Assessing the Impact of the Diffusion of Shale Oil and Gas Technology on the Global Coal Market

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Abstract

A spatial equilibrium model of the world coal market is developed that accounts for coal to natural gas switching in the electricity sector in the United States and Europe, the potential for China to exercise monoposony power in its coal purchasing behavior, and the impact of increasing the western US coal export port capacity. The global coal market equilibrium is computed as the solution to a nonlinear complementarity problem. Where possible parameters of the model are estimated econometrically. Where this is not possible the parameters are calibrated to global coal market outcomes in 2011. The model is used to assess how the shale gas boom in the United States impacts global coal market outcomes for different models of Chinese coal buyers' purchasing behavior and different scenarios for the capacity of coal export terminals on the US west coast. Athough reductions in US and European natural gas prices reduce coal consumption in the US and Europe, the percentage reduction in coal consumption in Europe is much less than that in the US. Increasing US west coast port capacity increases coal exports from the western US and reduces Chinese coal production. US coal prices increase which causes more coal to natural gas switching in the US, further reducing global greenhouse gas emissions. Modeling China as a monopsony buyer of coal reduces the absolute magnitude of these impacts.

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1 Introduction

Shale oil and gas technology is generally acknowledged to be the most economically important innovation in the energy industry in the past 30 years. In late 2004, the United States Energy Information Administration (EIA) estimated that North America had less than 15 years worth of natural gas reserves. By late 2005, the monthly average natural gas price reached as high $15 per million British Thermal Units (MMBTU), relative to historical prices in the range of $2/MMBTU to $3/MMBTU. However, at the same time, shale gas production in the United States began its rapid increase from slightly less than 1,300 billion cubic feet (BCF) in 2007 (the first year the EIA compiled shale gas production data) to more than 14,000 BCF in 2015, or more than 50 percent of US dry natural gas production.

This more than 40 percent increase in total domestic dry natural gas production led to a precipitous decline in US natural gas to prices into the range of $2/MMBTU to $3/MMBTU in late 2012, where they have remained since that time. Because the United States did not have the ability to export liquefied natural gas (LNG) from the continental US until March 2016, natural gas prices in the rest of world remained significantly higher, particularly in regions that rely on LNG imports. The prices of LNG imports to these regions were indexed to the global price of oil. According to the Federal Energy Regulatory Commission (FERC), in April 2013 when the price of Brent crude was in the range of $100 per barrel (bbl) to $110/bbl, the delivered price of LNG to Asia, specifically China, Japan, and Korea, was slightly more than $16/MMBTU, which is approximately the dollar per MMBTU price of $100/bbl oil.[1]. The dramatic drop in the price of oil in mid-2015 into the range of $40/bbl, led to a decline in delivered LNG prices in the rest of the world to between $6/MMBTU to $7/MMBTU.[2] The addition of US LNG exports in early 2016, was followed by LNG prices in the rest of the world in the $4/MMBTU to $5/MMBTU range.[3]

These events in the global oil and LNG markets trigged by the diffusion shale oil and gas technology in the US have also had an impact on the global coal market, the dominant energy source for the developing world and by far the world's fasting growing fossil fuel since the start of the 21^{st} century. The falling price of natural gas in the United States has led to a decline in coal use in the US electricity sector, from more than 50 percent of annual US electricity generation in 2009 to 33 percent in 2015.[4] Because of a megawatt-hour (MWh) of electricity produced from natural gas has one-half to one-third the greenhouse gas emissions intensity of a MWh produced from coal, this fuel switching has led to a signifficant reduction

[1] http://www.ferc.gov/market-oversight/mkt-gas/overview/2013/03-2013-ngas-ovr-archive.pdf, Slide 9.
[2] http://www.ferc.gov/market-oversight/mkt-gas/overview/2015/05-2015-ngas-ovr-archive.pdf, Slide 13.
[3] See http://www.ferc.gov/market-oversight/mkt-gas/overview/ngas-ovr-lng-wld-pr-est.pdf.
[4] https://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3

in US greenhouse gas emissions from the electricity sector over this same time period. Based on the US experience, increased shale gas production has been hailed as a path to lower global greenhouse gas (GHG) emissions.

The recent experience of the European Union (EU) with lower LNG prices points to a more nuanced story that it is explored in this paper. The lower US coal prices caused by the rapid increase in US shale gas consumption made eastern US coal more attractive in European markets. Combined with the historically higher prices of natural gas in Europe and the desire of a number of EU countries to retire their nuclear generation units led to increasing coal consumption in the EU between to 2009 and 2012. In addition, despite the fact that between 2010 and 2014, 17,580 MW of coal-fired generation capacity was taken out of service in the EU, a total of 14,469 MW was added.[5] Only very recently has coal use in the EU began to decline, but not nearly as rapidly as in the US.

The divergent experiences of the US and EU has important implications for the impact of shale oil and gas technology for the global coal market. Lower natural gas prices in regions that produce significant amounts of shale gas, currently only the US, causes coal to natural gas switching in their electricity sector to the extent the sector has the ability to shift production from coal to natural gas generation capacity. However, this reduces global coal prices which limits the incentive other counties have to switch from coal to natural gas, particularly those, such as the EU countries, that rely on more expensive LNG imports rather than domestic production of natural gas.

