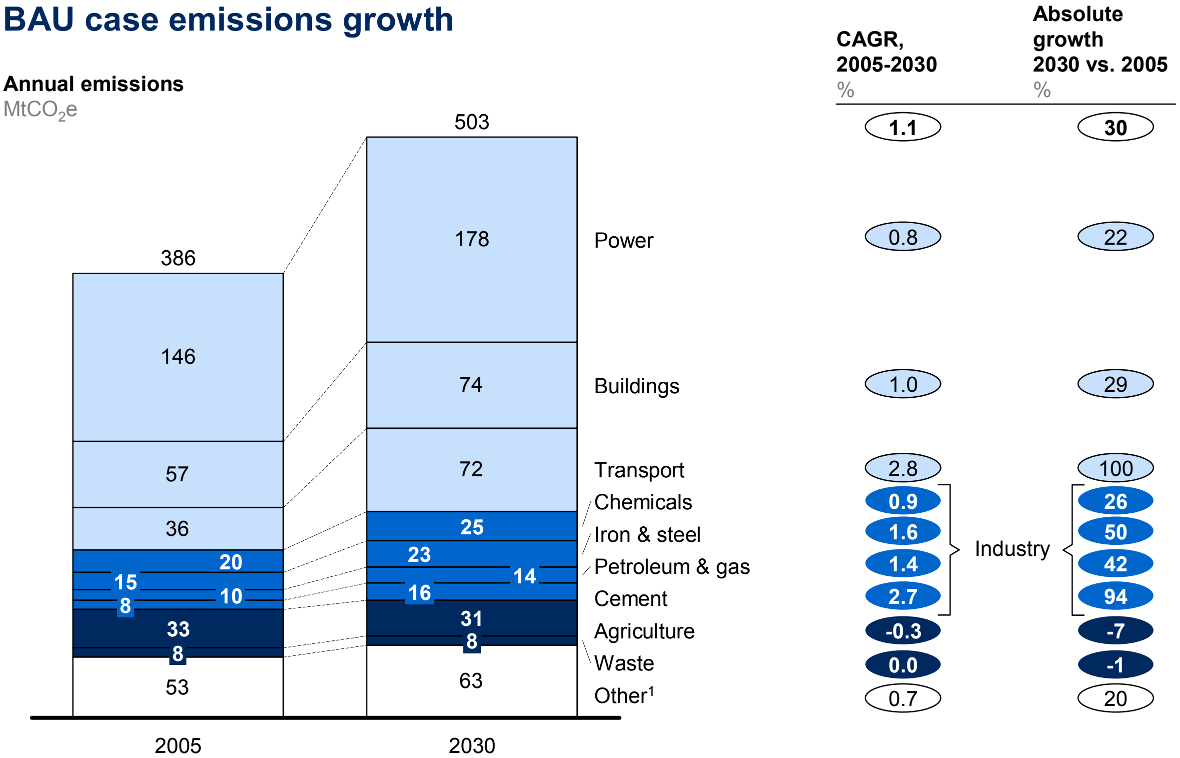
Under current trends, total emissions in Poland are forecasted to grow to 503 Mt by 2030, or 30% above 2005 levels of 386 $MtCO_2e$, at a rate of 1.1% per year, compared to projected annual economic growth of 3.4%. This means that the CO_2 intensity of the economy (i.e., the CO_2 emissions per unit of economic output) will continue to decline, which is consistent with the long-term trend among developed countries worldwide (Exhibit 17). This trend is being driven by the relative growth of the services sector and other reference-case decarbonization effects.

Compared to the EU-27, emissions are expected to grow faster in most sectors in Poland due to the country's faster economic growth until 2030. The especially aggressive growth of emissions in transport is due to the forecasted increase in passenger cars per 1,000 inhabitants (projected to reach EU levels of 500-550 cars per 1,000 people by 2030). In other sectors where dynamic growth is expected (e.g., cement, iron and steel), emissions growth is connected with production increases to supply materials to fuel the continuously strong growth in construction.

The relatively aggressive emissions growth in some sectors would, if unaddressed, alter the structure of emissions in Poland to resemble that of the EU-27 by 2030 (Exhibit 18). However, the power sector would still account for about one third of emissions in Poland (due to its large dependence on coal), as opposed to close to one fifth in the EU. Transport and buildings would continue to contribute somewhat smaller shares than in the EU, but the remaining sectors would represent very similar shares of the total emissions in Poland as in the EU. Given the continuing predominance of electricity production, abatement actions in the power sector would be disproportionately more important for overall emissions reduction.

Exhibit 17

BAU case emissions growth



NOTE: 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

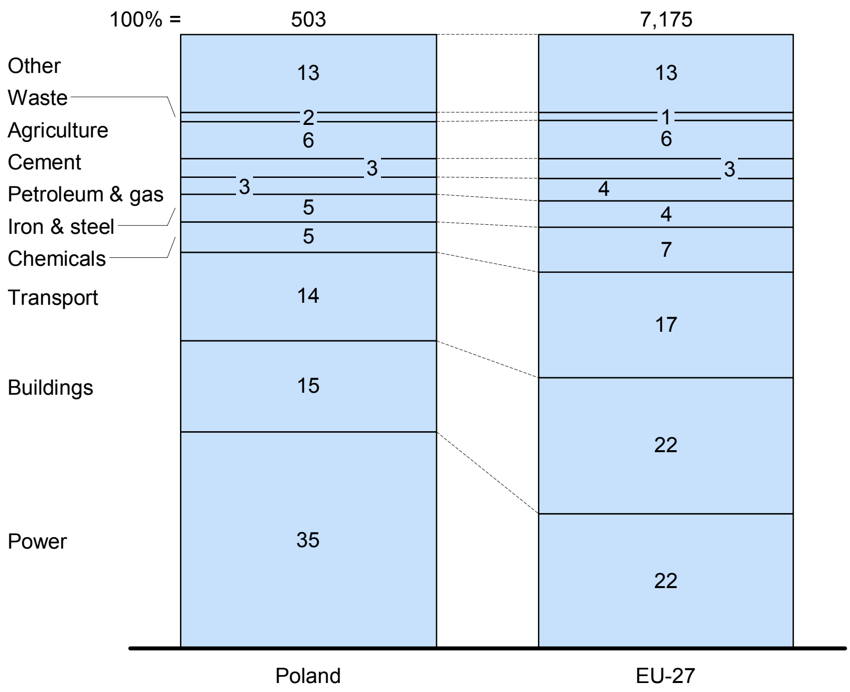
1 Includes among other: mining, light industry, food & beverage industry, glass production, colored metals, off-road transport, etc.

SOURCE: Poland GHG Abatement Cost Curv; KASHUE; sector specific sources

Exhibit 18

Business-as-usual emissions in Poland and in the EU-27

2030, $MtCO_2e$, percent



SOURCE: Poland GHG Abatement Cost Curve; McKinsey Global GHG Abatement v. 2.0

TOTAL ABATEMENT POTENTIAL

Abatement potential in Poland is significant, but capturing it would require pursuing a number of fragmented opportunities across the economy

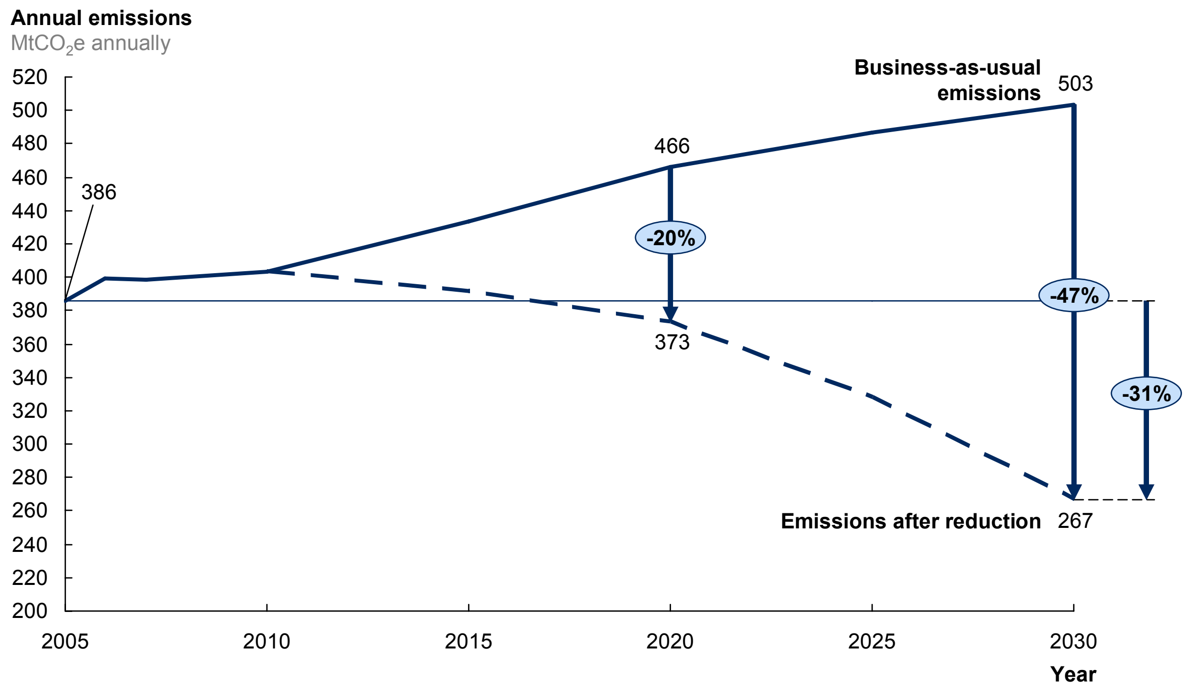
The cost curve identifies abatement potential of 236 $MtCO_2e$ by 2030 (Exhibit 19), a 31% reduction from 2005 levels, or 47% from the levels we would see in 2030 if Poland made little attempt to curb current and future emissions (the BAU scenario)[21]. The pace of abatement would pick up significantly only after 2020, when major projects in the power sector (e.g., large-scale offshore wind generation, nuclear, CCS) became operational. Thus, the abatement potential in 2020 is 87 $MtCO_2e$, or two and a half times less than the total abatement potential in 2030 (236 $MtCO_2e$)[22].

[21] Our BAU emissions projection represents the theoretical emissions trajectory that would occur under current trends, with little additional efforts made to address climate change. It was constructed from the bottom up, based on industry production levels and assuming natural improvements in technological efficiency. BAU emissions do not reflect current climate change regulations and targets.

[22] We did not account for potential rebound effects in our modeling. An example of a rebound effect would be if resources freed up by energy savings were used for alternative, potentially high-carbon consumption.

Exhibit 19

Emissions reduction potential relative to business-as-usual baseline



SOURCE: Poland GHG Abatement Cost Curve

Even though there is potential for deep cuts in GHG emissions in Poland, making them would require concerted, targeted actions by government, business, and consumers. Significant gains would have to be made, for example, in the energy efficiency of buildings and transportation, and the share of low-carbon energy sources would have to rise to over 50% of the total electricity supply in 2030, up from less than 2% in 2005[23].

Analysis shows that such changes would be feasible, but full implementation of all opportunities on the cost curve would represent a major undertaking. Looking at GDP emissions intensity (i.e. the amount of carbon produced per EUR 1,000 of GDP), to achieve the total identified technical potential by 2030, Poland would have to decrease its GDP emissions intensity by almost 70% against current levels, and by over 40% against the BAU scenario level.

As Exhibit 20 illustrates, our analysis identified roughly 125 different measures to reduce GHG emissions in Poland by 2030. The average cost of these measures is approximately EUR 10/tCO_2e. Measures with net economic benefit would contribute ~34% of the total abatement (81 MtCO_2e) in 2030. If these were pursued, the initial required investment would pay off over time, allowing consumers and businesses to reduce both emissions and costs. Most of the efficiency measures, and measures such as increased

[23] The exact share of low-carbon technologies would depend on the fuel mix in the power sector. We have analyzed several potential fuel mix scenarios, described in more detail on page 45.

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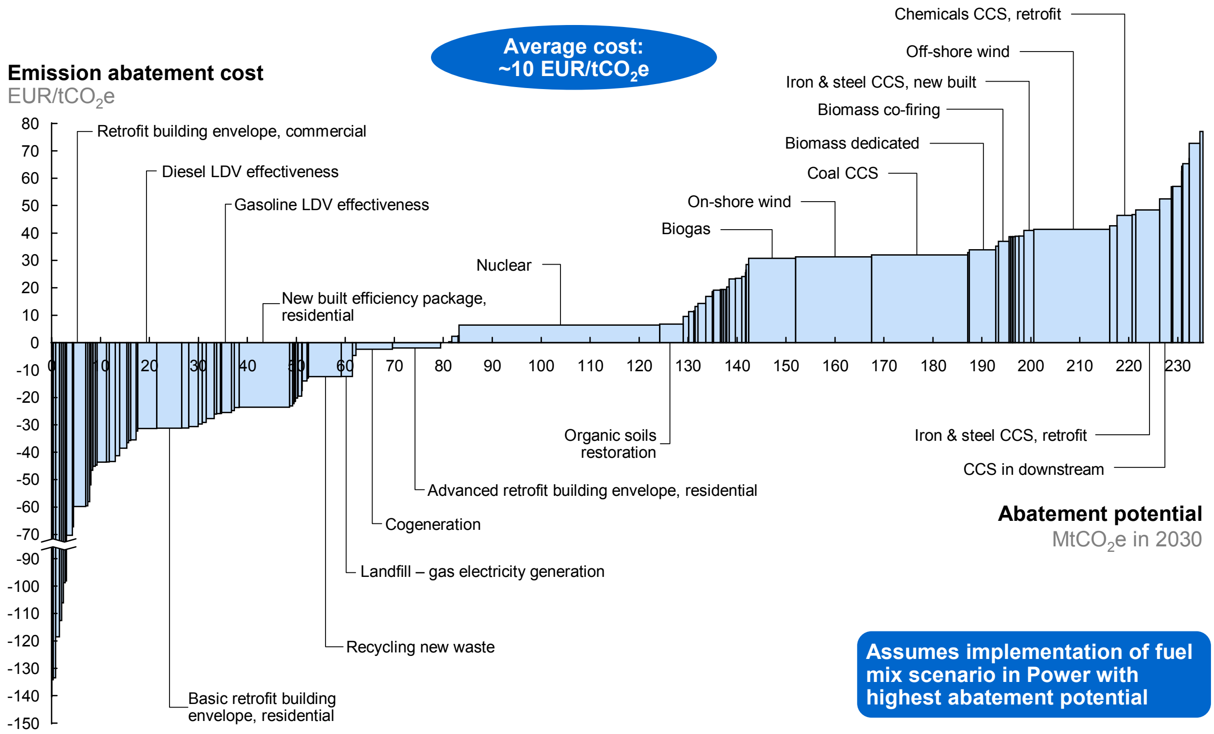
recycling, fall into this category. Most measures (117 $MtCO_2e$, or ~50% of the total potential) cost between EUR 0 and 40/tCO_2e. These include nuclear and onshore wind technologies, for example. The remaining 16% of the total abatement (37 $MtCO_2e$) is related to measures which cost over EUR 40/tCO_2e. This category includes offshore wind, CCS in industry, and solar PV. Additional incentives would likely be required in order to capture these opportunities.

