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MIT JOINT PROGRAM ON THE SCIENCE AND POLICY of GLOBAL CHANGE

Report No. 251
October 2013

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# Regulatory Control of Vehicle and Power Plant Emissions: How Effective and at What Cost?

Sergey Paltsev*†, Valerie Karplus*, Henry Chen*, Ioanna Karkatsouli*, John Reilly* and Henry Jacoby*

**Abstract**

*Passenger vehicles and power plants are major sources of greenhouse gas emissions. While economic analyses generally indicate that a broader market-based approach to greenhouse gas reduction would be less costly and more effective, regulatory approaches have found greater political success. Vehicle efficiency standards have a long history in the U.S and elsewhere, and the recent success of shale gas in the U.S. leads to a focus on coal–gas fuel switching as a way to reduce power sector emissions. We evaluate a global regulatory regime that replaces coal with natural gas in the electricity sector and imposes technically achievable improvements in the efficiency of personal transport vehicles. Its performance and cost are compared with other scenarios of future policy development including a no-policy world, achievements under the Copenhagen accord, and a price-based policy to reduce global emissions by 50% by 2050. The assumed regulations applied globally achieve a global emissions reduction larger than projected for the Copenhagen agreements, but they do not prevent global GHG emissions from continuing to grow, and the reduction in emissions is achieved at a high cost compared to a price-based policy. Diagnosis of the reasons for the limited yet high-cost performance reveals influences including the partial coverage of emitting sectors, small or no influence on the demand for emissions-intensive products, leakage when a reduction in fossil use in the covered sectors lowers the price to others, and the partial coverage of GHGs.*

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# 1. ALTERNATIVE PATHS TO GHG EMISSIONS CONTROL

## 1.1 The Push for Regulation

Most quantitative studies of global efforts to reduce greenhouse gas (GHG) emissions assume some form of price-based policy that is imposed either by a tax or a cap-and-trade system (e.g., Kriegler et al., 2013; Paltsev et al., 2013; van Vuuren et al, 2011; Clarke et al., 2009) This policy choice is motivated in part by the ease of simulating these measures in computer models, but more importantly a price-based approach is widely seen as a low-cost means of achieving emissions reduction targets. Unfortunately, with the exception of a few local or regional examples,[1] progress in developing a price-based approach has faltered. Instead, governments are turning ever more frequently to familiar instruments for environmental control: regulations and subsidies.

The U.S. provides an example of the process. The Waxman-Markey cap-and-trade legislation passed the U.S. House of Representatives in 2009 but failed in the Senate, and this measure is no longer seriously under consideration in the U.S. Various proposals have come forth for a carbon or greenhouse gas tax, most recently the Climate Protection Act of 2013 (U.S. Senate, 2013), but prospects for serious consideration of a new tax are poor. Instead, a number of regulatory measures have been imposed, and others are under consideration—to be added to regulatory and subsidy programs already in place.

Moreover, even where taxes or trading systems have been adopted they usually are supplemented by regulatory measures. The European Trading System (ETS) is an example. It applies only to about half of Europe's emissions, leaving a combination of regulations and subsidies as the policies of choice in other sectors. Even where the ETS applies, overlapping regulatory targets are in place for renewable power generation and efficiency improvement. In addition, regulatory measures of the type explored here are proposed as part of a possible sectoral approach to an international agreement on emissions reduction (Sawa, 2010; Gavard et al., 2011).

Because electric power generation and personal transportation contribute a large fraction of anthropogenic GHGs, and technical means are available for lowering their emissions, these two sectors are an attractive target for further regulatory action. To some degree such a move is already underway. In the U.S. the shale gas bonanza has generated excitement about the possibility of reducing greenhouse gas emissions by shifting from coal to gas for power generation. Spurred by falling gas prices, a redispatch of existing generation units led to a drop in coal generation from 50% to 42% of U.S. generation over the period 2005 to 2011, to be largely replaced by less $CO_2$-intensive natural gas, which rose from 19% to 25% of the national total. Studies of potential future growth of U.S. natural gas production suggest that further replacement of coal with gas in electric generation could be a large part of a program to further reduce U.S.

[1] These include experimentation with carbon taxes in several countries (Carbon Tax Center, 2013) and cap-and-trade systems including the European Trading System (ETS), a California implementation and the Regional Greenhouse Gas Initiative (RGGI) in the Northeastern U.S.

GHGs even taking account of leakage of methane from the natural gas supply system (MITEI, 2012; Jacoby et al., 2012). Because shale resources are widely distributed internationally, the U.S. experience has ignited interest elsewhere in such a fuel shift in the electric sector.

Passenger vehicles are viewed as an important target for climate policy around the world. Many governments have increased the stringency of future new vehicle fuel economy (or equivalent per distance emissions) standards to unprecedented high levels within the last decade. Fuel economy standards target reductions in vehicle fuel use or emissions per unit of distance traveled. These standards apply only to new vehicles, and do not constrain the total quantity of fuel use or emissions. Among the adopting regions, the EU and the U.S. have enacted some of the toughest standards. The latest U.S. fuel economy standards would raise the combined city-highway test-cycle fuel economy from around 27.5 mpg in 2007 to around 48 mpg (or 163 grams/mile) in 2025 (combined for cars and light trucks). Policymakers claim that relative to new vehicles produced in 2016, the 2017–2025 rule will reduce U.S. oil consumption by 4 billion barrels of oil and $CO_2$ emissions by 1.8 billion metric tons over the lifetimes of model year 2017 to 2025 vehicles (U.S. EPA, 2013). China, Korea, Canada, India, Japan and Australia also have fuel economy standards in place. The objective of this analysis is to investigate the economic, energy and environmental implications of a regulatory approach to emissions mitigation that focuses the substitution of gas for coal in power generation and raises vehicle efficiency. We explore the implications of advances that have been put forth as technically feasible, near-term policies on the assumption they are extended to global application. How would such an approach contribute to the goal of reducing climate change risk, and at what cost? Achievements under such a regulatory approach are compared to those under other potential futures including scenarios of the continuation of current policies, and the adoption of a global target achieved with a universal price on greenhouse gas emissions, and the adoption of regulatory measures in the interest of short term response to be supplemented later by a price-based regime.

### 1.2 A Regulatory Scenario and Alternatives

To explore a regulatory approach to global GHG reduction we construct a case where controls are imposed on both electric power generation and personal transport. In the electricity sector we assume that regulations are imposed that replace all oil and coal with natural gas in every region by 2050, on a linear path from 2010. In the personal transport sector the national vehicle fleets of *new* personal transport vehicles are required, also by 2050, to improve their miles-per-gallon (MPG) performance from their 2010 standard to the level shown in **Table 1**. This path for automotive design leads to an average for the global *on-the-road* fleet rising from 23 MPG in 2010 to 43 MPG in 2050. This advance is assumed to be achieved by a combination of improvements in gasoline and diesel vehicle efficiency, penetration of hybrid, plug-in and pure electric vehicles, and addition of biofuels into the fuel mix. Low-carbon second-generation biofuels are assumed to be available, only limited by cost. It is further assumed that no emissions control measures beyond those already committed are taken in other economic sectors such as air, rail and truck transport, industry, commerce, agriculture or households.