Physical contraints on coal imports and exports complicate the process of assessing the impact of shale oil and gas technology on the global coal market. For example, coal producers in the Powder River Basin (PRB) in Montana and Wyoming argue that significant amounts of PRB coal could compete the in vast Asian market if there was enough port capacity on the west coast to allow a larger volume of exports.

Although there is the potential for the exercise market power by large coal supplying regions, a potentially more important factor is the exercise of monopsony power by China, which consumes approximately 50 percent of the coal produced annually and became the largest coal importer in the world in 2011 despite the fact that imports account for approximately 5 percent of China's total production. These circumstances and the fact that China is a planned economy with a strong desire to keep domestic electricity prices low to stimulate economic growth provides a strong incentive and the opportunity for China to exercise monopsony power in its coal purchases, a further factor complicating the assessment of the impact of the shale oil and gas on the global coal market.

This paper constructs a spatial equilibrium model of the global coal market that: (1)

[5] https://www.bloomberg.com/view/articles/2015-12-22/europe-s-hooked-on-u-s-coal-but-that-can-t-last

accounts for coal to natural gas switching in electricity sector based on relative prices (in countries where the mix of installed generation capacity allows this to occur), (2) allows for the existence of physical import and export constraints on global coal flows, and (3) allows for the possiblity of the exercise of monopsony power by China. This model is used to assess the implications of a collection possible future conditions in the global natural gas market on the location of production, minemouth and delivered prices of coal, and the consumption of coal.

The modeling scenarios quantify the extent to which that the shale gas boom in the US has has impacted US and EU coal consumption and the geographic distribution of global coal production. Several counterfactual results demonstrate that these reductions in US and EU coal consumption could be easily erased and global coal consumption increase if the shale gas boom in the US ends. The modeling results also demonstrate that relaxing the the western US coal export capacity could benefit both US coal producers and reduce global GHG emissions. Specifically, US coal production is preserved as a result of this port expansion and there is unlikely to be significant short-term change in coal consumption outside of the US because of limited opportunities for electricity sectors outside of the US and EU to substitute away from coal in the short and medium term. However, the increased coal production in the US that results from expanding the west coast coal port capacity raises US coal prices, which increases coal to natural gas switching in the US, and indirectly in the EU, which reduces greenhouse gas emissions in the US and EU, with little or no impact on greenhouse gas emissions in other parts of the world with little or no ability to switch from coal to natural gas. Even allowing for modest own-price elasticities of demand for coal other major coal-Consuming regions of the world still preserves the basic result that expanding the western US coal port capacity reduces global GHG emissions.

Remainder of paper first provides background on the global coal market and the available empirical evidence on how the shale gas boom in the US has impacted global LNG prices and global coal market outcomes. This is followed by a presentation of the details of the global coal model, how the parameters of the model are estimated, and how the various model solutions are computed. Section 5 describes the counterfactual scenarios considered and the modeling results obtained. The paper closes with a summary of the conclusions from the modeing effort.

2 Background on Global Coal and Natural Gas Markets

On an total energy basis, since 2000 global coal production has increased more than the sum of the increases in global production of energy from all other sources over the same time period.{footnote**?** argues that an increase in the volume of coal traded globally during the previous 20 years created an unified global market for coal. Figure 1 plots the total increase in annual coal production from 2000 to 2012 in millions of tons of oil equivalent (MTOE). This figure also reports the net increase in total annual production in MTOE for oil, natural gas, nuclear energy, hydroelectric energy and renewable energy (geothermal, solar, wind and other renewables) over the same time period. The increase in annual global coal production between 2000 and 2012 on a MTOE basis is greater than the sum of the MTOE increases for all of the other sources combined. Except for renewables, coal also had, by far, the highest annual percentage increase in consumption over this time period, at 4.15 percent per year. Renewables had a larger MTOE percentage increase, largely because the amount of energy produced from renewables was so small in 2000.

The vast majority of the growth in coal consumption since 2000 occurred in the developing world, primarily China and India. As **?** notes, the rapid growth in coal consumption in China since 2000 closely tracks the rapid growth in its Gross Domestic Product (GDP) in China over the same time period. Almost one hundred years ago, the same coincident rapid increase in coal consumption and GDP growth occurred in the United States. This phenomenon has repeated itself in many other industrialized countries at various times in the past and has led many observers to call coal the engine of economic development. As more industrialized countries shift to lower carbon-intensity sources of energy such a natural gas and renewables, the demand for coal in these countries is likely to fall, which will reduce the delivered price of coal to all developing countries, increasing the likelihood that these countries consume more coal.

Figure 2 plots the annual coal production in MTOE from the major coal-producing regions in 2014. China produces 45 percent of global coal output, which is almost four times the amount of coal produced by the next largest producer, the United States. Other major coal producers are Indonesia, India, Australia, Russia, South Africa and Colombia. Despite being the largest coal-producing country in the world, China is also the largest coal consuming country in the world. Depending on the year, China is the largest or one of the largest coal importing country in the world. India is also a major coal consuming country and a major coal importer.