Exhibit 20

GHG abatement cost curve for Poland in 2030[1]



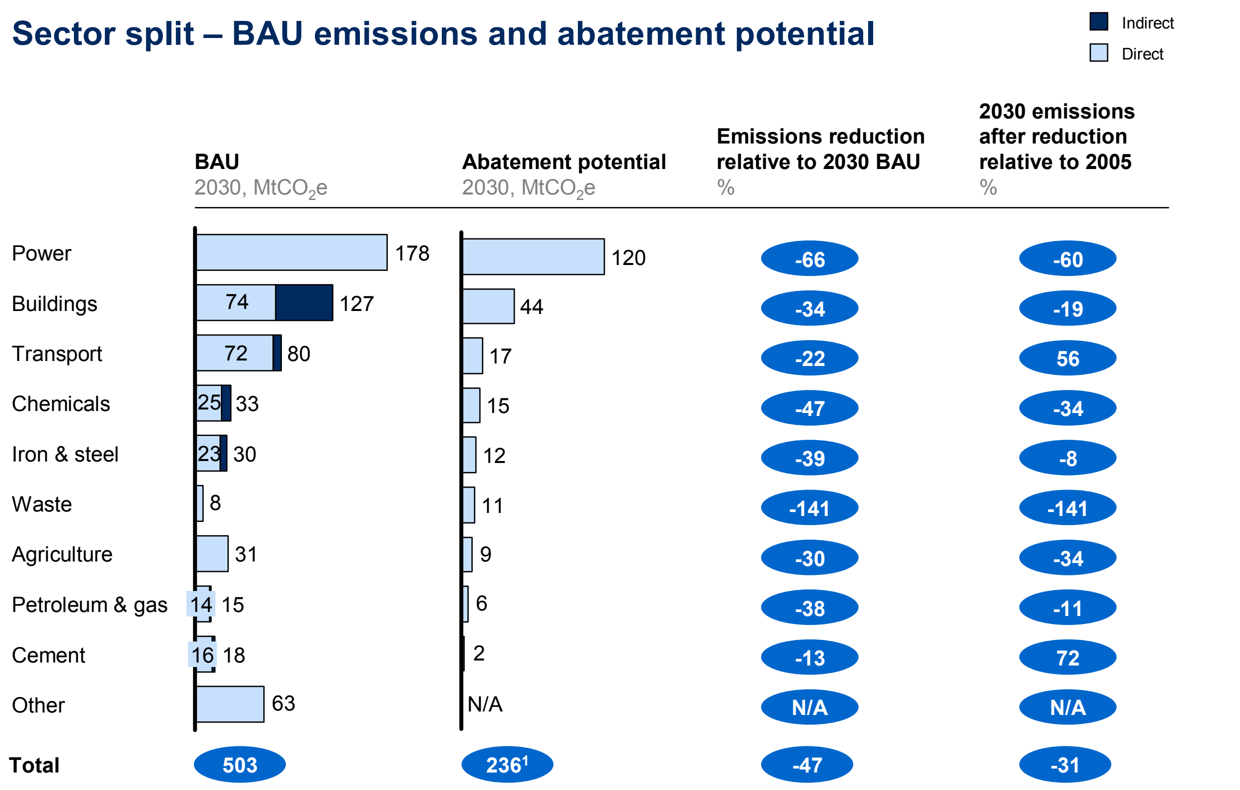
1 Only the most significant abatement opportunities are named

SOURCE: Poland GHG Abatement Cost Curve

The opportunities, which fall into each of these cost buckets, are fragmented and spread across all sectors of the economy (Exhibit 21). Despite the diversity of measures that could be implemented to reduce emissions, four broad groups can be identified: opportunities to improve energy efficiency (69 $MtCO_2e$, or 29% of the total potential), opportunities related to changing the power generation fuel mix (100 $MtCO_2e$, or 42%), opportunities related to using CCS in industry and power (35 $MtCO_2e$, or 15%), and all other opportunities (33 $MtCO_2e$, or 14%).

In the sections that follow, we look at each of the four groups of opportunities in detail, discuss the main barriers to implementation, and touch on the policy measures that could overcome them.

Exhibit 21



1 Including Forestry

SOURCE: Poland GHG Abatement Cost Curve

ENERGY EFFICIENCY

Energy efficiency measures pay off over time, but major barriers must be removed to unlock this potential

Energy efficiency measures account for ~30% of the total identified abatement potential in 2030. The implementation of these measures would generally reduce the energy intensity of the economy, and thus the amount of fossil fuels required for economic growth – and their related emissions. Energy efficiency measures could greatly accelerate the rate of decoupling of economic development from GHG emissions while minimizing risks and ensuring sustainability[24].

Exhibit 22 shows the Polish energy efficiency cost curve for 2030. Of the total identified energy efficiency, ~65% (44 $MtCO_2e$) is in the buildings sector. These measures include better insulation as well as more energy-efficient appliances, water heaters, and lighting. Around 20% of the abatement (15 $MtCO_2e$) is in the transport sector, due to more fuel-efficient vehicles. The remaining 15%

[24] As an EU member state, Poland is obligated to increase energy efficiency in the buildings sector under EC directive 2006/32/EC. The government has accepted an indicative target of achieving 9% energy savings by 2016 with an intermediate target of 2% in 2010.

(10 $MtCO_2e$) is in industry, and could be achieved through measures such as improving motor systems in chemical plants and implementing energy efficiency projects in petroleum and gas.

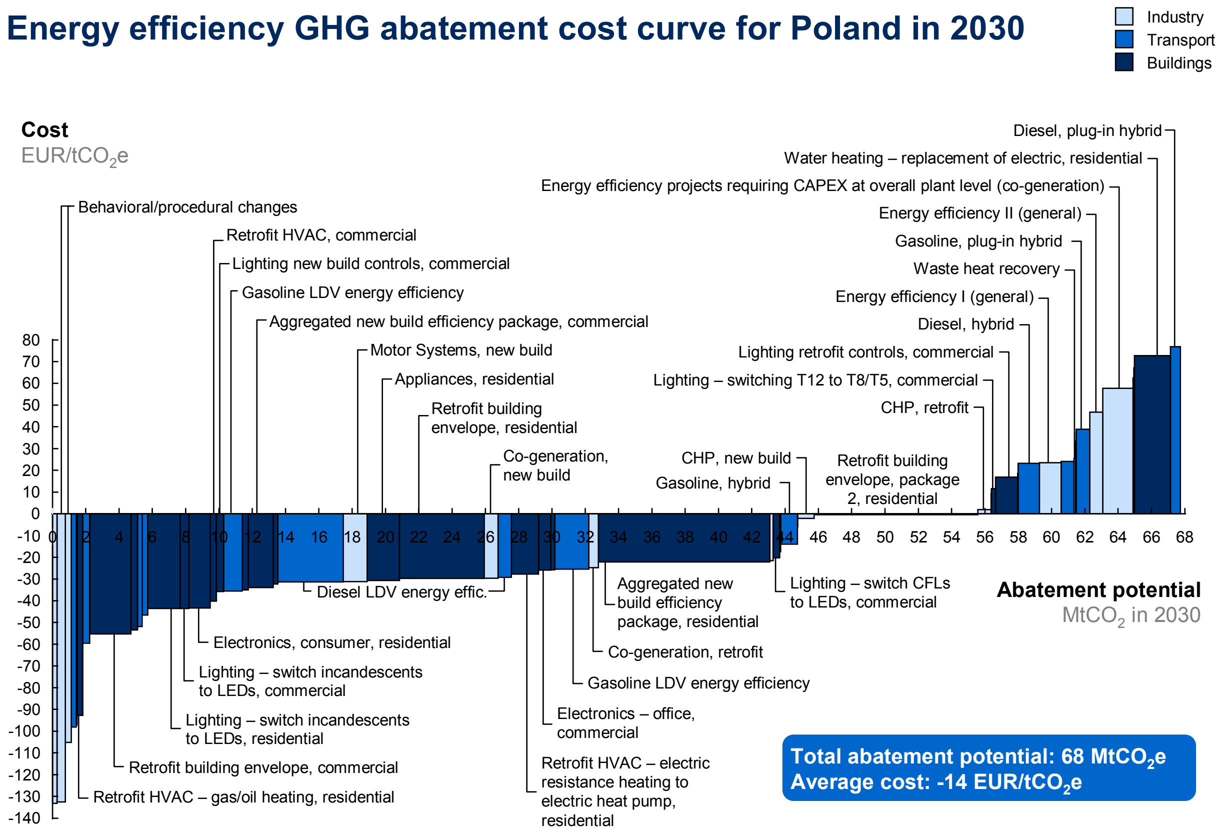
In terms of costs, energy efficiency measures present a net benefit to society and should be implemented regardless of climate change discussions. Across sectors and over time, investments in improving energy efficiency result in net savings of about EUR 14/tCO_2e. Costs vary by sector, with GHG emissions reductions in buildings, transport, and industry saving EUR 18, 8, and 6/tCO_2e, respectively.

Given the net savings and the relatively low risk inherent in energy efficiency measures, it is important to understand why these levers have not yet been implemented and are not assumed in the BAU scenario.

In the following subsections, we touch on the energy efficiency measures with the highest abatement potential, some of the typical implementation barriers, and several mechanisms to address these barriers.

Exhibit 22

Energy efficiency GHG abatement cost curve for Poland in 2030



SOURCE: Poland GHG Abatement Cost Curve

Abatement potential

Buildings: Eight of the 11 most significant abatement levers are in the buildings sector. The largest potential is in improving the energy efficiency of residential buildings through a combination of measures, ranging from improved airtightness and insulation of attic and wall cavities to more sophisticated building retrofitting and passive heating and cooling standards. Implementing these measures in full could bring down heating and cooling consumption to ~30 kWh/m^2 and abate ~15 $MtCO_2e$ in 2030.

Enforcing strict energy efficiency regulations on both commercial and residential building projects is the next most important abatement lever in the sector, potentially reducing total emissions by about 12 $MtCO_2e$. Capturing this potential would depend on the public sector's willingness and ability to agree on and enforce sufficiently high building standards, and timely action by regulators would be crucial.

Of the remaining measures, replacing incandescent and CFL lighting with LED, implementing lighting controls in commercial buildings, and replacing appliances and electronic equipment with more efficient alternatives could abate 9 $MtCO_2e$ in 2030. Retrofitting HVAC (heating, ventilation, and air conditioning) and hot water pumps, and replacing electric heating systems with gas and solar systems, could abate around 4 $MtCO_2e$ in 2030.

Apart from the most sophisticated retrofitting of lighting controls and replacing water heating systems, all these measures would pay off over time.

Transport: In the transport sector, increasing the fuel efficiency of vehicles would keep emissions from growing at the same pace as projected road activity in Poland (3% per year). Our analysis focuses on improving efficiency and assumes this level of road activity as a given. Driving activity – and, therefore, the energy efficiency of the whole transportation system – could be reduced by other than technological measures (for examples of such levers see Appendix – Examples of Other Technological GHG Reduction Levers in Transport by Andrzej Kassenberg, PhD, Institute for Sustainable Development).

A wide range of technological measures – such as reducing vehicle weight, improving the aerodynamics and efficiency of engines, and automatically monitoring tire pressure – could increase the fuel efficiency of internal combustion engine (ICE) vehicles. Moreover, adding an electric battery to the vehicle's power train (full and plug-in hybrid vehicles) reduces the amount of fuel consumed and, thus, GHG emissions.

The first type of measures – improvements to ICE vehicles – offers the greatest abatement potential for Poland in 2030 (10 $MtCO_2e$). This opportunity is split unevenly between passenger cars and medium and heavy duty vehicles. ICE improvements in passenger cars account for 8 of the 10 $MtCO_2e$ and result in a net economic benefit: the net cost of abatement is EUR -35/tCO_2e. The remaining 2 Mt could be abated by improving the efficiency of medium and heavy vehicles. In this case, additional efficiency measures would be much more costly, since trucks and vans are already much more efficient fuel than most passenger cars.