**Table 1.** New fleet vehicle efficiency standard in miles per gallon (MPG).

| | 2010 | 2050 |
|---|---|---|
| USA | 28 | 80 |
| Canada | 29 | 80 |
| Mexico | 20 | 60 |
| Brazil | 20 | 60 |
| Rest of Americas | 20 | 55 |
| Europe | 45 | 100 |
| Russia | 20 | 55 |
| Rest of Europe & Central Asia | 20 | 55 |
| China | 35 | 85 |
| India | 24 | 70 |
| Japan | 43 | 80 |
| Dynamic Asia | 37 | 80 |
| Rest of East Asia | 20 | 60 |
| Australia and Oceana | 27 | 80 |
| Middle East | 20 | 70 |
| Africa | 20 | 60 |

Termed the ***Regulations Scenario***, the effectiveness and cost of a regime based on the previously described measures is compared with four alternative futures:

- ***No Policy Scenario***. No greenhouse gas control measures are taken by the nations beyond those in place before the Copenhagen Agreement.[2]
- ***MIT Copenhagen Scenario***. Nations are assumed to meet the emissions reductions to 2020 pledged under the agreement reached in the Copenhagen meeting of the Conference of Parties (COP) of the Climate Convention and confirmed in the subsequent COP in Cancun, as modeled by the MIT Joint Program, with these targets extended to 2050.[3] This scenario is the basis for the 2012 MIT Outlook (MIT Joint Program, 2012).
- ***Least Cost Scenario***. A policy is adopted by all nations that takes effect beginning in 2015, set to achieve a 50% reduction in greenhouse gas emissions below the 2000 level by 2050. It is modeled as achieved by a price measure—e.g., by a $CO_2$ tax or cap-and-

[2] Several nations that earlier made emissions commitments under the Kyoto Protocol have since backed out of the agreement, and the base year of the simulations accounts for any achievement the early years of the 2008-2012 Kyoto commitment period, so ultimate reductions under the Protocol are not specifically included in the simulations.

[3] Although China's Copenhagen intensity target is in terms of $CO_2$, it is modeled in these simulations as a GHG commitment.

trade system applied uniformly across all sectors and nations (with revenues rebated to households in each region).[4]

- ***Combined Scenario***. The Least Cost Scenario is employed in sequence with the Regulations Scenario.

This regulatory approach to emissions control and the other scenarios considered for comparison are assessed without regard to current political likelihood, but the analysis does consider practical supply issues such as biomass resource availability, vehicle turnover times, delays in infrastructure development, etc.

The environmental performance of all but the last of these scenarios, and the cost of the Regulations compared to the Least Cost Scenario, are considered in Section 2, and the limitations of the regulatory approach are diagnosed in Section 3. In Section 4 we consider the possibility of sequential policy development, formulating under which the Combined Scenario employs both the assumed Regulations Scenario and the Least Cost Scenario.

### 1.3 Analysis Method

Assessment of the performance of the Regulations Scenario and alternatives needs to take account of the interaction of the electricity and transport sectors with other components of the energy sector and with other parts of the economy, and for this purpose we apply the MIT Emissions Prediction and Policy Analysis (EPPA) model (Paltsev et al., 2005). EPPA is a recursive–dynamic multiregional general equilibrium model of the world economy—divided into 16 nations and multination regions—which is built on the Global Trade Analysis Project (GTAP) data set of world economic activity augmented by data on the emissions of greenhouse gases, aerosols and other relevant species, and details of selected economic sectors. The model is used to study global population and economic growth, technology development and energy use, and to project greenhouse gas (GHG) emissions and prepare assessments of GHG control policies both for individual countries and for proposed international agreements (Paltsev et al., 2005).

The model projects economic variables (gross domestic product, energy use, sectoral output, consumption, etc.) and emissions of greenhouse gases ($CO_2$, $CH_4$, $N_2O$, HFCs, PFCs and $SF_6$) and other air pollutants (CO, VOC, NOx, $SO_2$, $NH_3$, black carbon and organic carbon) from the supply and combustion of carbon-based fuels, industrial processes, waste handling and agricultural activities. The model identifies sectors that produce and convert energy, industrial sectors that use energy and produce other goods and services, and the various sectors that consume goods and services (including both energy and non-energy). The model covers all economic activities and tracks domestic use and international trade. Energy production and conversion sectors include coal, oil, and gas production, petroleum refining and an extensive set of alternative low-carbon and carbon-free generation technologies. The regional and sectoral breakdown of the version of the EPPA model applied here are shown in **Table 2**.

[4] In this assumed burden sharing the developed regions include the U.S., Canada, Japan, EU, Russia, Australia and New Zealand.

**Table 2.** Structure of the MIT Emissions Prediction and Policy Analysis Model

| Countries/Regions | Sectors | |
|---|---|---|
| United States | Non-Energy | Energy |
| Canada | Crops | Coal |
| Japan | Livestock | Crude Oil |
| European Union+[a] | Forestry | Oil from Shale |
| Australia/New Zealand | Food | Refined Oil |
| Russia | Services | Liquid Fuel from Biomass |
| Rest of Europe | Energy-Intensive Products | Natural Gas |
| India | Other Industries Products | Synthetic Gas from Coal |
| China | Industrial Transportation | Electricity Generation Tech. |
| Dynamic East Asia[b] | Household Transportation | Conventional Fossil |
| Mexico | Purchased Transportation | Hydro |
| Brazil | Internal Combustion Vehicles | Nuclear |
| Central and S. America | Conventional Hybrid Vehicles | Advanced |
| Middle East | Plug-in Electric Vehicles | Biomass (BELE) |
| Africa | Electric Vehicles | Natural Gas Combined Cycle |
| Rest of World | | NGCC with CCS |
| | | Coal with CCS |
| | | Solar and Wind |
| | | Wind with NG backup |
| | | Wind with Biomass backup |

[a]The European Union (EU-27) plus Norway, Switzerland, Iceland and Liechtenstein.

[b]Including South Korea, Malaysia, Philippines, Singapore, Taiwan and Thailand.

Importantly for this study, account is taken of the fugitive emissions of methane from its supply and use system. Emissions rates, taken from the Edgar data base, differ among regions, but the global average is about 4% of produced natural gas (Waugh et al., 2011).

For analysis of the implications of these policy scenarios for atmospheric greenhouse gas concentrations and climate change the EPPA model is integrated into the MIT Integrated Global System (IGSM) framework (Sokolov et al., 2005). The analysis covers the greenhouse gases specified in the Kyoto Protocol ($CO_2$, methane, nitrous oxide and a set of industrial gases). For purposes of economic analysis within the EPPA model, the marginal cost abatement for different GHGs are valued based on their 100-year Global Warming Potentials as defined by the Intergovernmental Panel on Climate Change. The IGSM explicitly treats the fate of emissions once in the atmosphere and the radiative forcing of each substance separately. Details of the IGSM and its EPPA component, and their application to issues of climate risk and policy development can be found at http://globalchange.mit.edu/.