Hybrid vehicles present an opportunity of ~4 $MtCO_2e$ at a weighted average cost of EUR ~25/tCO_2e. Although fuel use in hybrids is almost half that of ICE vehicles, fuel cost savings do not fully make up for the significant additional capital consumers need to invest upfront (see box on the following page for hybrid and electric vehicles in transport).

Industry: GHG abatement from energy efficiency measures in industry is split among three sectors: 3.4 $MtCO_2e$ could be abated by introducing energy-saving measures and increasing cogeneration in chemical plants, 3.5 $MtCO_2e$ could be abated by increasing general efficiency and cogeneration in iron and steel plants, and -3 $MtCO_2e$ could be abated by implementing efficiency projects and improving processes and maintenance practices in oil and gas plants.

New technology in transport – hybrid and electric vehicles

The cost curve considers two types of alternatives to the internal combustion engine (ICE).

Hybrid vehicles: Full hybrid vehicles (partially powered by a battery charged by the vehicle's stop-go cycle) and plug-in hybrid vehicles (partially powered by a battery charged by plugging it into the power grid) could reduce GHG emissions significantly (~4 $MtCO_2e$) by 2030. Their potential is determined by the relatively high share of new car sales such vehicles could account for by 2030: 20 to 25% for full hybrids and 10 to 20% for plug-in hybrids. However, attaining such a high share of new sales would be a significant challenge. Comparing a hybrid vehicle with a similar gasoline vehicle highlights the difficulty. A standard hybrid vehicle costs at least EUR 8,000 more than a standard car, while saving the consumer about 2 liters of fuel, or EUR 2 per 100 kilometers. Assuming the average annual distance travelled per vehicle is 11,000 kilometers and the vehicle's useful life is 15 years, these savings are insufficient to make up for the premium. For the hybrid to be competitive, the price difference would have to fall by two thirds, or fuel prices and taxes on ICE vehicles would have to increase significantly.

Fully electric vehicles (EV): Vehicles powered solely by a chargeable battery do not appear to present a big opportunity by 2030 for several reasons. First, most forecasts of their share of new car sales in 2020 and 2030 put converge at ~2% per year. We assume the same for Poland in our abatement case. Second, while the additional upfront cost for an EV is assumed to decrease significantly over time, it is still likely to be about EUR 6,000 in 2030. Thus, the abatement potential in Poland is both insignificant (0.1 $MtCO_2e$) and costly (EUR ~135/tCO_2e). Finally, and most importantly, the high carbon intensity of electricity in Poland means that an electric vehicle using 0.25 kWh of coal-produced electricity per kilometer actually pollutes more than the average gasoline vehicle, which uses ~7 l/100 km.

Implementation barriers

Although most of the above-mentioned measures would result in savings, and it is clearly in the interest of both consumers and companies to introduce them, capturing the abatement potential could prove very challenging. The following three hurdles prevent the maximization of energy efficiency.

High upfront investments

- ***Buildings***: Even though energy efficiency measures generally pay off over time, they require homeowners to invest money upfront. In addition, households often expect investments to pay for themselves within 3 to 4 years. However, many of the measures on the cost curve entail payback times of 5 to 10 years, depending on the type of measure and the interest rate applied. In addition, even when the payback period is sufficiently short, capital constraints may prevent households from pursuing efficiency opportunities.

- ***Transport***: The additional cost to the consumer per vehicle can reach EUR 3,000 to 4,000 for more energy-efficient models. Though this investment should pay off over the lifetime of the vehicle, consumers usually do not rely on pure cost-benefit analysis when making buying decisions. Thus, even if able to pay the premium, a consumer may choose to spend it on other features or accessories.

- ***Industry*****:** Energy efficiency projects are characterized by lower anticipated rates of return than other capital projects. Requiring relatively short payback times on investments due to capital constraints, industrial companies often choose not to pursue energy efficiency opportunities. This is particularly true because price volatility in the energy supply heightens the risk of efficiency projects not paying off. Furthermore, many banks consider energy efficiency investments to be higher risk, which increases the cost of financing.

Agency issues

- ***Buildings*****:** The owner, operator, occupant, and bill payer (i.e., benefitting party) of a building may be separate entities or may not be involved in the building for the entire relevant time period. As a result, he or she may not have an interest in supporting energy efficiency and GHG abatement. For example, property owners have little incentive to add insulation to buildings, as the resulting savings go to their tenants.

- ***Transport*****:** Given the irrationality of consumer preferences, it may not be clear to car makers that buyers would be willing to pay a premium for fuel-saving measures, even if the consumer would benefit. Therefore, fuel reduction options may not be offered at all.

Lack of awareness

- ***Buildings*****:** Although energy labeling is mandatory on appliances, and will become mandatory on buildings as well, lack of information still leads to unnecessary inefficiencies. Heaters and air conditioners may operate well below their nominal efficiency due to improper installation or maintenance. Consumers often do not understand the true added incremental cost of appliances and the cumulative benefits of purchasing a more energy-efficient one.

- ***Industry*****:** "The more you look, the more you find" is an oft-repeated, empirically substantiated observation of business leaders who have enjoyed sizeable gains through energy and process efficiency improvements. However, identifying and capturing efficiency opportunities are neither straightforward nor easy to learn to do.

Measures to overcome barriers

Designing the right policy framework to capture this potential in a cost-effective manner is a major challenge, requiring finding ways to overcome an array of market imperfections. Several mechanisms exist to address these barriers and to help achieve the targets[25].

White Certificates System**:** This market-based mechanism is intended to encourage investment in energy efficiency measures. Several EU countries (e.g., France, the United Kingdom, Italy) have implemented the system in one form or another. The mechanism encourages energy efficiency investments by defining obligatory certificate targets for national energy suppliers. Certificates can be denominated in MWh or other energy measures, and any project, as defined in the national regulations, which realizes energy savings is eligible to receive a white certificate. White certificates are traded on a national platform or in an auction. Energy suppliers who fail to present the required number of white certificates at the end of a certification period are liable to a fine, as defined by national legislation.

[25] Rather than a comprehensive list of all policies addressing energy efficiency, we aim to present a selection of measures which directly address the barriers to implementation we have listed.

If properly implemented, such a mechanism could address all three barriers at once. Since investing parties receive proportionate compensation for their initial spending (in addition to, or instead of, the benefit of a lower energy bill), general awareness of energy consumption increases among interested parties, and agency issues are resolved

***National Thermo-Modernization Fund*:** The fund addresses the high initial investment required to improve insulation by covering up to 25% of credit loans taken out to increase thermal insulation of buildings. Available to building owners and administrators in Poland since 1998, the fund has paid for more than 13,000 projects.

***ETS*:** The system provides a powerful financial incentive for plants to reduce emissions, especially given the planned increase in the share of traded allowances until 2020. The added cost of allowances could dramatically change the economics of efficiency measures and shorten the payback times.

***Educational programs and best practice exchange*:** To address the second barrier, awareness and educational programs could be implemented to help industry sector participants identify and capture opportunities across their facilities and manufacturing processes. Other options include business-led seminars and best practice exchange conferences, which could help ensure the diffusion of innovation and expertise across an industry. Such measures are especially important for capturing the potential in small- and medium-sized enterprises, which often lack the scale to develop energy efficiency expertise on their own.

***Other measures*:** Those include stimulating supply and demand for energy-efficient buildings by providing extra floor space for developers or service-tax rebates for certified green buildings. Clear labeling and public information campaigns could also have significant positive impact by raising awareness among consumers.

In transport, the extent to which barriers are addressed would largely depend on decisions made in other countries, since Poland does not have the scale to affect market changes in the automotive sector. The availability of more efficient gasoline- and diesel-powered vehicles could be influenced by EU regulations on the maximum allowed fleet average CO_2/km emitted, currently set at 130 g/km.

However, if governments were supportive of the implementation, they could come up with additional steps of their own. For example, the UK ties vehicle sales tax and annual licensing fees to CO_2 emissions, the US offers tax rebates of up to USD 3,000 for hybrid purchases, and California pays motorists to retire older, more polluting vehicles.

LOW EMISSIONS POWER SUPPLY

Poland's chosen energy fuel mix will have lasting implications for emissions and its potential depends on deciding quickly due to the long implementation timeline

Power is by far the largest sector, both in terms of emissions and opportunities to reduce them. In 2005, power sector emissions in Poland reached 146 $MtCO_2e$, or 38% of total emissions. In our BAU projections, emissions are expected to grow to 178 $MtCO_2e$, which would keep the sector's share of emissions at roughly the same level. This would be due to increased electricity demand and assumed preference for coal-based generation. However, opportunities to reduce emissions are many and fall into two categories: demand reductions through energy efficiency and fuel mix decisions (e.g., coal-fired plants versus renewable energy, CCS, and nuclear energy). If the full potential were to be captured, GHG emissions would have to be reduced by around 120 $MtCO_2e$ to ~60% below 2005 levels. However, the implementation challenges are not only technological (e.g., CCS) but also involve complicated tradeoffs outside the CO_2 solution space, such as supply security, nuclear energy risks, and the economic importance of coal mining.

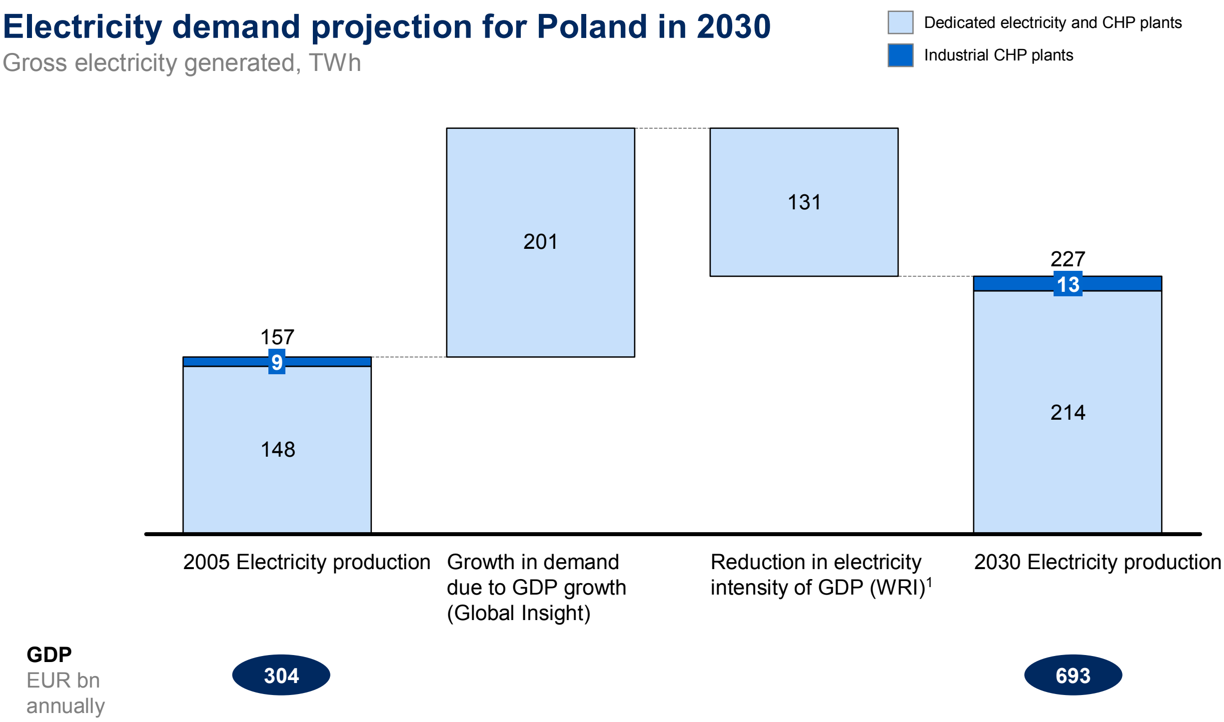
In BAU, we expect gross energy production to grow to ~227 TWh, or 45% above 2005 levels[26]. The growth would be driven primarily by GDP growth, accompanied by improvements in GDP electricity intensity. In this scenario, the Polish economy is assumed to grow ~3.4% per year in real terms[27]. At the same time, GDP electricity intensity improves by ~1.7% per year, mostly due to structural changes in the economy[28] (e.g., more growth in services) and natural energy efficiency improvements in industry (Exhibit 23).

Our BAU case also assumes a slight decrease in carbon intensity due to more efficient coal plants and a slight fuel mix switch towards renewables. However, power production remains largely coal based, with ~80% of installed capacity coal fired.

Exhibit 23

Electricity demand projection for Poland in 2030

Gross electricity generated, TWh



1 Also includes improvement in transmission losses (based on Energy Policy 2030)

SOURCE: PSE Operator; ARE; Global Insight; World Resource Institute in Europe

26 Moreover, this estimate assumes reduced transmission and distribution loss from the current ~9.5% to ~8.5% (in line with Energy Policy 2030).

27 Global Insight.

28 Historical data is based on GDP electricity intensity from ARE; forecasts until 2030 are based on trends for Europe from the World Resource Institute.

Additional energy efficiency improvements (discussed in the previous section) in electricity-consuming sectors could reduce demand for power compared to BAU. According to our model, BAU's 1.5% annual growth in energy production could be reduced to 1% if all electricity saving measures were implemented in the other sectors. The total net emissions savings from these measures would amount to ~29 $MtCO_2e$ per year in 2030.

Estimating the impact and cost of each low-carbon technology in the fuel mix is complex. The result depends on the learning rates of different technologies, the development of fuel prices, natural limitations (e.g., the availability of storage for CCS), the setup and capacity of the power grid, and many other factors. We have not attempted to capture the full complexity of the power market, nor have we tried to forecast how the power generation mix will develop. Instead, we modeled five abatement scenarios for the power sector to illustrate the impact of different technologies (Exhibit 24). Note that the scenarios are not actual development forecasts for 2030.

Exhibit 24

Cost and abatement potential of different power scenarios

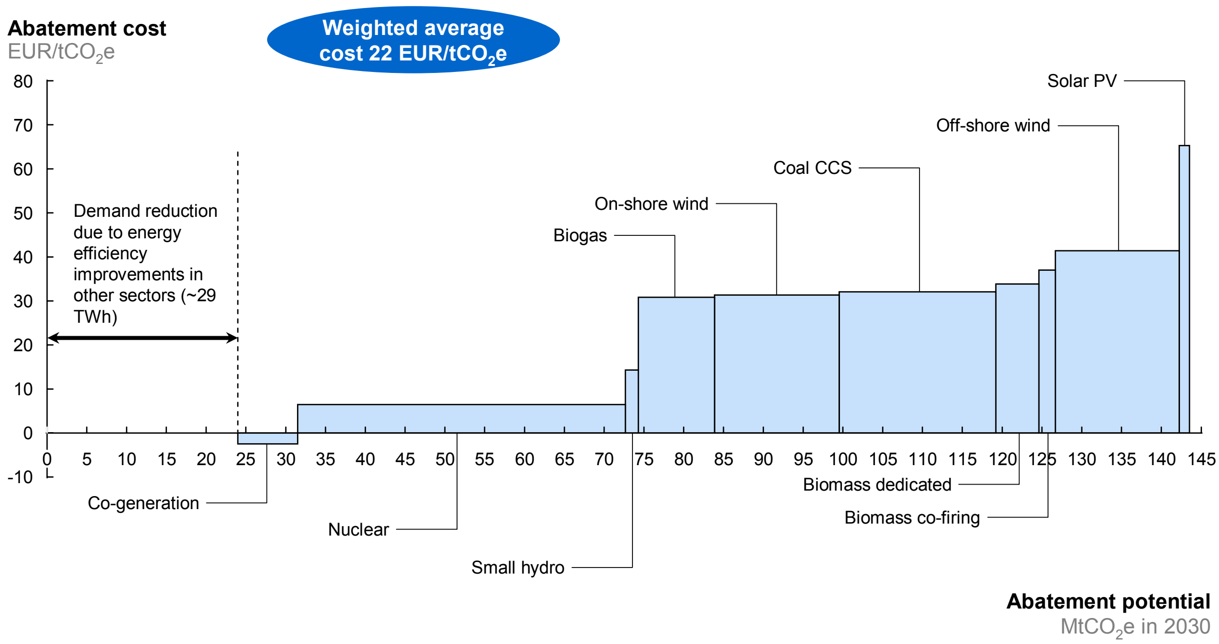
	Abatement potential $MtCO_2e$	Weighted average cost of abatement EUR/tCO_2e	Scenario description
A Low Emissions	120	22	▪ Natural retirement of coal power blocks (new blocks will still be required until 2020) ▪ Remaining power demand is met by wind and nuclear energy
B Focus on Nuclear	93	18	▪ Maintain current levels of coal-based production ▪ Remaining power demand is met by nuclear energy
C Focus on Renewables	81	32	▪ Maintain current levels of coal-based production ▪ Remaining power demand is met by wind energy
D Focus on Gas	68	24	▪ Maintain current levels of coal-based production ▪ Remaining power demand is met by gas plants
E Energy Policy 2030	97	21	▪ Assumptions from Poland's current official energy policy

SOURCE: Ministry of Economy; Poland GHG Abatement Cost Curve

- *Low Emissions*. In this scenario, we assume a maximum focus on low-carbon energy supply. Coal-fired power plants are retired when they reach the end of their natural life cycles (although new coal-based plants would still be required until 2020). The ensuing power supply gap, as well as the increase in energy demand, is closed by nuclear and renewable sources. In this scenario, we assume the most aggressive shift in power supply in Poland, resulting in installed capacities of chosen abatement technologies of 16 GW for wind, 6 GW for nuclear, 3.61 GW for gas, and 0.89 GW for biomass. Whereas such a shift would be technologically feasible, its economic and social consequences require further analysis. Exhibit 25 presents the cost curve for this scenario. The cost of each technology (but not the average cost of any given scenario) is very similar to the remaining scenarios, the key difference being the size of the potential.

Exhibit 25

Power GHG Abatement Cost Curve in 2030: Low Emissions scenario



SOURCE: Ministry of Economy, Energy Policy 2030, Poland GHG Abatement Cost Curve

- ***Focus on Nuclear.*** In this scenario, we assume electricity production from coal is maintained close to current levels (i.e., retired plants are replaced by new coal-fired capacity), and the gap resulting from the increase in power demand is filled by nuclear power. This scenario assumes the availability of 3 GW of wind, 6 GW of nuclear, 3.61 GW of gas, and 0.89 GW of biomass.
- ***Focus on Renewables.*** In this scenario, power capacity expansions focus on renewable sources with no nuclear capacity development. As in Focus on Nuclear, electricity production from coal is maintained at roughly the current level, in addition to 16 GW of wind, 3.61 GW of gas, 0.89 GW of biomass, and no nuclear.
- ***Focus on Gas.*** In this scenario, power capacity expansions are based on gas (up to 7.2 GW) and nuclear (up to 2 GW) with wind and biomass at 3 GW and 0.89 GW, respectively. Coal-based plant capacity is maintained at 2005 levels.

- ***Energy Policy 2030.*** In this scenario, we modeled the costs and abatement potential of the country's current plans, which focus on developing renewable sources and nuclear. Operating indices (e.g., uptimes, energy efficiencies) were kept at the same level as those of Energy Policy 2030. Also corresponding to Energy Policy 2030, our scenario assumes the following capacities: 7.9 GW for wind, 4.8 GW for nuclear, 3.61 GW for gas, and 1.2 GW for biomass.

Each scenario has different costs, benefits, and risks. Exhibit 31 summarizes the costs, the capex, and the level of CO_2 reduction in each scenario. There is no obvious winner, though individual scenarios do score low or high on different criteria:

- ***Required capex.*** Capex differences between scenarios are substantial. Nevertheless, higher investment costs are usually accompanied by lower operating costs as well as higher potential savings from avoided CO_2 emissions allowance purchases (Exhibit 26). Thus, although reaching the full potential in the Low Emissions scenario would require the highest incremental capex of around EUR 35 billion, it could prove to be the most economically viable scenario in the long run, provided only opex and CO_2 emissions charges were taken into account. On the other hand, the Focus on Gas scenario is characterized by the lowest capex of all the scenarios (around EUR 12 billion), but at the same time has the highest opex and the lowest potential for avoiding CO_2 charges. Thus, decision makers need to understand the tradeoff between upfront investment and potential future savings before selecting a preferred scenario.

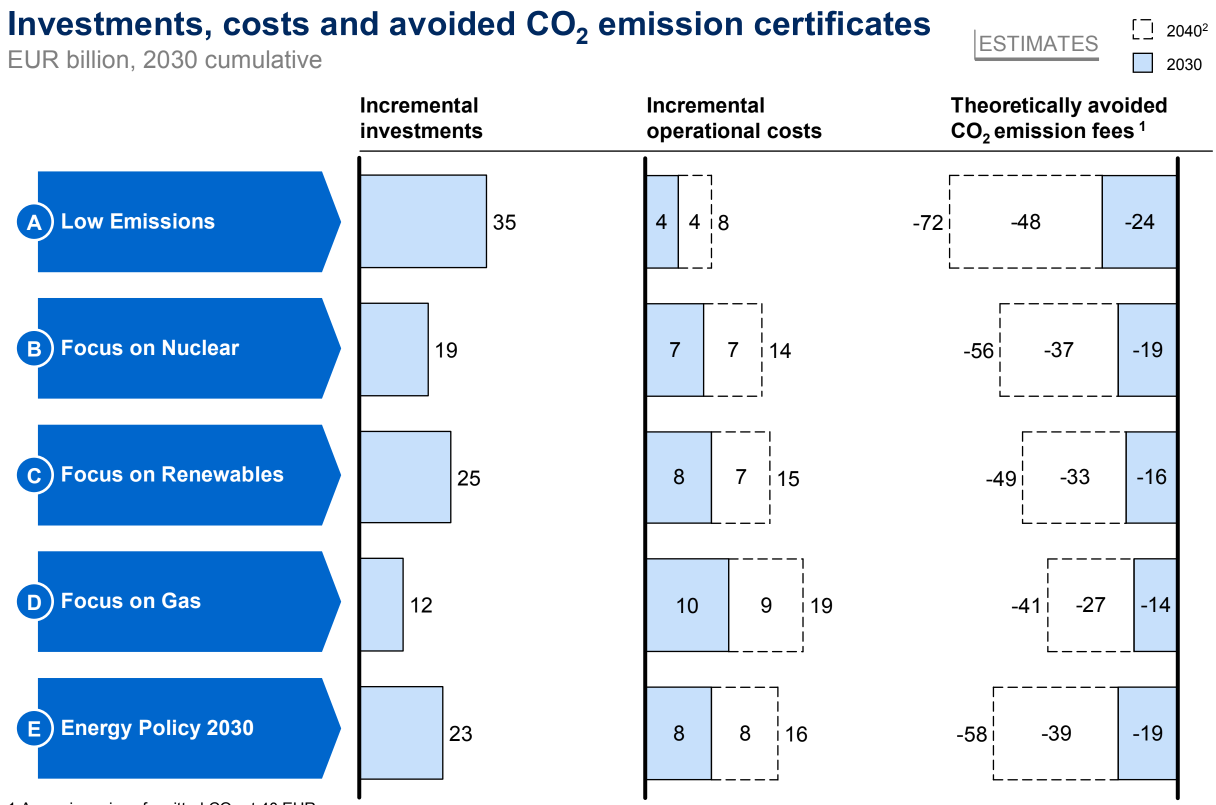
- ***Execution risk.*** CCS relies on new technologies that have not yet been demonstrated at scale. Even nuclear entails some execution risk due to the limited recent experience with nuclear construction and the limited number of players on the market.

- ***Abatement potential.*** Each of the options results in large reductions relative to BAU, but Low Emissions and Focus on Nuclear offer the greatest benefits, as both show the greatest potential for replacing coal-fired installed capacity.

- ***Energy security.*** Coal and biomass feedstocks appear reasonably secure in the mid term, with significant domestic sources available for each. Nuclear generation would probably require uranium imports, but the supply should be reasonably secure given the wide range of potential sources, including several stable democracies. The Maximum Gas scenario could be vulnerable to disruptions, given the concentration of available supply.

- ***Social acceptance.*** Some of the technologies involved still need to overcome significant social reservations. Communities may be reluctant to accept the construction of generation or storage facilities in their vicinities. Wind turbines may also be unacceptable to segments of the population because of their impact on the landscape.

Exhibit 26



1 Assuming price of emitted CO_2 at 40 EUR
2 Assuming unchanged fuel mix structure fro 2030, and resulting linear growth of abatement potential and operating costs

SOURCE: Poland GHG Abatement Cost Curve

The potential to decarbonize the Polish power supply is clear. Nevertheless, the opportunities and the concrete measures involved require further analysis and commitment on the part of decision makers. The political and macroeconomic aspects of the coal-based power supply and the need for emissions reduction need to be weighed.

To overcome the main implementation obstacles – technological uncertainty and cost – an attractive financial, regulatory, and political environment for companies is needed. High investment in new generation technologies could be mitigated by incentives and compensation systems that would allow those technologies to get a firm foothold more quickly. On the other hand, regulatory actions could be undertaken to facilitate effective licensing and deployment processes for various technologies (e.g., nuclear). Moreover, grid regulation could allow new technologies to be integrated. It is crucial that the direction be set immediately. The lack of clarity is a big problem for power sector players, whose asset lifespans are counted in decades.

CARBON CAPTURE AND STORAGE

CCS technology could present an important GHG reduction opportunity for Poland if technological and regulatory challenges are overcome

CCS is a promising new technology with significant abatement potential across the power and industry sectors. Even if Poland chose to pursue the Low Emissions scenario from 2010 onwards, as much as 38% of the country's total electricity would be supplied by coal plants in 2030.

CCS is still in its technological infancy, and its commercial viability remains highly uncertain due to competition from other low-carbon technologies, legal and regulatory issues, and possibly limited social acceptance. The potential of CCS is determined by several factors, including cost, pace of adoption, and the maximum storage capacity available.

Although numerous studies have indicated that the geological potential of CCS is significant – possibly reaching billions of tons – the ability to capture this potential is uncertain. One of the objectives of the ongoing EU-sponsored CCS demonstration plants is to confirm the availability of storage capacity and the potential for sustainable exploitation.

Due to this uncertainty, we have capped the potential for Poland at 30 to 40 $MtCO_2$ per year by 2030. This would mean 5 to 6 large-scale CCS power plants operating in Poland, abating ~20 $MtCO_2$ per year, with the remaining storage capacity used by industry. We assumed that, if industry players build CCS installations, they will have available storage capacity even though their cost of abatement will be higher than in the power sector.

However, if the technology matures faster than expected and technical difficulties related to storage and transportation are resolved soon, storage capacity could be much higher, resulting in a big increase in annual abatement potential from ~20 to 60 $MtCO_2$. To demonstrate the maximum CCS potential, we simulated removal of the storage volume gap within the Low Emissions scenario (Exhibit 27).

REMAINING LEVERS

Other levers could reduce emissions by a further 33 $MtCO_2e$, with significant potential in waste management and agriculture

So far, we have discussed most of the levers that offer clear benefits to society in the form of energy efficiency, as well as the options related to the fuel mix to be chosen for Poland's future energy supply.