## 2. PERFORMANCE AND COST OF INDEPENDENT ALTERNATIVES

### 2.1 Emissions and Climate Impact

#### *2.1.1 Global Greenhouse Gas Emissions*

**Figure 1** shows the projection of global GHG emissions in $CO_2$ equivalents ($CO_2$-e) under four of the policy scenarios. The Copenhagen Agreement stabilizes emissions out to its 2020 terminal date, but since the commitments of several developing countries are stated in terms of emissions intensity (GHG per unit of GDP) extension of the agreement to 2050 yields continued emissions growth. The Regulations Scenario delivers more substantial reductions than MIT Copenhagen, but these measures are not sufficient to avoid continuing growth in global emissions. Also, in 2050 the Regulations Scenario cuts global emissions by only about one-third of the reduction achieved by the Least Cost Scenario.

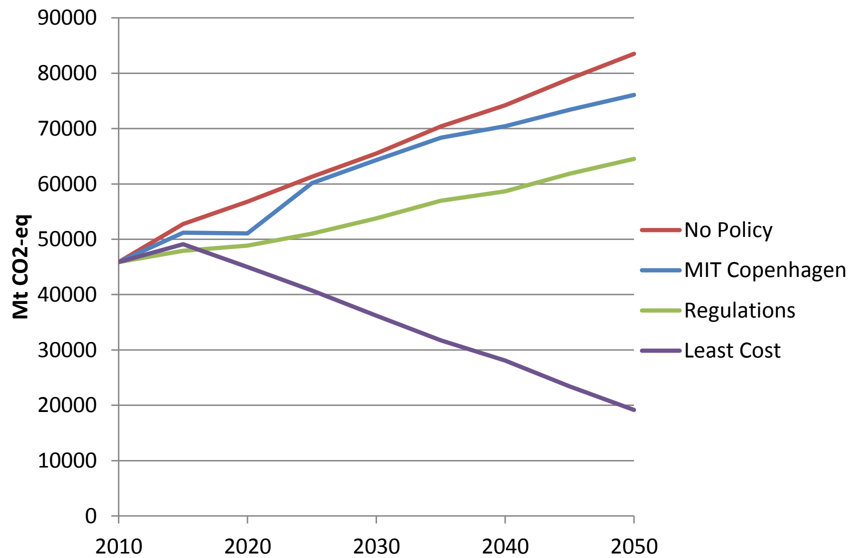



**Figure 1.** Global greenhouse gas emissions under alternative policies.

**Figure 2** shows where among the economic sectors of the U.S., EU and China the main coal-to-gas substitution occurs under the Regulations Scenario, compared with conditions under the MIT Copenhagen and the Least Cost scenarios. Compared to the U.S. and Europe, China shows its highest increase in gas use under the Regulations Scenario, which comes in its power generation sector. In part this result is attributable to the fact that in 2010 coal in China accounted for a higher share of electricity generation (almost three-quarters) than in either the U.S. (around 45%) or Europe (about a quarter). The faster economic growth in China also generates a higher increase in gas consumption compared to other regions. Under the MIT Copenhagen Scenario and the Least Cost Scenario, on the other hand, China's gas use grows less strongly or even declines.

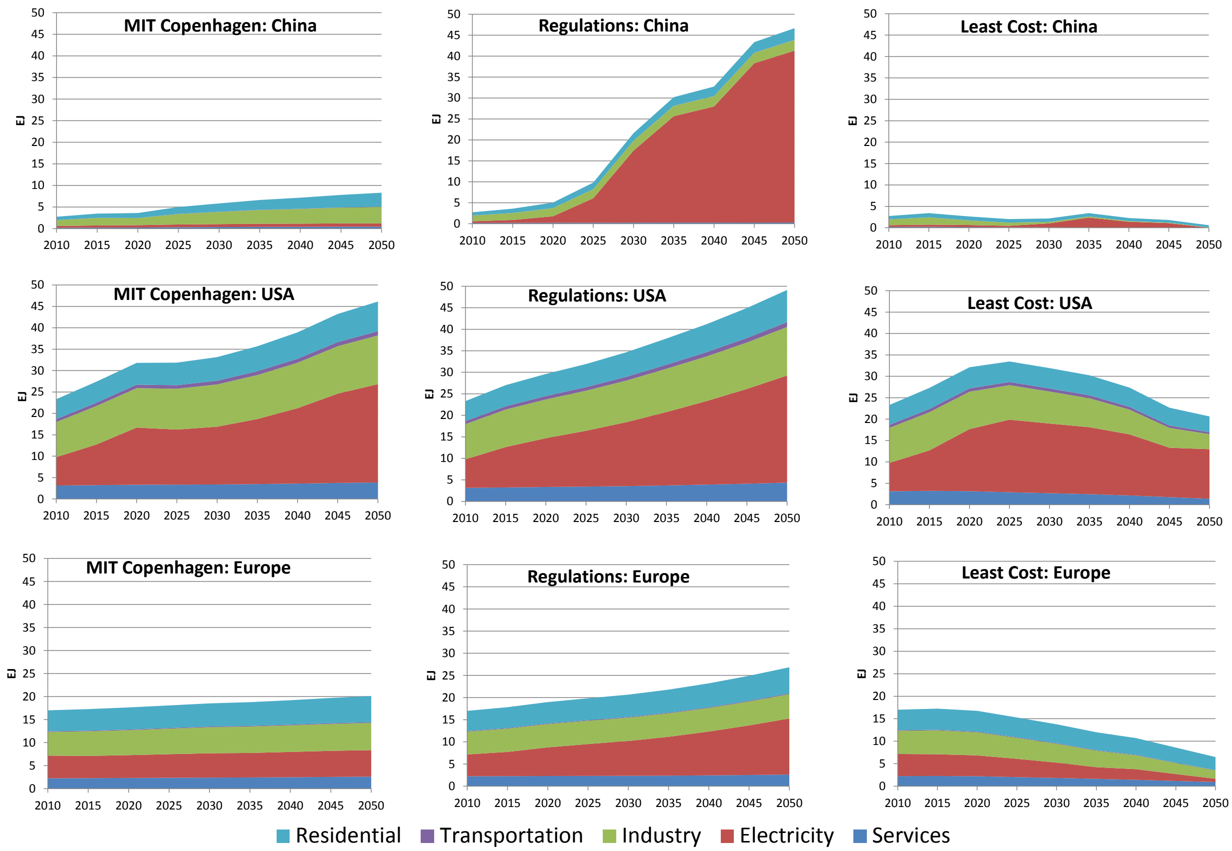



**Figure 2.** Gas use by region under alternative policies.

**Figure 3** shows how the emissions reduction is achieved in personal transport under the Regulations Scenario and the Least Cost Scenario. (Note that the total emission reduction is much greater under Least Cost, as shown in Figure 1.) Plug-in hybrid vehicles (PHEVs) do not play a significant role under either policy because their costs are higher than alternatives. Indeed, under the cost assumptions applied here, hybrid electric vehicles (HEVs) outcompete PHEVs or pure electrics (EVs), delivering the required vehicle efficiency standards at lower cost.