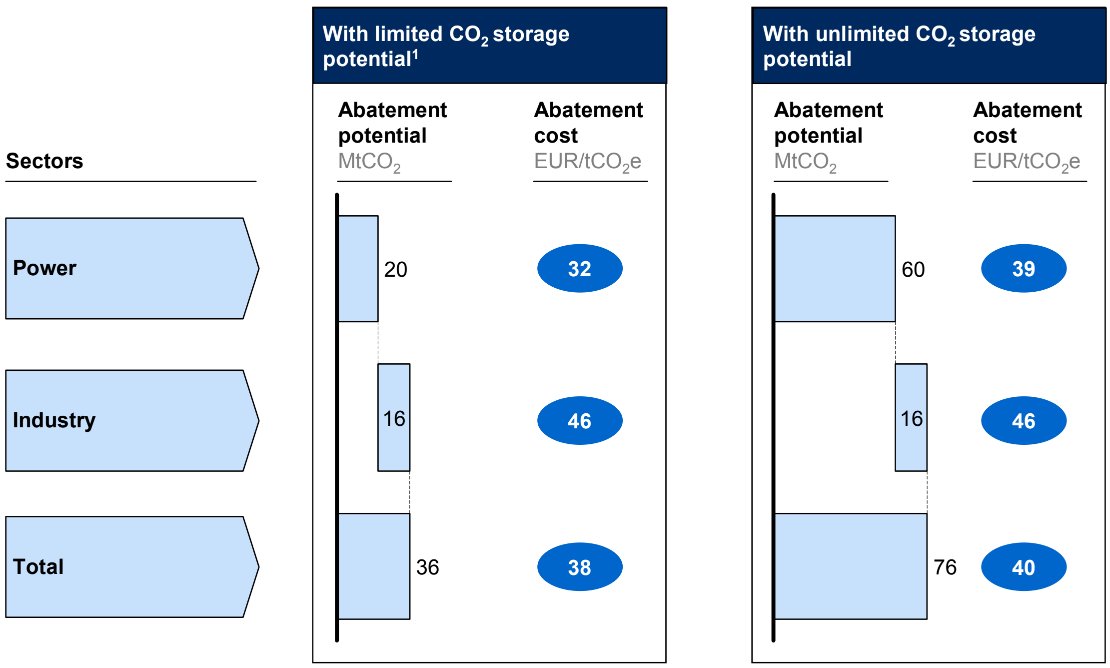
However, there are a multitude of other levers, which add up to an abatement potential of ~33 $MtCO_2e$, or around 14% of the total. These measures vary in terms of cost and abatement potential, and are dispersed throughout all sectors of the economy (Exhibit 28).

These opportunities fall into three main categories: industry, which encompasses the four industries we analyzed in depth; consumer-related, which relates to waste management and transport; and land use, which consists of measures in agriculture and forestry. In the final sections of this chapter, we touch on all three (Exhibit 29).

Exhibit 27

CCS technology might constitute a large abatement potential

2030



1 Assuming limitations in storage potential adaptation of 30-40 $MtCO_2$ per annum in 2030. This limitation might also apply to the construction of transportation pipeline

SOURCE: Poland GHG Abatement Cost Curve

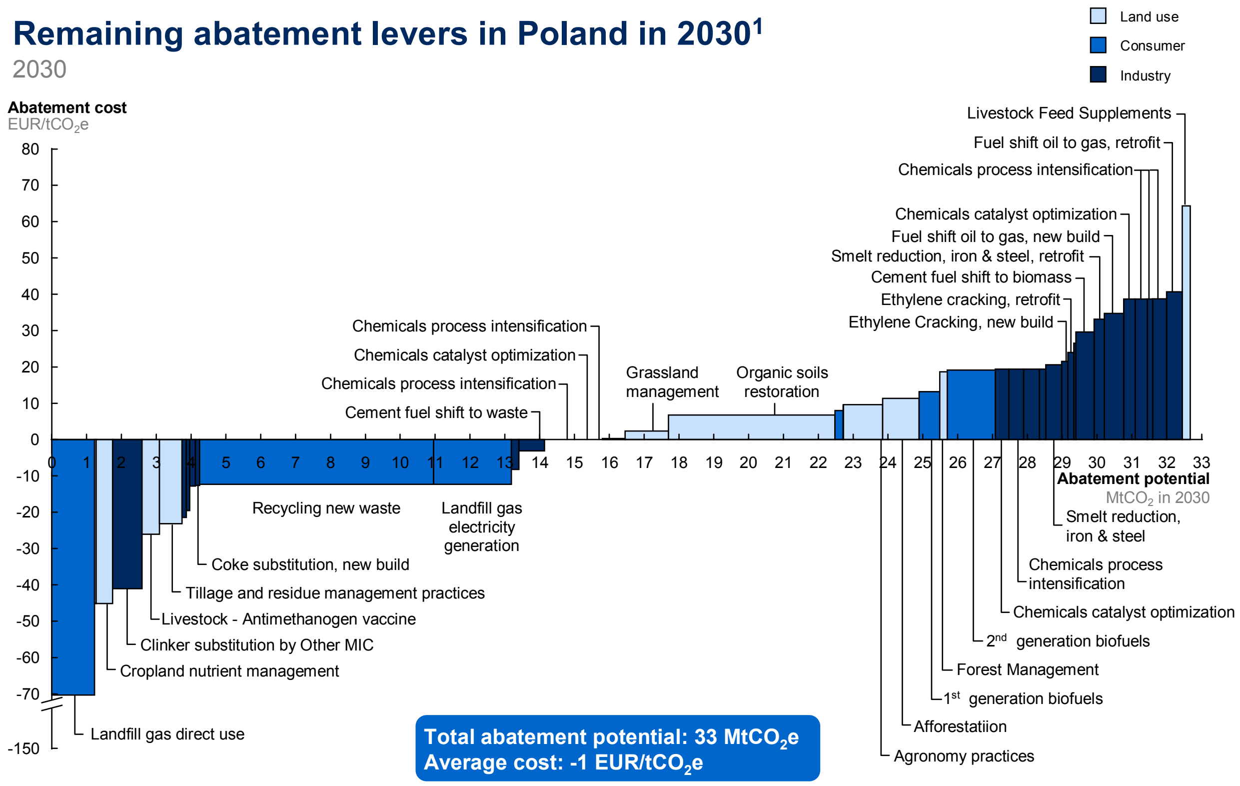
Industry

Less than a third (9.4 $MtCO_2e$) of the abatement potential from the remaining levers could be achieved through measures in industry. This potential also accounts for less than a third of the total potential in Polish industry in 2030 (35 $MtCO_2e$). This is due to the significant optimization which heavy industry has undergone in the past two decades, as well as certain technical limits that stand in the way of fully implementing certain measures. For example, even though it is technically possible to substitute up to 40% of the clinker in cement with slag (a non-polluting byproduct of pig iron production), the limited availability of this material limits the potential of this measure.

Over half the potential is in chemicals, where optimizing processes and catalyst use could reduce emissions by about 5 $MtCO_2e$. The remaining potential is related to substituting biomass for coal as fuel. The average cost of other measures in chemicals, amounting to 21 EUR/tCO_2e, is lower than the average cost for the sector

In cement, most of the potential (1.3 $MtCO_2e$) derives from shifting from coal to waste and biomass fuel, and substituting clinker, the main emissions-intensive ingredient in cement, with other materials, notably limestone. On average, these measures would result in net savings for the industry. The BAU case already assumes a large substitution share for waste fuel (about 50%). Any additional substitution would depend on the availability of waste and biomass meeting the required calorific value.

Exhibit 28



1 Only the most significant abatement opportunities are named; for fuel list of abatement opportunities considered, please see Appendix III

SOURCE: Poland GHG Abatement Cost Curve

The remaining opportunities – split between iron and steel, and petroleum and gas – include process modifications, such as direct casting in the case of the former, and measures to reduce methane leakage in mid-stream gas, such as by replacing seals and better compressor maintenance, in the case of the latter.

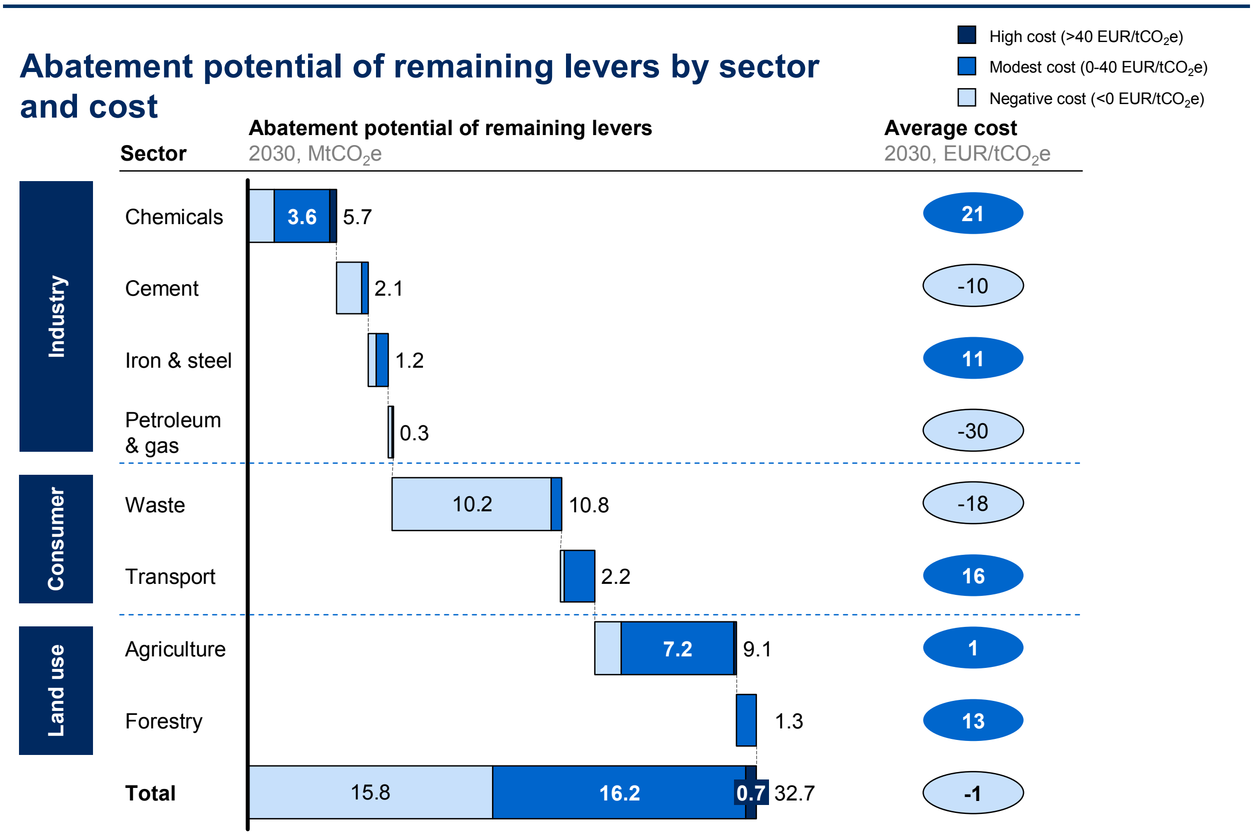
Since the opportunities in industry are so fragmented, their implementation would greatly depend on the efforts of specific industries, or even plants, and on the ability and willingness of businesses to adapt their processes.

Consumer-related

Opportunities in the consumer-related sectors of municipal waste management and transport could add up to 13 $MtCO_2e$ by 2030. Around 85% (11 $MtCO_2e$) is in waste management, while the remaining 15% (2 $MtCO_2e$) comes from transport.

The main opportunity in this group lies in waste management, where recycling alone could reduce emissions by up to 6.7 $MtCO_2e$ in 2030. Every ton of CO_2e reduced by recycling results in a net savings of about EUR 12 because both resources and energy for new production are saved. Such abatement would require increasing the share of recycled waste from roughly 50%, which we assume in the BAU scenario, to EU-15 levels of 85 to 90%. Successful implementation of this lever would be conditional on the removal of barriers to increased recycling – such as the very low cost of landfills, fragmented waste ownership, and lack of reliable information about waste collection and handling – and making it possible for businesses to capture the economic benefits of this opportunity.

Exhibit 29



SOURCE: Poland GHG Abatement Cost Curve

Capturing and using methane from existing landfills could reduce emissions by 3.5 $MtCO_2e$ in 2030. However, landfill fragmentation across Poland makes it difficult to build up the waste mass required for powering a methane electricity station, and regulations do not clearly support such investment projects. Nevertheless, both implementation barriers could be addressed by enacting regulatory measures to shift waste ownership and financial incentives, such as the current Green Certificates System..

The opportunity in transport derives mostly from increased use of biofuels. Our reference case already assumes that 10% of the energy (in terms of calorific value) in transport would be supplied by biodiesel and bioethanol by 2030. A small abatement potential of 0.6 $MtCO_2e$ is related to increasing this share from 10 to 13%. The remainder would result from using second generation biofuels currently under development. Successfully implementing second generation biofuels in Poland's transport energy mix could reduce 1.4 $MtCO_2e$ in 2030 at a cost of about EUR 19/tCO_2e.

Land use

The total abatement potential identified in land use in Poland is 10.3 $MtCO_2e$: 9.1 Mt in agriculture and 1.3 Mt in forestry. These potentials of 30% in agriculture and 3% in forestry are much lower than global estimates (59% and 109%, respectively) for several reasons.

First, the potential is driven globally by reforestation, afforestation, and less deforestation. However, the potential for afforestation in Poland is limited, as major afforestation efforts have already been carried out in the past 20 years. Plans to afforest further cropland and pastureland are assumed in the BAU scenario.