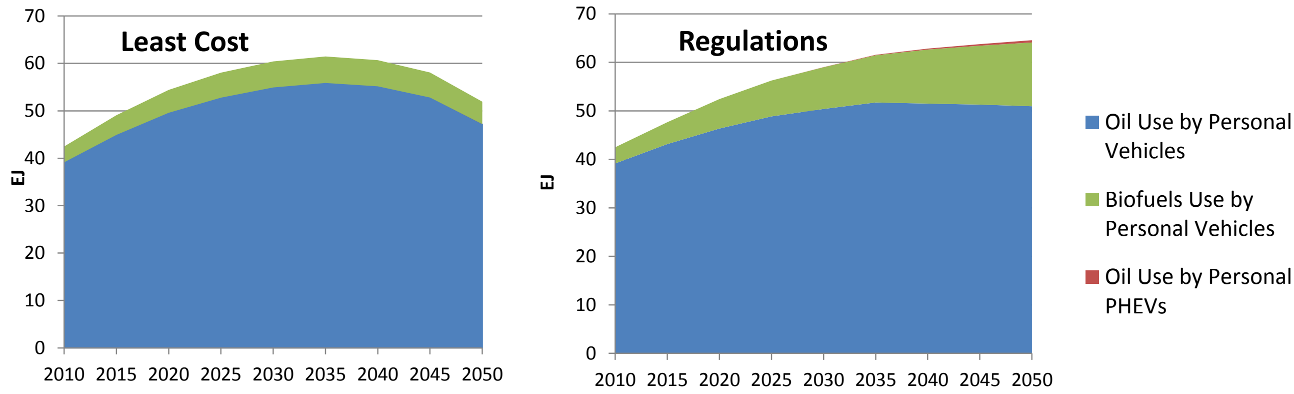



**Figure 3.** Fuel efficiency standards and personal vehicle demand under Least Cost compared to the Regulations Scenario.

Given the substantial $CO_2$ reductions that the Regulations Scenario requires in electricity and transport, which are two large emitting sectors, a greater impact on global total emissions might be expected than that shown in Figure 1. In Section 3 we explore the reasons for this weak performance at the all-sector, global scale.

### *2.1.2 Effect on Projected Climate Change*

The emissions projections in Figure 1 are analyzed using the climate science component of the MIT Integrated Global System Model (Sokolov et al., 2005), which contains a detailed representation of the carbon cycle and the chemistry of the other greenhouse gases, to explore the effect of these different scenarios on projected climate change. One step in this analysis is a calculation of the atmospheric GHG concentrations under the various policy scenarios. These are presented in **Figure 4**. The different GHGs are aggregated in terms of their instantaneous effect on the Earth's radiation balance, so their overall effect is stated in terms of $CO_2$-eq, which in this measure is the $CO_2$ concentration that would have the same instantaneous effect as all the gases together.[5]

[5] This a different definition of $CO_2$-eq then that defined by global-warming potentials. The GWP measure is widely used for policy formulation applied to emissions. It adjusts instantaneous radiative forcing based on different lifetimes of gases. The definition used here is based on instantaneous radiative forcing given actual concentrations at any given point in time. It more accurately reflects the effect on climate at any given point in time.

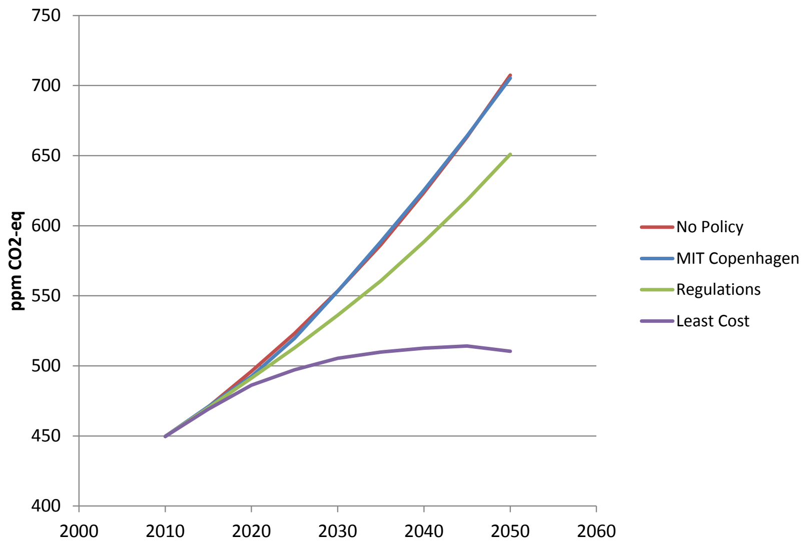



**Figure 4.** Atmospheric greenhouse gas concentrations under alternative policy assumptions.

Note that the MIT Copenhagen and No Policy scenarios produce essentially the same outcome. In these two scenarios, and under the Regulations Scenario, the human emissions rate exceeds the rate of uptake by the oceans and biosphere throughout the period, so atmospheric concentrations continue to rise. By 2050 the Regulations Scenario reduces the concentration by only about 50 ppm below the MIT Copenhagen Scenario. The 50% reduction in global emissions in the Least Cost Scenario is projected to be aggressive enough to stabilize atmospheric concentrations at around 500 ppm.

The effect of these emissions scenarios on projected global temperature increase relative to its preindustrial level is shown in **Figure 5**. The effects on global temperature of the Regulations Scenario, or even of the 50% Least Cost target, are much less substantial than the emissions reductions (Figure 1), or even of the change in atmospheric GHG concentrations (Figure 4). The smaller effect occurs for several reasons. Most important is the inertia in the climate system. Because of the heat uptake by the ocean, the climate system is still adjusting to emissions from before the 1990 start of the climate simulation and their addition to concentrations. Also, because the simulation period extends only to 2050, the full effect of the Regulations Scenario, in relation to a MIT Copenhagen or a No Policy world, has not been realized. If the simulation was extended to later decades in the century the projected temperature reduction attributed to the Regulations Scenario would be greater.

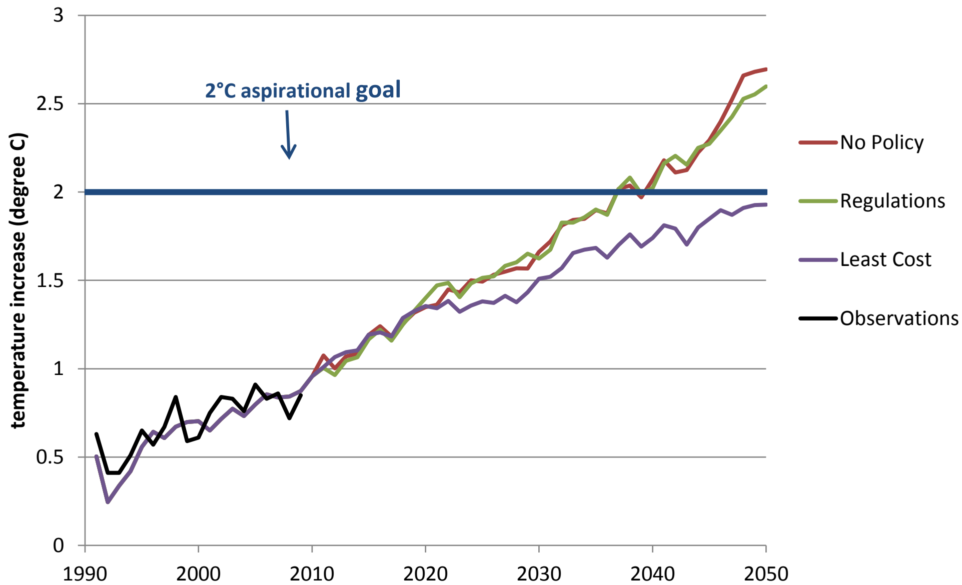



**Figure 5.** Global temperature relative to preindustrial level under alternative global policy scenarios.

Also significant in the temperature result in Figure 5 is the influence of aerosols, which are not taken into account in Figures 1 and 4. To simplify somewhat, aerosols come in two forms: black and white. Reducing coal use reduces the emissions of black aerosols, another warming agent, but also reduces the emissions of sulfur compounds. The sulfur emissions are the precursors of white or reflecting aerosols, which are a cooling influence. With the sharp cut in coal burning in the Regulations Scenario the loss of reflecting aerosols is the larger influence.