Second, Polish forests are managed under strict rules, and the limited additional abatement possible could be achieved only through improved forest management through fertilization, fencing to restrict grazing, and improved forest regeneration.

Third, some Polish agricultural practices, such as extensive farming and crop rotation, already contribute to lower emissions, and our reference case assumes continued improvements in nutrient management and land tillage.

The most important abatement opportunity in agriculture (4.8 $MtCO_2e$) relates to restoring organic soils. The soils in question are drained marshlands currently used for agriculture. When marsh water is drained, the organic matter at the bottom comes into contact with aerial oxygen. This matter begins to decay rapidly, releasing large amounts of CO_2 into the atmosphere. It is believed that reflooding former marshlands could stop this process, reducing emissions as a result. As with all emissions and abatement estimates in land use, this should be treated with caution. Since soil properties vary significantly with location and over time, their emissions are highly difficult to measure, and major uncertainty is involved.

In addition to this uncertainty, effective measures to reduce emissions in agriculture are hard to implement. The most important barriers to overcome are the fragmentation and habits of farmers, as well as, in the case of land restoration, the challenging logistics of reflooding organic soil areas. Therefore, even though cost estimates for measures in this category are moderate (Exhibit 28), transaction costs could increase our estimates considerably.

GHG Abatement Investment

GHG Abatement Investment

Required additional investment would average 0.9% of GDP. Operational cost savings and avoided CO_2 allowance costs could largely compensate for the upfront investment

Many of the opportunities we have discussed result in energy savings and pay off over time. However, unlocking this potential and the related savings often requires heavy upfront investments, which could act as a barrier to addressing these opportunities. In addition, financing costs and government policies could seriously impact the economics of abatement opportunities.

This section explores the required incremental investment in Poland, the potential savings, and the effect certain public administration measures could have on the cost of abatement from the point of view of the individual investor.

Required additional investment by 2030 is estimated at 0.9% of GDP per year

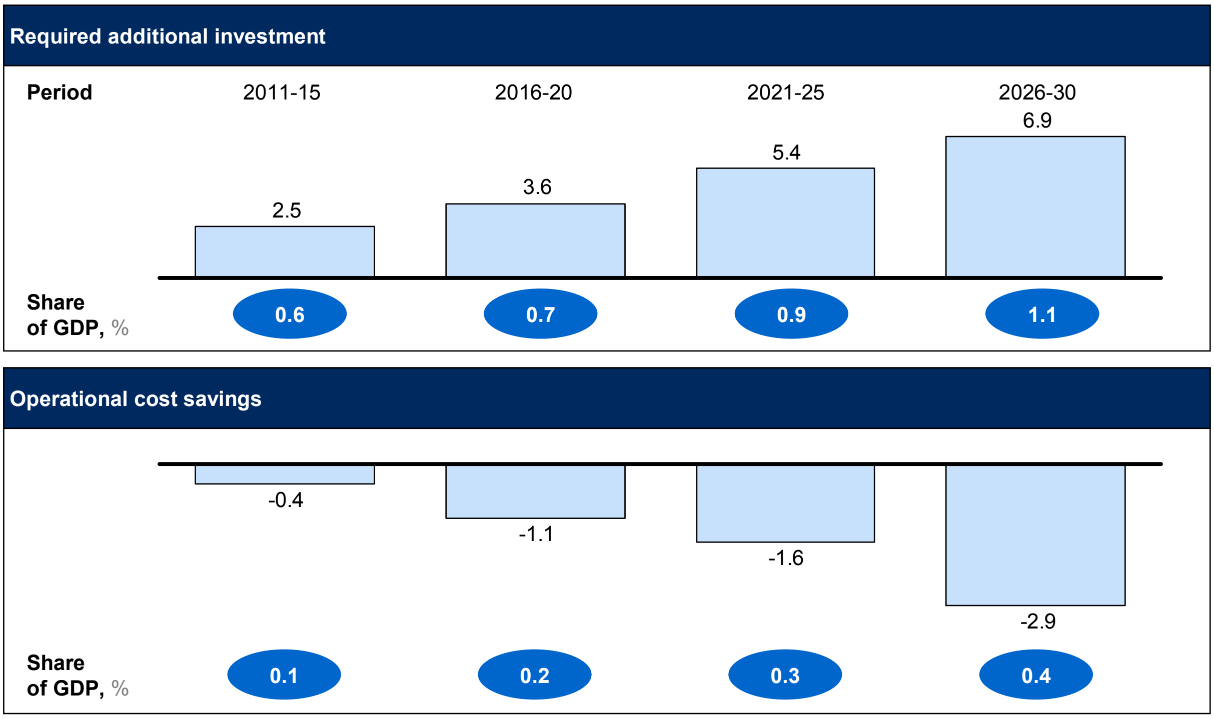
To realize the abatement potential on the GHG abatement cost curve for Poland, the total incremental investment (i.e., in addition to what would have to be invested in our BAU scenario) from 2011 to 2030 is estimated at EUR 92 billion. This assumes that all the opportunities suggested by the cost curve are implemented, from those with the largest net savings to those with the highest economic costs. If any initiatives were delayed, or if the order of implementation varied, the required investment could be much higher.

The required investment, estimated to grow faster than GDP, would account for about 0.6% of GDP from 2011 to 2015, and up to 1.1% from 2026 to 2030. This increase would result from the large investments in the power sector (e.g., nuclear, offshore wind, CCS) after 2020 to capture the full abatement potential (Exhibit 30).

Exhibit 30

Required additional investment

Annual average in each 5-year period, EUR billion



SOURCE: Poland GHG Abatement Cost Curve

Operational cost savings and the avoided cost of carbon allowances could make up for the initial capital outflow

As discussed above, many abatement opportunities result in savings of energy or raw materials. They therefore pay off – or at least make up for some of the initial cost over their lifetimes. The abatement opportunities we have analyzed do not entirely compensate for the initial investment, but the net cost of abatement in Poland would be positive by 2030: around 10 EUR/tCO_2e. Exhibit 30 summarizes the total operational cost savings for Poland in each five-year period from 2011 to 2030.

As with investment, operational savings grow faster than GDP. Their share grows from 0.1% from 2011 to 2015 to 0.4% from 2026 to 2030. It should be noted that some of the energy savings related to investments made prior to 2030 would materialize only later on, as new low-carbon infrastructure continued to function over time. This is especially true of the transport sector, where large additional investments made in fuel-efficient vehicles (both ICE and hybrid) from 2021 to 2030 would continue to bring fuel savings over the following 10 to 15 years.

One mechanism with the potential to dramatically alter the economics of abatement and shorten payback times for capital-intensive abatement projects is carbon trading. If carbon were priced and traded, the cost of total annual emissions would constitute another cost position on company or governmental P&L statements, just like administrative costs do today. Therefore, the cost of each avoided ton of CO_2 could be treated as a savings or avoided cost. If the entire abatement potential portrayed on the Polish cost curve were captured, the avoided cost of carbon could reach more than EUR 83 billion for the 2011-2030 period, assuming full auctioning and carbon prices of EUR 30/t up to 2020 and EUR 40/t between 2021 and 2030. In terms of share of GDP, avoided carbon costs are similar to the incremental investment required to realize the total technical abatement potential. Thus, one conclusion might be that under a carbon trading regime, Poland would incur similar capital outflows as in our abatement case, but likely without the positive effects that carbon abatement investments could have on the broader economy.

Required investment varies by sector and does not necessarily correlate with cost

The total investment is distributed unevenly among different economic sectors and does not necessarily correlate with the total cost of abatement. Sectors such as buildings and transport, where measures result in a net economic benefit for society, actually require considerable upfront financing. In industry sectors, upfront investment is modest compared to the capital required in buildings and transport. This difference is related to the scale of these sectors and their different operating costs. In the power sector, large capital investments in low-carbon infrastructure would be required, but the resulting operational savings would be too small to make up for the initial capital outflow (Exhibit 31).

Like capital requirements, operational costs vary by industry. Energy efficiency measures in transport and buildings bring significant savings, and additional savings could come from shifting energy production to renewables, such as wind. In waste management, recycling actually reduces costs in production industries such as paper, glass, and metal, but since savings depend on measures in waste management, we have accounted for them here. Operational costs would actually grow in chemicals, and in iron and steel, due to measures modifying some production processes. Similarly, operational costs would grow somewhat in agriculture, because certain abatement measures (e.g., farming extensification) are more labor intensive.

It seems reasonable that investments should first be channeled into projects offering the largest economic benefit over time, bearing in mind that such projects frequently require the largest capital investment. However, pressure to reduce emissions in a capital-constrained environment could have the opposite effect. With capital limited, investors may choose to finance measures with lower investment costs before financing those with lower costs over time. This could greatly increase the overall cost of abatement over time. Therefore, policy measures to encourage the right kind of behavior could be required.

Exhibit 31

Required additional investment and abatement costs by sector

	Sector	Incremental investment 2011-30, EUR bn	Incremental operational costs and savings[1] 2011-30, EUR bn	Abatement costs 2030, EUR/tCO_2e
Power and industry	Power	35.0	4.3	22
	Chemicals	4.3	0.5	22
	Iron & steel	4.0	0.8	31
	Petroleum & gas	1.1	-0.2	13
	Cement	~0	-0.2	-2
Consumer	Buildings	24.0	-20.3	-18
	Transport	22.4	-11.3	-5
	Waste	1.4	-3.2	-18
Land use	Agriculture	0	0.2	1
	Forestry	~0	0	13
	Total	92.2	-29.4	10

1 Costs presented as positive numbers whereas savings as negative

SOURCE: Poland GHG Abatement Cost Curve

Implementation Path and Scenarios

Implementation Path and Scenarios

Poland could address carbon abatement opportunities by pursuing an ambitious strategy, differentiated by sector, across three groups of measures, some requiring immediate implementation, others long-term planning. Delaying action or avoiding fuel mix decisions would drastically reduce abatement potential by 2030 and beyond

Poland has the potential to achieve significant abatement, but given the complexities involved and the fragmentation of opportunities, capturing the full potential would require concerted action. The relatively easy-to-capture measures – which are clearly in Poland's interest, regardless of the steps taken by other countries – could be pursued at once. The more expensive or difficult ones would require a more measured approach.

As a basis for discussions, we have constructed an implementation matrix by grouping similar abatement opportunities together (e.g., various uses of methane captured from landfills, each of which was modeled separately, have been grouped under "landfill gas use") and arraying them into three distinct groups according to cost and ease of capture. The result is an implementation matrix for Poland (Exhibit 32).

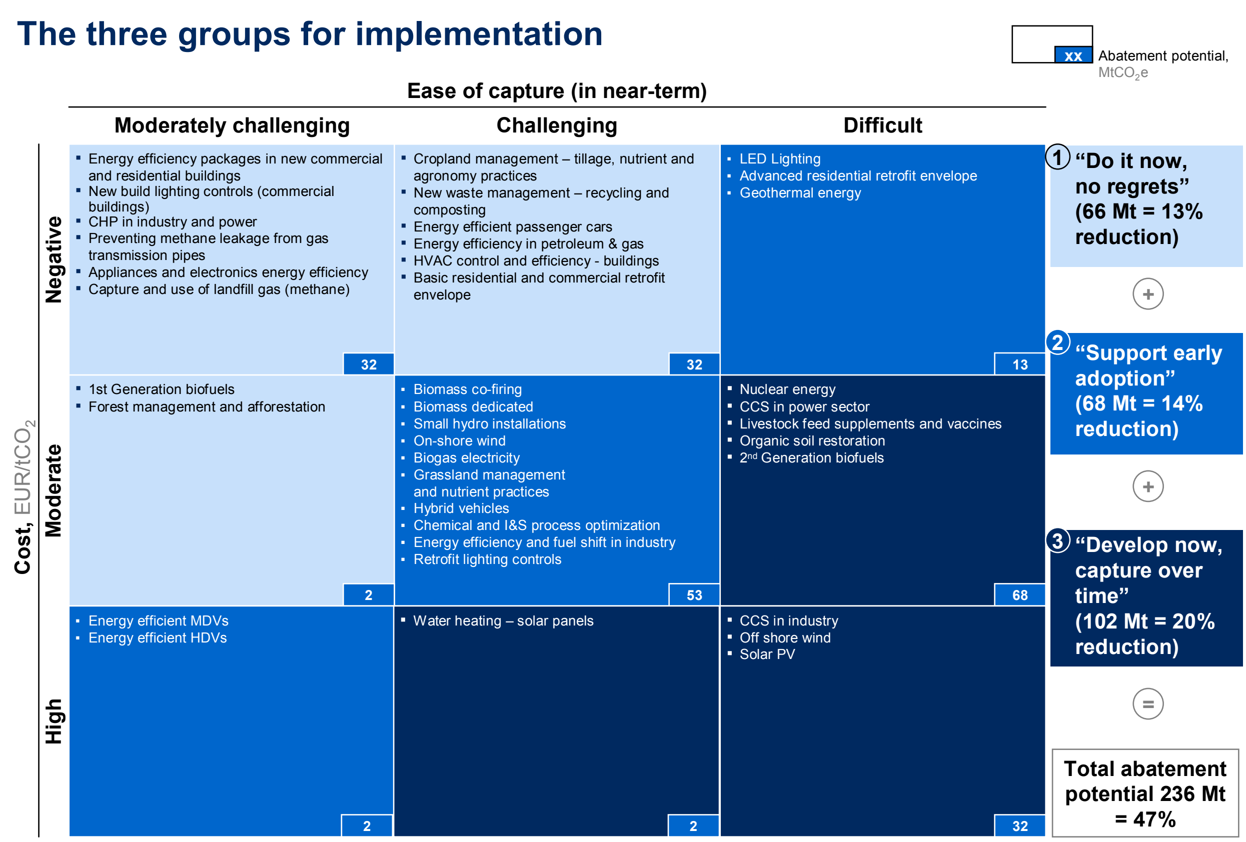
The three groups, each marked with a different color on the matrix, contain all the measures on the cost curve, going from the cheapest, most readily achievable options in Group 1 to the most challenging and costly ones in Group 3. While the investments made in each group would play out over different periods of time, action would be needed across all three as soon as possible. For example, just because Group 3 investments may not pay off for some time, laying the groundwork should not be postponed.