The 50% global reduction in emission under the Least Cost Scenario is sufficient to bring the path of increasing global temperature by midcentury into a zone that is consistent with the maintenance of the target of a 2°C limit above its pre-industrial level. However, temperature is still rising, and so maintaining that goal will depend on further cuts beyond 2050, enough to counter remaining inertia in the system.

### 2.2 Cost Effectiveness

A price-based policy will, in general, yield emissions reductions at a cost lower than a collection of regulatory measures, and comparison with the performance of a universal price penalty on GHG emissions is an extremely tough test for the assumed Regulations Scenario. Still, exploration of this difference can help inform judgments about the design of regulatory measures and how they might be improved.

Comparing the cost of reductions achieved in the Regulations vs. the Least Cost scenarios is not straightforward, however. For a least cost solution based on market approach there is a single price of GHGs, which is a cost of reduction at the margin. This price rises with increasing stringency of the policy; for example, in the least cost scenario with international emissions trading considered here global carbon price reaches around \$75/t $CO_2$-e in 2030 and around

$500–600/t by 2050. Because the Regulations Scenario involves several policies, each with its own cost at the margin, there is no single price or marginal cost. It is possible, however, to calculate the average cost of the Regulations Scenario, to be compared with the average cost of the Least Cost Scenario. One measure of the cost of emissions mitigation is the loss in national consumption, which is related to the change in gross domestic product but is a better measure of the welfare effect of policy. Using this definition of cost the average cost of emissions reduction is computed by simply dividing the global cost in each year by the tons of $CO_2$ equivalent reduction below that of the MIT Copenhagen Scenario.

**Figure 6** presents this result for the Regulations and the Least Cost scenarios. As expected, the results show the Regulations Scenario to be a relatively expensive approach to emissions reduction. Throughout the period to 2050 they impose a higher average cost per ton reduced than does the price-based policy. It is worth reiterating that the price per ton $CO_2$-e of the Least Cost Scenario, which reflects the marginal cost of reduction, is substantially higher than the average cost plotted in the figure. The price reflects the cost of the most expensive actions required to achieve each year's reduction, but of course many mitigation actions are less costly.

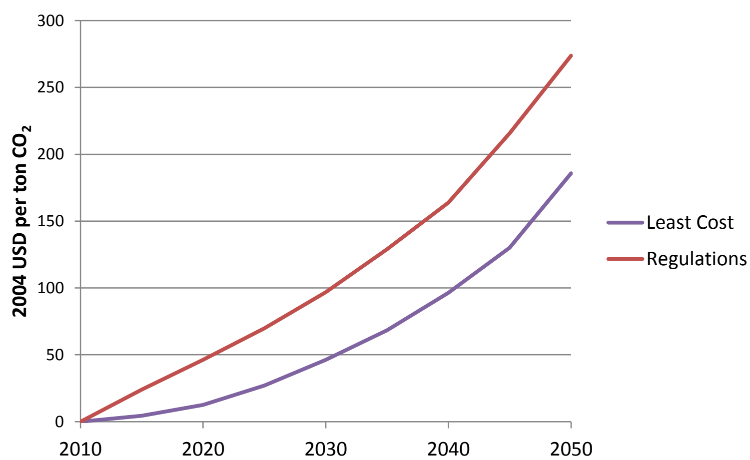



**Figure 6.** Average cost of greenhouse reduction, Regulations Scenario and the Least Cost Scenario.

This difference in average cost of emissions reduction can be attributed to several features of a regulatory approach, as compared to imposition of a uniform financial penalty on emissions. A main cause of the high Regulations Scenario cost is the effect of the very stringent vehicle efficiency standards laid out in Table 1, with a strong contribution to the global cost from regions such as the U.S. and Europe that face a combination of large vehicle fleets and very great increases in MPG, as well as from countries with rapidly growing vehicle markets, such as China. On a global average, the realized miles per gallon (MPG) are increasing from 23 MPG in 2010 to 43 MPG in 2050 in the Regulations Scenario. Increasing fuel efficiency standards in this way raises average vehicle costs. The corresponding number in 2050 under MIT Copenhagen is 26 MPG, while the Least Cost Scenario reaches only 32 MPG in 2050.

In 2050, average MPGs in the Regulations Scenario are 38 in China, 33.5 in India, 64 in Europe, and 51 in the U.S. The corresponding numbers under the Least Cost Scenario are 24.5 in China, 28.5 in India, 47 in Europe, and 34 in U.S. The resulting changes in vehicles per capita and total vehicles in these scenarios are plotted in **Figure 12**, which shows the developing countries to be most sensitive to the cost increase. This difference between the developed and developing nations emerges because the cost of increased vehicle efficiency is the same across regions, but the vehicle cost before the increase in fuel efficiency requirement is lower in developing countries. Thus, the percentage increase in vehicle price to meet the efficiency standards is higher in developing countries than in developed ones. For the same reason, Figure 12 shows that the total personal vehicle numbers in developing countries are more sensitive to the fuel efficiency standards required by the Regulations Scenario, even though their total vehicle fleets will increase significantly over the decades to 2050.

Despite the fact that MPG increases are more modest in China, efficiency increases result in significant additional new vehicle costs in a highly price-sensitive market, significantly limiting new vehicle purchases in the Regulations Scenario as households substitute toward other transport modes in future years. Thus in China vehicle ownership rates are reduced relative to the MIT Copenhagen Scenario and, though this change brings less expenditure on vehicles and fuel, an economic model like EPPA values the loss of mobility and the cost of substituting other forms of transport.

## 3. DIAGNOSIS OF THE REGULATORY APPROACH

The regulatory approach as framed here does not achieve frequently mentioned emissions targets, or the 2 $^{\circ}$C temperature targets shown in Figure 5. Moreover,the emissions reduction that it does achieve comes at substantially higher cost than would be the case with a price-based approach. Factors that contribute to these differences in performance and cost can be summarized as follows.

### 3.1 Emissions From Outside Electricity and Personal Transport

For three of the policy scenarios **Figure 7** shows $CO_2$ emissions by consuming sector. The reduction in emissions of the Regulations and Least Cost scenarios are presented in relation to emissions under MIT Copenhagen. Here can be seen one main reason why the Least Cost approach is so much less costly than emissions mitigation by the Regulations Scenario. Under the Regulations Scenario almost all of the reductions come from limiting the increase in $CO_2$ emissions from the two targeted sectors, electricity and personal transport. Therefore this limited regulatory approach misses lower cost reductions in other sectors, and reduction in other greenhouse gases, that a price-based policy exploits. Particularly important for this cost-saving effect are the reductions in in the industry, household and commercial transport sectors which allow the very high cost of the ambitious targets for automobile technology and biofuels to be avoided.

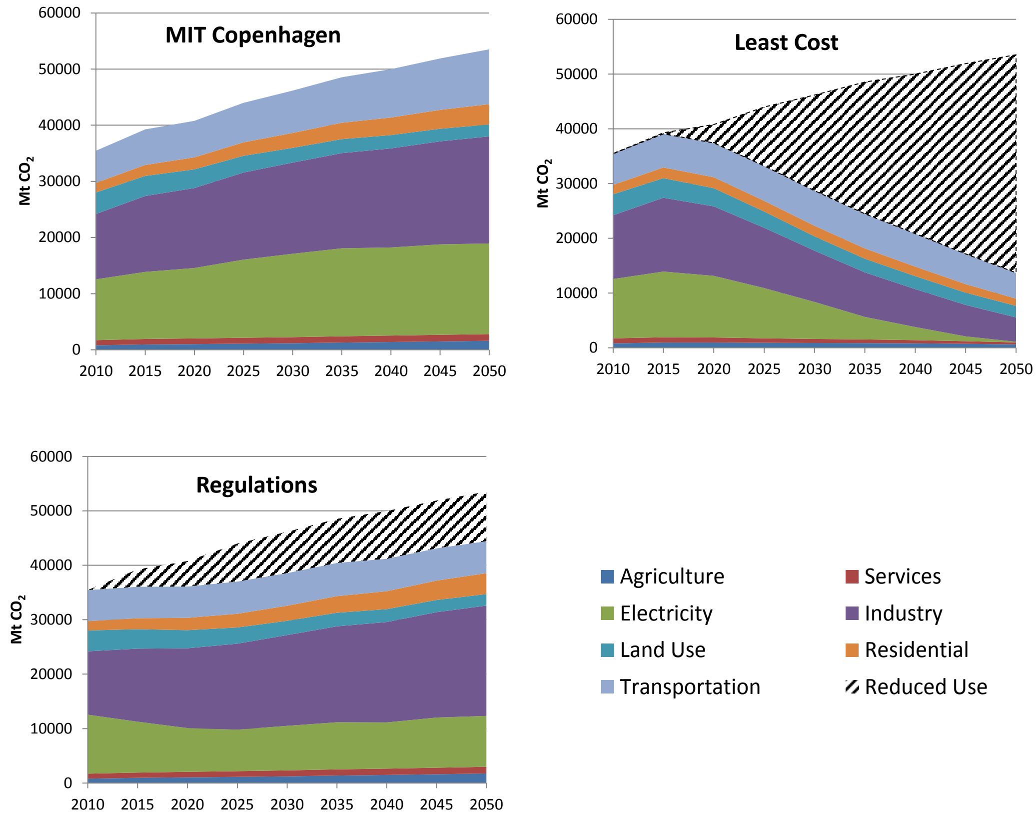



**Figure 7.** Scenarios of emissions reduction.

### 3.2 Limited Incentives in the Electric Sector

Even in the targeted electric sector, the Regulations Scenario fails to take advantage of potential emissions reductions. The various options are shown in **Figure 8**, which plots global generation in terawatt-hours by technology, again showing the demand reduction in relation to conditions under the MIT Copenhagen Scenario. The Regulations Scenario replace coal with natural gas, and the resulting increase in electricity price yields a small reduction in electricity demand. The price-based approach on the other hand not only replaces coal with gas but also increases the use of renewables and nuclear power and takes advantage of cost-efficient reductions in electricity demand. Late in the period the ever more stringent reduction target in the Least Cost Scenario lead to the phase-out of gas without capture and the introduction of relatively expensive gas generation with capture and storage. Even though the costs at the margin are high in these later years the many reductions are being achieved by (intra-marginal) lower cost actions, leading to the average cost plotted in Figure 6.

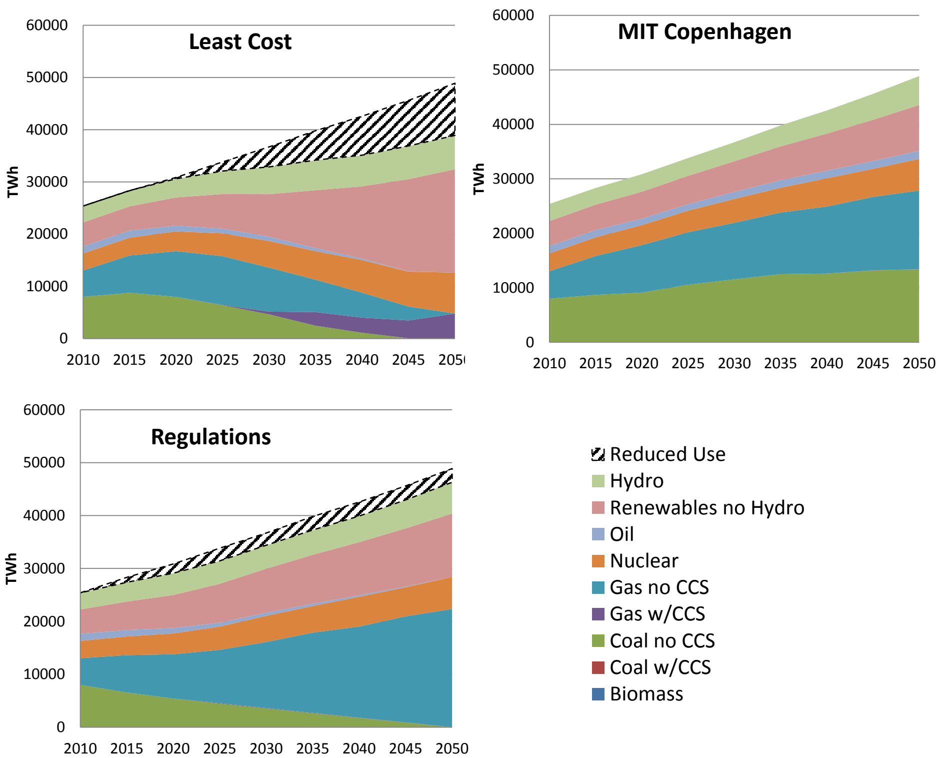



**Figure 8.** Electricity generation by fuel type.

### 3.3 Expansion of Use of Coal Outside the Electric Sector

The Regulations Scenario focuses on coal in the electric sector, and in some countries like the U.S. this limited target in fact covers something over four-fifths of coal use. But this use pattern is not universal. For example, as shown in **Figure 9** only about half of China's coal use is in the electric sector, and other uses are free to grow with no restraining incentives.