Such a classification necessarily simplifies the abatement process. The purpose of the matrix is to map the opportunities in terms of cost and capability. Whereas the cost of different measures has been determined by the cost curve, the ease of capturing specific opportunities has been assessed qualitatively and verified by leading climate change, governmental, and industry experts in Poland. Representing just one possible classification, the matrix aims to serve as a starting point for a broader discussion.

Group 1 – "Do it now, no regrets"

Group 1 encompasses opportunities based on existing technology with low-to-moderate implementation barriers and modest costs (i.e., less than EUR 40/t). Many of these opportunities are in Poland's interests, regardless of whether it is seeking to reduce emissions or not. These are no regret moves. They cost little but would yield great benefits, including ~66 $MtCO_2e$ of emissions reduction (27% of the identified potential), and rely on proven, widely available technological solutions that are either currently used or being rolled out in other EU countries.

Exhibit 32



SOURCE: Poland GHG Abatement Cost Curve

Group 2 – “Support early adoption”

Group 2 covers opportunities that provide abatement at relatively low cost, but which are fairly difficult to implement – or vice versa (i.e., somewhat expensive, but the means for capturing them already exist or could be built fairly quickly). Since the technology for these opportunities is available, many should be easily achievable by 2020, assuming sufficient measures are taken to remove the structural and financial barriers that currently prevent large-scale implementation. Taken together, these measures account for about 68 $MtCO_2e$ of emissions reduction (29% of the identified potential). Measures in this group are already being implemented on a small scale. Moreover, working mechanisms are in place – such as the White Certificates System and the ETS – which could support implementation over time.

Group 3 – “Develop now, capture over time”

Group 3 covers the most challenging opportunities – those that cost a lot and face tough hurdles, either because they are not yet technologically available or because they pose planning risks and demands on infrastructure. Included are nuclear energy, CCS, and offshore wind power. This group is extremely important for Poland, since it contains the measures with the largest abatement potential in 2030 (about 102 $MtCO_2e$, or 44% of the identified potential) and much greater gains thereafter. Therefore, they should be actively explored now. Levers in this group are likely to be important even after 2030, as they would offer scope for continued growth at a time when Group 1 and Group 2 may have reached their full potential. Opportunities in this group are still in the R&D or early technology stage (e.g., CCS) or have long planning lead times (e.g., nuclear). Whereas the technological issues would likely be addressed on a global level, laying the groundwork for capturing these opportunities quickly should commence as soon as possible.

While the cost curve ranks various abatement actions purely by cost, classification of an opportunity equally depends on qualitatively assessing the ease of capture. We have considered a number of factors:

- ***Financing issues***
  - ***Capital intensity.*** An abatement opportunity may be cost-neutral or cost-negative overall but still difficult to implement at scale if it requires high upfront investment (and long-term payback times).
  - ***Acceptable payback times.*** Consumers, businesses, and governmental agencies often demand short payback times on investments. As a result, measures that take slightly longer to payback, such as energy efficiency investments, may not be implemented even in the absence of prohibitive upfront costs.
  - ***Uncertainty about future costs.*** The fact that implementing new technologies on a large scale involves the risk of higher than expected costs further complicates projects with long planning cycles. Two technologies with the same estimated cost in 2030 may very well have strikingly different confidence intervals, making the payback uncertain and one of the technologies more expensive to finance.
- ***Regulatory and institutional capability.*** The fact that implementing new technologies on a large scale involves the risk of higher than expected costs further complicates projects with long planning cycles. Two technologies with the same estimated cost in 2030 may very well have strikingly different confidence intervals, making the payoff uncertain and one of the technologies more expensive to finance.
- ***Principal-agent issues.*** Some energy efficiency opportunities result in net savings overall but do not benefit the person who could or should implement them. Building insulation is a good example, where the landlord typically bears the cost of insulation while the tenant enjoys the energy savings.
- ***Entrenched behaviors.*** Some opportunities require persuading large numbers of individuals to start behaving differently. In agriculture, for instance, many smallholding farmers need to adopt new practices (e.g., cropland tillage) if abatement is to be achieved.
- ***Supply chain bottlenecks***. A market shortage of low-carbon technologies and products, such as wind turbines and solar water heaters, could be a hurdle to implementing some opportunities.
- ***Political feasibility and other acceptance issues.*** Does implementing the opportunity create more winners than losers? Does the opportunity imply any potential negative side effects? For example, increasing the cost of landfills to create incentives for communities to segregate new waste could be politically unpopular. Similarly, building a large number of hydroelectric plants could negatively affect river ecosystems, and introducing large-scale biomass production could reduce biodiversity in the surrounding area.

Addressing these issues quickly and effectively would be a massive challenge for Poland. In the sections that follow, we discuss the implications of several scenarios.

Implementation scenarios

The three implementation groups assume Poland would capture the entire abatement potential in the cost curve. However, the abatement opportunities outlined in this report are potential. They represent the best case scenario if each opportunity were pursued to its maximum economic potential below EUR 80/tCO_2e, and they assume successful implementation across sectors.

This section introduces the notion of implementation leakages. Four integrated implementation scenarios are outlined, each assuming a different degree of success and commitment to action on climate change. These scenarios are intentionally simplified compared to the complex policy discussions now underway, since our objective is to illustrate the order of magnitude of different conceivable courses of action, not to make recommendations or state preferences.

Considered together, the four implementation scenarios suggest that Poland cannot afford to put off action or avoid controversial carbon abatement decisions if significant progress is to be made in decarbonizing its economy. An immediate commitment to even an imperfect implementation plan is a prerequisite for putting Poland onto a low-carbon growth pathway (Exhibit 33).

- ***Full Implementation*** assumes the most comprehensive approach to reducing carbon emissions. In this scenario, combating climate change becomes the number one priority of Polish society, government, and business. Comprehensive action is taken in all sectors of the economy as of 2010, and all abatement opportunities below EUR 80/tCO_2e are pursued to their full potential leading to 30% lower emissions in 2030 than in 2005. A highly optimistic yet challenging scenario, full implementation would best position the Polish economy for capturing the low-carbon growth opportunities of the future.

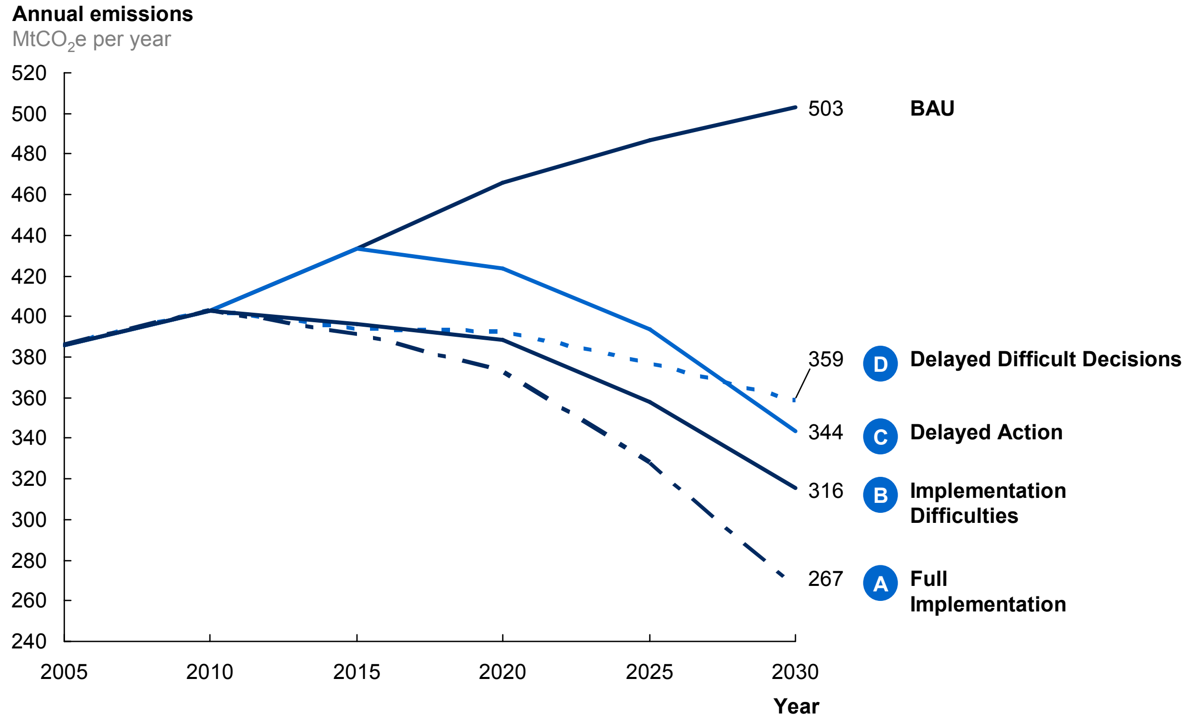
- ***Implementation Difficulties*** assumes strong commitment from society, government, and business to limit GHG emissions in Poland. However, certain measures are assumed to be partially ineffective or delayed due to persistent system inefficiencies (e.g., lack of consumer awareness, entrenched behaviors). In this scenario, only 90% of the potential in Group 1 is captured, only 75% of the potential offered by the more challenging opportunities in Group 2 is realized (e.g., increasing energy efficiency in industry), and only two thirds of the maximum capacity for CCS, offshore wind, and nuclear in Group 3 is installed by 2030. As a result, emissions are 18% lower in 2030 than they were in 2005.

- ***Delayed Action*** assumes that society, government, and business take a wait-and-see stance, and action is delayed by five years. Concerted action to reduce emissions is finally taken, leaving emissions in 2030 about 11% lower than in 2005. The five-year delay in taking action means that additional carbon-intensive infrastructure for power generation has been built, making further reductions much more costly and difficult.

- ***Delayed Difficult Decisions*** assumes that controversial implementation decisions for tackling climate change are avoided while more feasible actions are taken. Thus, no steps are taken to build nuclear, CCS, or offshore wind capacity in Poland. All other measures are pursued to their fullest and implementation starts on time. Emissions are only 7% lower in 2030 than they were in 2005. While still resulting in overall emissions reduction, this scenario would make sustainable low-carbon growth extremely difficult to achieve. Since all other opportunities are assumed to have been exhausted by 2030, failing to secure a low-carbon energy supply by that date would result in resumed emissions growth in line with GDP.

Exhibit 33

Scenarios' impact on abatement potential



SOURCE: Poland GHG Abatement Cost Curve

In terms of the implications that these scenarios would have for emissions in 2020, reduction levels vary greatly depending on the baseline year assumed for Poland (Exhibit 34).

Compared to 1988 emissions, each scenario results in a 25% to 34% reduction, with Delayed Action faring the worst. Delayed Difficult Decisions would still allow Poland to reduce emissions by 2020, as most of the measures in question (e.g., CCS, nuclear) would start functioning only after 2020. Compared to 1990, however, implementing the full technical potential on the cost curve would result in a mere 19% reduction. Finally, if estimated 2020 emissions are compared to 2005 levels, even the best case scenario results in only ~3% reduction.

Therefore, the challenge for the country until 2020 is to cap emissions growth by implementing available potential in energy efficiency, recycling, and agriculture while completing the groundwork for large post-2020 abatement opportunities in the power sector.

Exhibit 34

Scenarios' impact on overall reduction potential in 2020

Scenario	Annual emissions, 2020 $MtCO_2e$	Change vs. 1988 %	Change vs. 1990 %	Change vs. 2005 %
BAU	466	-18	2	21
Delayed Difficult Decisions	393	-31	-14	2
Delayed Action	424	-25	-8	10
Implementation Difficulties	389	-32	-15	1
Full Implementation	373	-34	-19	-3

SOURCE: Poland GHG Abatement Cost Curve; KASHUE; National Inventory Report

Uncertainties and Sensitivities

Uncertainties and Sensitivities

As with any report of such scope and duration, our research has been affected by uncertainties regarding the impact and cost of abatement opportunities

Assumptions concerning the volume and impact of abatement opportunities in different sectors are highly sensitive to the success of implementation. Implementation of some of the abatement measures included in the cost curve (e.g., CCS, offshore wind) has never been attempted on such a large scale. On the other hand, technological breakthroughs could deliver unanticipated abatement potential. Estimates of the cost of abatement and the investment required are highly sensitive to assumptions about energy prices, the rate of future technological development, interest rates, and GDP growth. Sensitivities surrounding abatement volumes were discussed at length in the previous section on implementation scenarios. In the following section, we focus on cost sensitivities.

Abatement cost is sensitive to assumed energy prices

Recent years have shown that energy prices are sometimes subject to extreme volatility, with oil prices fluctuating between roughly USD 50 and 150 per barrel in a span of less than six months. Whether high energy prices alone would be enough to produce a reduction in emissions is a perennial question in the climate change debate. Our study suggests that high energy prices help, but they do not deliver sufficient reductions in emissions on their own.

It is true that an increase in energy prices reduces the average cost of GHG abatement by making energy efficiency opportunities more profitable and alternative energy sources cheaper. If we assume an average oil price of USD 90 per barrel (rather than the USD 60 assumed by the IEA in our BAU forecast) and a proportionate increase in other energy prices, the average cost of abatement in our model falls to EUR ~4/tCO_2e. As a rule of thumb, increasing oil prices by USD 10 (currently EUR ~6.7) per barrel cuts average abatement costs by EUR 2/tCO_2e in the USD 60 to 120 per barrel range[29]. However, increasing energy prices is not a cheap way to reduce emissions. Energy price increases result in a wealth transfer from oil users to oil suppliers that is several times higher than the savings in emissions abatement costs.