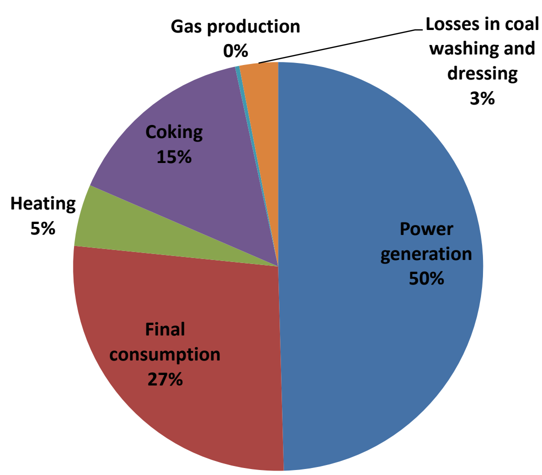



**Figure 9.** China's coal use by sector, 2010 (China Energy Yearbook, 2011).

Therefore, the partial coverage of coal use has a perverse effect illustrated in **Figure 10**. In China the elimination of coal in electricity generation lowers the coal price, stimulating its use in the Industry and Residential sectors, as shown in the left-hand side of the figure. The application of a universal emissions price reduces coal use in these sectors as well as in electric power. Under the Regulations Scenario, the partial coverage of coal use and the associated coal leakage lead to reductions in coal use in the U.S. and other developed counties, but to increases in China and India as shown on the right-hand side of the figure.

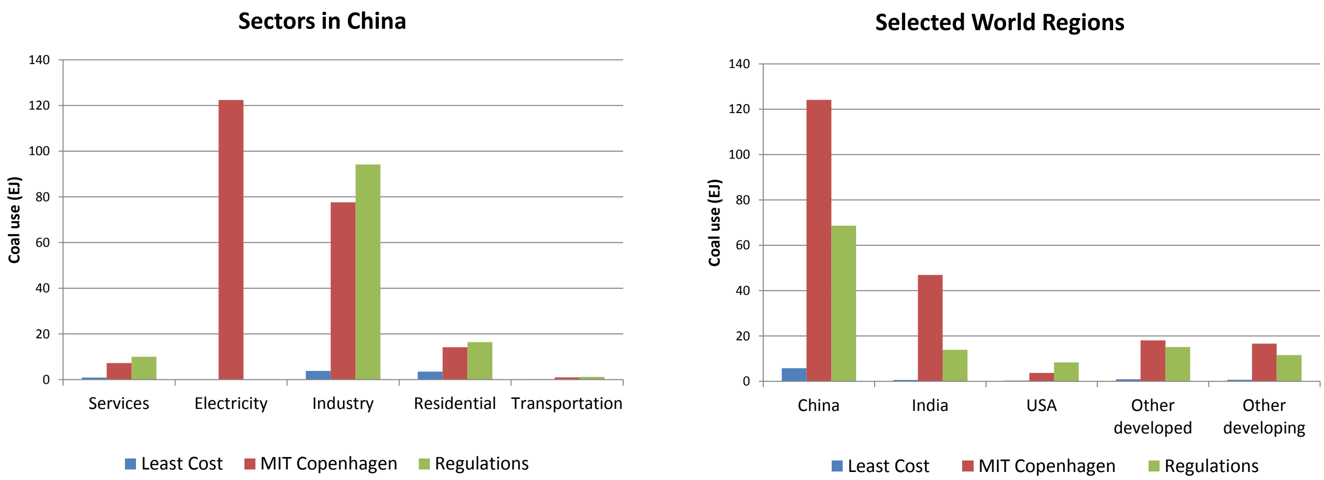



**Figure 10.** Projected coal use in 2050 by sector and region.

### 3.4 Limited Coverage of the Transport Sector

The cost-increasing effect of partial coverage also appears in the transport sector, whose oil use is shown in **Figure 11**. By 2050 the Regulations Scenario accomplishes a substantial reduction in oil use in personal vehicles, in relation to the MIT Copenhagen Scenario. This reduction reflects both the effect of the programmed increase in vehicle efficiency and the "rebound" effect whereby the lower cost per mile of a more efficient vehicle leads to additional miles driven. But note that oil use in commercial vehicles (trucks, buses, trains, airplanes and ships) continues to grow apace, with no reduction below the levels under the less stringent MIT Copenhagen Scenario.

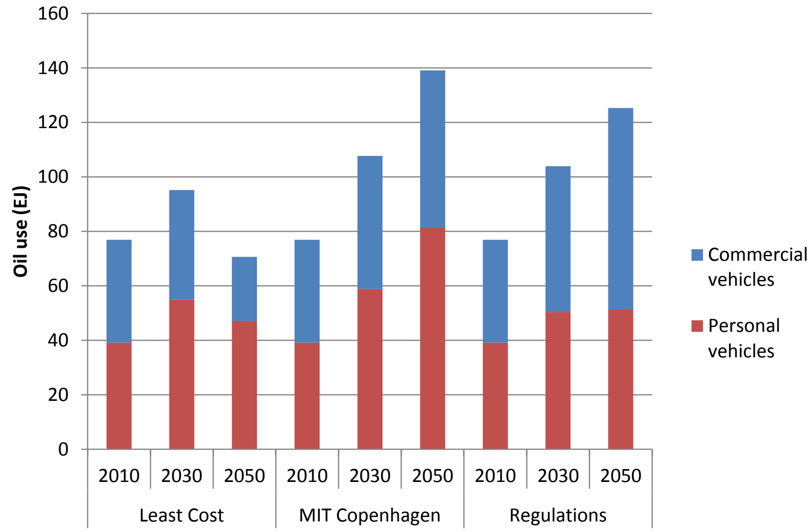
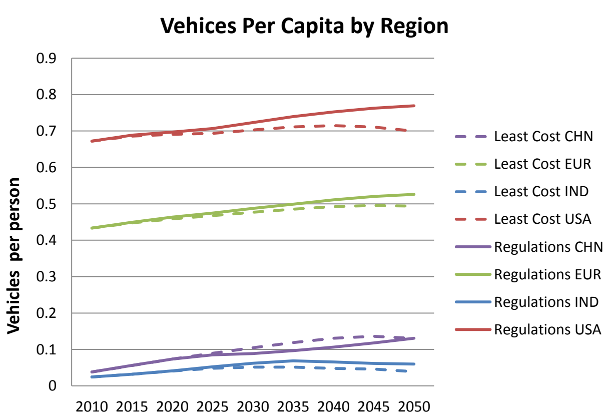



**Figure 11.** Fuel use in the global vehicle fleet.

On the other hand, the price-based measure applied in the Least Cost Scenario provides incentives both to improve vehicle efficiency and to reduce miles driven or ton-miles, leading a reduction in fuel use (and thus in emissions) for all components of the transport sector. Fuel use by personal vehicles in 2030 is higher in the Least Cost Scenario than in assumed the Regulations Scenario, indicating that the regulatory approach is forcing higher efficiency vehicles into the market much earlier than is needed for the least cost approach, again contributing to the higher cost of this policy. Under the Least Cost Scenario opportunities are exploited for emission reductions that are cheaper than the very stringent vehicle standards that are assumed in the Regulations Scenario.