High energy prices have another important side effect that our model does not capture: the impact of high energy prices on energy consumption. However, in a recent study[30], the McKinsey Global Institute estimated that an increase in the price of oil from USD 50 to USD 70 per barrel would cut global energy demand in 2020 by as little as 1.1%, all else equal. There are two reasons for this limited effect: first, due to regulated, subsidized, or heavily taxed end user prices, oil price changes impact only a small proportion of the range of energy prices paid by end users; second, high oil prices accelerate GDP growth, and therefore energy demand, in oil-exporting countries, where oil tends to be subsidized and energy productivity is low.

29 Other energy prices tend to follow the historical pattern of price correlations between oil, gas, and coal.

30 "Curbing Global Energy Demand Growth: The Energy Productivity Opportunity", McKinsey Global Institute (MGI, May 2007 (www.mckinsey.com/mgi).

Future development of power generation technologies is uncertain

The future pace of technological development, particularly for emerging technologies with high expected learning rates, is also uncertain. However, even if costs do not decline as rapidly as we have assumed, the overall effect on the average cost and volume of GHG abatement remains moderate. We have modeled the effect of various rates of capex development for several emerging technologies[31]. For example the average abatement cost of nuclear increases by about EUR 4/tCO_2e when the investment required to install 1 GW of capacity is increased by EUR 500 million. For offshore wind, a similar change in capex leads to an increase of EUR 15/tCO_2e. While significant changes may take place in terms of the specific technologies implemented, other low-carbon technologies are likely to compensate for the gap in many cases.

Capital-intense abatement opportunities are sensitive to interest rate levels

The BAU scenario assumes a 4% interest rate, similar to long-term risk-free rates. This is because we take a government perspective on the cost of abatement: if a government wanted to incentivize a capital-intense abatement opportunity, it could borrow at the nearly risk-free rate to do so. Increasing the interest rate boosts capital costs and therefore increases the total cost of abatement. A higher interest rate is a more accurate reflection of the situation decision makers face when making investments based on, for example, their companies' weighted average cost of capital. Setting the interest rate at 8% instead of 4% increases the overall cost of abatement from EUR 10/tCO_2e to about EUR 19/tCO_2e (Exhibit 35). Capex-intensive short-lifespan abatement measures such as solar and wind see even higher cost increases.

GDP growth influences fuel mix levers

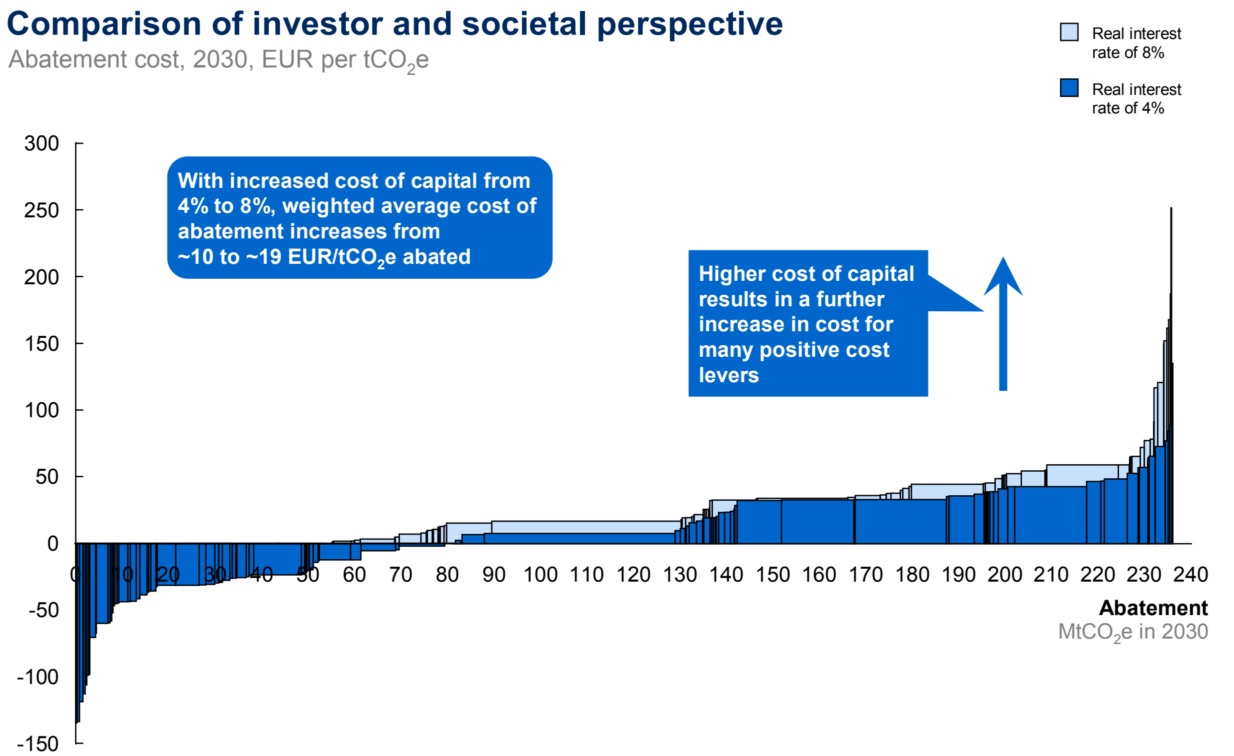
We have generally assumed average annual real GDP growth of 3.4%[32]. However, since GDP growth is hard to predict, we analyzed two other GDP growth scenarios as well, 2.4% growth and 4.4% growth, and their impact on the power sector (the largest sector in terms of emissions and reduction potential). In the lower GDP growth scenario, the average abatement cost in power decreases by EUR ~6/tCO_2e, mostly due to the reduced GDP growth resulting in lower demand for electricity[33], and thus a smaller gap to be filled by CO_2-abating technologies. For example, offshore wind farms, which are expensive in terms of the cost per ton of abated CO_2, need not be built in this scenario. In the higher GDP growth scenario, the average cost of abatement increases by EUR ~3/tCO_2e due to the need to build new, mostly coal-based capacity in response to increased electricity production (263 TWh), especially until 2020, when no nuclear plant has yet been finalized and only a few wind farms have been installed. Some abatement is nevertheless observed by this stage, since the new coal plants would be less CO_2 intensive. As the cost of abating additional units of CO_2 increases, the levers introduced to meet abatement targets are more expensive after 2020.

[31] Nuclear, CCS, offshore and onshore wind.

[32] Source: Global Insight.

[33] We estimate that demand for electricity in the low GDP growth scenario would not grow until 2030.

Exhibit 35



NOTE: Includes investor perspective WACC; Excludes carbon prices, fuel taxes and subsidies, feed-in tariffs, CAPEX subsidies, and OPEX subsidies

SOURCE: Poland GHG Abatement Cost Curve

Appendix

Appendix – Examples of Other Technological GHG Reduction Levers in Transport

Written by Andrzej Kassenberg, PhD, Institute for Sustainable Development

Activities to slow down transport intensity growth in the economy and in everyday life

The basic rule is to rationalize travelling and cargo transport needs (demand management). This means focusing on influencing demand for transport services and ways to meet that demand, reducing both traffic and transport or travel duration, and splitting transport tasks. This can be achieved through an appropriate spatial economy, an individual consumption model, motor policy, and fiscal resource allocation. Transport needs can be limited by using modern communication techniques. This necessitates developing telework, teleconferences, teleshopping, e-governance, e-health, telelearning, and so on. Appropriate spatial planning can reduce the need for travelling. Therefore, city expansion, such as suburbanization, should be reduced. Homes, workplaces, and services should be concentrated where public transportation is available. Office and commercial activities should be located in urban centers or in other areas with good mass transport. Lastly, changes should be made to the spatial organization of production, storage, and distribution. Promoting local production and products, reducing the need for transport services, facilitating new job creation, and building up local economies are also important.

Activities to hinder growth or reduce the share of energy-intensive means of transport

Congestion charges and road pricing can be important levers, and their revenues can be used to support environmentally friendly transport, such as rail, biking, or walking. The key instruments supporting changes in transportation and climate protection behavior include vehicle purchase fees (promoting low-GHG vehicles), overall infrastructure charges, and vehicle charges (e.g., annual highway or expressway charges, charges for using specific sections of roads, such as tunnels or bridges, congestion charges, city entrance charges, parking fees to balance supply and demand for street space and improve mass transit). It is also important to develop eco-mobility chains (i.e., facilities combining public transport with bike and pedestrian traffic, both inside the city and beyond, or launching obligatory plans for big companies with mass transit systems).

Activities to improve transport effectiveness

It is crucial to launch measures to improve vehicle utilization, such as encouraging multi-modal cargo transport, park-and-ride systems, and more intensive transport utilization. Included among such measures are advanced logistics solutions, car pooling and lift sharing, rationalizing public transport services by adjusting them to match needs that change with time and place, and using diversified rolling stock (e.g., in size, quantity, and frequency) in order to fully utilize its capacity without jeopardizing travel efficiency and comfort.

Intelligent transport systems can be used to manage mobility, especially in cities. Major traffic management levers include dedicated lanes and control systems to prioritize mass transit, separate lanes for carpoolers, special streets and footpaths, division of cities into sectors with diversified availability, improved mass transit quality (e.g., by separating tram tracks and traffic lanes, or reserving certain streets for buses), and telematics for integrated transport management systems.

Educational activities

It is important to educate people about the need for balanced mobility and to conduct relevant information campaigns to change social behaviors. This can seriously influence future behavior, helping users to make rational transportation choices. Transportation policies have a strong and direct impact on lifestyles, and they are often controversial, so people need to be well informed about the reasons for such choices. In addition to changing behaviors, it is important to promote so-called eco-driving (i.e., use of fuel-efficient vehicles).

Glossary

Abatement costs (EUR/tCO_2e)	Additional costs (or savings) resulting from use of a technology with low GHG intensity compared with the projected intensity of the current technology (excluding secondary effects from a socioeconomic perspective). In this study, these are assessed from the perspective of the relevant decision maker, i.e., taking into account the specific discount rate(s) and amortization period(s)
Abatement cost curve	Compilation of abatement potentials and costs for a specific sector or country
Abatement lever	See "Lever"
Net economic benefit	Savings for the decision maker, taking into account the specific amortization period(s) and discount rate(s)
Abatement potential ($MtCO_2e$)	Potential for reducing GHG emissions by implementing an abatement lever, assuming a penetration rate that is ambitious but feasible
Baseline year	Base year for measuring achieved reductions in GHG emissions in the context of the Kyoto Protocol (1988 for CO_2 emissions; 1995 for a number of other greenhouse gases)
BAU	Business-as-usual. See "Reference case"
CAGR	Compound annual growth rate
CCS	Carbon capture and storage – technologies for capturing and storing CO_2
CHP	Combined heat and power (plant)
CNG	Compressed natural gas
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent, i.e., specific value of the intensity of a greenhouse gas, expressed in the greenhouse effect of carbon dioxide, e.g., 21 for CH4 (methane), 310 for N_2O (nitrous oxide)
Current technology	Average energy/GHG efficiency in the current (2005) mix of sales or investments.

Decision maker	A party that decides to make an investment, i.e., a company (e.g., the owner of an industrial facility) or an individual (e.g., the owner of a car or home)
ETS	Emissions Trading Scheme of the European Union
EUR	Euro
GHG	Greenhouse gas in the context of the Kyoto Protocol, i.e., CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), HFC/PFC (hydrofluorocarbons), and SF_6 (sulfur hexafluoride)
Gt	Gigaton(s), i.e., one billion (109) metric tons
IGCC	Integrated gasification combined cycle – a combined gas and steam turbine system with an upstream coal gasification system
HDV	Heavy duty vehicle – a road vehicle with a total mass exceeding 16 t
HVAC	Heating, ventilation, air conditioning
kWh	Kilowatt hour(s)
Lever	Abatement lever – a technological approach to reducing GHG emissions, e.g., more efficient processes or materials
LDV	Light duty vehicle – passenger cars and light vans with total mass up to 3.5 t
MDV	Medium duty vehicle – vans and delivery trucks with total mass of 3.5 to 16 t
Mt	Megaton(s), i.e., one million metric tons
MWh	Megawatt hour(s), i.e., one thousand kWh
PJ	Petajoule, i.e., one quadrillion (1015) joules
Reference case	Base GHG emissions scenario, which assumes no further climate change regulations, no significant investment in low-carbon solutions beyond fulfilling current legal obligations (signed before June 2009), and continued historical rates of efficiency improvements in each sector

Sector Grouping of businesses in this study, specifically:

- Power: emissions from power generation (centralized, decentralized, industrial) and from generation of heat for local and district heating networks
- Industry: direct and indirect emissions of all industrial branches except power generation and transport; includes industrial heat generation
- Buildings: direct and indirect emissions from private households and the tertiary sector (commercial and public buildings, buildings used in agriculture)
- Transport: emissions from road traffic (passenger – small, midsize, and large passenger cars; freight – light ("sprinter class"), medium, and heavy trucks)
- Waste management: emissions from waste disposal and sewage treatment
- Agriculture: emissions from livestock farming and soil management
- Forestry: emissions from land use, land-use change and forestry (LULUCF), mainly due to deforestation, decay, and peat

T Metric ton(s); i.e. one thousand kg

TWh Terawatt hour(s), i.e., one billion kWh

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