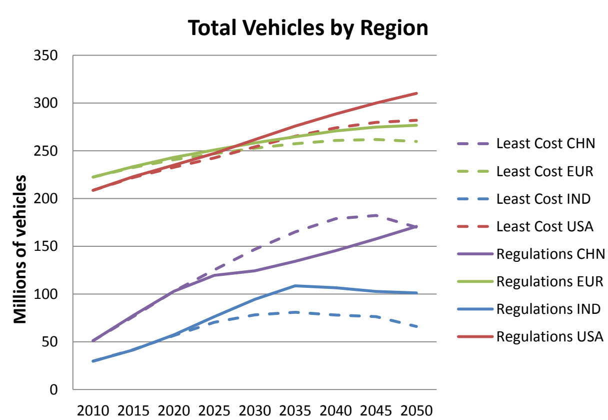




**Figure 12.** Comparison of personal vehicle use.

## 4. SEQUENTIAL POLICY DEVLOPMENT

The Regulations Scenario could serve as a pragmatic policy strategy for emissions reductions in a circumstance where lower-cost approaches, with wider coverage of sectors, are either not feasible or only likely to be implemented at some point in the future. It is useful, therefore, to consider the implications of a combined approach wherein both of these policies are eventually put into effect on a global scale. To explore this possibility we impose the Regulations Scenario beginning in 2010 and then initiate the Least Cost target, with its first influence felt in 2015.

The results in terms of cost per ton of $CO_2$-equivalent reduced are shown in **Figure 13**, which also shows the cost curves for the Regulations and Least Cost approaches if pursued independently (as in Figure 6). If the two policies are implemented in sequence the cost per ton reduced is higher than the Least Cost approach in the early years, but over time two phenomena, one in the electric sector and one in transport, combine to yield an average cost of the combination that is only slightly above the cost of the Least Cost Scenario. In the electric sector the rising emissions price in the Least Cost Scenario soon begins to drive coal from the generation mix (see Figure 8) and so supersedes the effect of the regulatory constraint on coal use. On the transport side, the high cost of the tightened vehicle standards (which yield a high average cost when applied alone and the quantity reduced is small) now spread across the much larger $CO_2$-eq quantity when the reduction is 50% of the 2000 level. The higher cost of the auto standards is still felt, but its impact on average cost is greatly diluted.

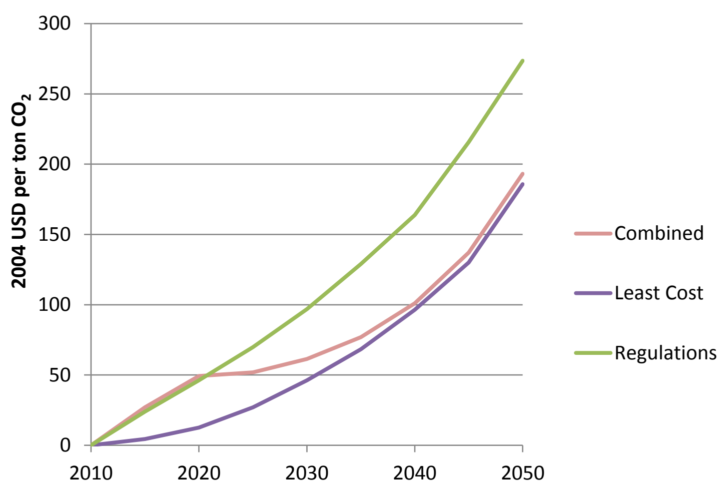



**Figure 13.** Cost of Regulations, Least Cost and Combined policies.

It is also worth noting that the mileage standards in the Regulations Scenario spur modest investment in plug-in hybrid vehicles (see Figure 3), which the model simulates as being more costly when produced for the first time and on a limited scale. The model simulates how costs fall with increased adoption of this advanced vehicle technology, making this option less costly to deploy in later years in response to an ever-tighter emissions cap. Thus, the Regulations

Scenario, by forcing earlier adoption of advanced vehicle technology, lowers vehicle costs in later years compared with the Least Cost Scenario. However, this advantage comes at a much higher cost in earlier years.

## 5. SUMMARY AND CONCLUSIONS

While analysts concerned with national cost of GHG control have long advocated a GHG pricing policy, by a cap–and–trade system or a tax, covering all emissions sources and gases, governments more often pursue sectoral policies and technology standards. Given these political realities, the Regulations Scenario represents a more politically practical approach to GHG reductions, focusing on solutions that are within reach and that do not depend on technological breakthroughs. Assessment of such an approach requires an economy-wide analysis framework as applied here, and the results of our analysis of the performance of a regulatory approach as formulated here, compared to alternative policies, can be summarized in five points:

- The Regulations Scenario could achieve substantial reductions in GHG emissions in two important sectors, electricity and personal transportation. These achievements yield a global reduction larger than projected for the Copenhagen Agreement. They would not, however, prevent global GHG emissions from continuing to grow over the decades to 2050.
- The main reasons why the Regulations Scenario does not yield larger global accomplishments are:
  - The partial coverage of emitting sectors of the economy,
  - The only small influence on the demand for emissions-intensive products by the economy as a whole and even within the covered sectors (e.g., demand for electricity, and miles or ton-miles traveled),
  - The leakage when reduction in fossil use in the covered sectors increases energy use and emissions on other sectors, and
  - The partial coverage of GHGs: a focus on $CO_2$ and no explicit downward pressure on the other gases.
- The regulatory approach in electricity and personal transport, as formulated here, involves significantly greater average cost per ton of $CO_2$ reduction than does a policy that applies a common penalty across all GHG emissions.
- If the Regulations Scenario is imposed as a way to get started on larger emissions reductions, and then combined with a broader GHG pricing policy pursuing a deep global cut in emissions, its requirements will eventually be overtaken by the pricing policy. Remaining higher costs of the regulatory targets become diluted so that in later years the difference in average cost per ton between a least cost approach and one preceded by a period of regulatory action becomes very small.

These results suggest a wider range of possibilities that could be considered in anticipation of any program of GHG regulations. For example, efficiency measures could be introduced for a full range of commercial transport modes, and gas substitution for oil and coal could be extended to industrial uses and residential settings. Also, the potential role of renewable energy (wind, solar and biomass) and nuclear energy under different cost and engineering assumptions was not fully considered in these simulations. Finally, a broader range of least-cost instruments could be considered, for instance by undertaking a combination of a carbon tax and emissions trading system in some sectors (e.g., electric power) with regulatory provisions in others.

In moving from the present analysis to examination of a broader range of sectors, sensitivities, and policy designs, however, continued attention would need be devoted to the important drivers of results that emerged in this study—i.e. the rebound effect incentivized by efficiency gains, leakage of emissions to uncovered sectors, and the interactions of policy with the relative size and features of regional markets.

**Acknowledgments**
We thank BP for their support of this study. The MIT Integrated Global System Model (IGSM) and its economic component used in the analysis, the Emissions Prediction and Policy Analysis (EPPA model, are supported by a consortium of government, industry and foundation sponsors of the MIT Joint Program on the Science and Policy of Global Change, including U.S. Department of Energy, Office of Science (DE-FG02-94ER61937). For a complete list of sponsors see http://globalchange.mit.edu/sponsors/current.html.

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