Vast majority of coal is used in the electricity sector. More than 40 percent of global electricity production in 2014 was provided by coal. The share of natural gas in the global electricity supply mix is increasing, but significant use natural gas in the electricity sector typically only occurs in industrialized countries. The pipeline infrastructure necessary to deliver significant amounts of natural gas to a large number of natural gas-fired generation units requires a signifcant up-front investment and a stable political regime to ensure the pipeline network operates without interruption and is priced to achieve cost recovery for its investors As consequence, there are few regions of the world with significant fuel-switching capability between coal and natural gas–the US and the EU.

Figure 3 contains the generation shares by fuel source for the US electricity supply in 2014. Coal and natural gas contributed 33 percent and 28 percent, respectively to the US electricity supply. Figure 4 contains the same graph for Europe in 2014. Natural gas supplieed 16 percent and coal 25 percent of Europe's electricity supply. Thanks primarily to France, 24 percent of Europe's electricity came from nuclear power. The story for China and all other developing countries is much different. Figure 5 shows that 75 percent of China's electricity came from coal in 2014 and virtually none came from natural gas. India's electricity supply mix looks very similar to China's with the vast majority of electricity produced from coal.

Other major coal consuming countries such as Australia, South Africa, Korea and Japan have limited opportunities to shift away from coal. For the case of Australia and South Africa, very little natural gas is used in their electricity sectors. Different from North America and Europe, Korea and Japan do not have access to domestic natural gas and must therefore rely on LNG delivered under long-term take-or-pay contracts. Moreover, there are capacity constraints in the LNG import faciliteis in these countries that limits their abilty to shift from coal to natural gas.

These facts argue in favor of modeling the demand for coal in all regions but Europe and North American as price inelastic, because of the limited opportunities to substitute away from coal and into natural gas in the short and medium term. Because of the availability of pipeline supplied natural gas and the coal and natural gas-fired generation mix in both US and the European Union, the demand for coal in these countries is assumed to be responsive to both the price of coal and the price of natural gas.

Figure 6 plots the estimated landed prices of LNG at various import facilities around the world from January 2009 to June 2016 available from the Federal Energy Regulatory Comission (FERC).[6] This graph illustrates several important features of the global LNG market. First, LNG historically traded at a slight dollar per MMBTU price discount relative to oil in global markets. This is shown by the landed LNG prices in Europe, Asia and North America (Lake Charles, LA and Cove Point, MD) all trading at roughly the same prices, slightly less than the $/MMBTU price of a barrel of oil at that time, until early 2010, when noticeable amounts of shale gas production first began to occur up in the US.[7]

[6] http://www.ferc.gov/market-oversight/mkt-gas/overview/archives.asp posts these prices on monthly basis.

[7] There is approximately 5.6 MMTBTU per barrel of oil.

The divergence between prices in North America, Europe, and Asia that started in mid-2010 reflects three features of the global LNG market. First, the continued decline in the North American prices reflects the increased production of shale gas in the United States. The high prices in Europe reflect the fact that pipeline gas from Russia and other Eastern European countries competes with LNG in Western Europe. The significantly higher prices in Asia during most of the sample period reflects the fact that oil is the only competing fuel to LNG imports in this region, so LNG prices were indexed to the dollar per MMBTU price of oil at an international trading hub and during this time period the global price of oil was in the range of $ 100/bbl. Convergence between prices in Asia and Europe beginning in late 2014 and the downward trend in LNG prices in these regions are the direct result of a global price of oil in the range fo the 30 to 40 dollars per barrel. The continued differential between the North American prices and prices in Asian and Europe is the result of the US having access to cheap domestic shale gas, whereas these countries are paying for LNG, at a price that must recover both the liquefaction cost at the export terminal and re-gasification cost at the import terminal, as well as the cost of extracting the natural gas. At least for the near term these costs will continue to result in a 2 to 3 dollars per MMBTU differential between the price of natural gas in North America and prices in Europe and Asia. This differential in natural gas prices between Europe versus the US has important implications for the extent of coal to natural gas switching that will take place in the European electricity sector.

3 Model of Global Coal and Natural Gas Markets

This section describes the spatial equilbrium model of the global coal market. The model's inputs include marginal cost curves for each coal producing region and demand curves for coal for North America and the European Union, the two regions with a non-trivial ability to substitute natural gas for coal. Other inputs include transportation costs between producing and consuming regions and ocean port capacity constraints on import and exports between regions. With these inputs, the model computes a spatial equilibrium for coal production and prices in each producing region and consumption and delivered prices in each consuming region. Differences between production and consumption in each part of the world yields global coal flows.

The model has two types of agents: producers and consumers. The producers each represent one or more major coal producing regions in the world. The consumers represent large consuming regions, often aggregated to the country-level. The model allows for the possibility that each consumer or producer can behave as a price-taking or make their consumption or production choice recognizing that it impacts the price paid for coal or received for coal.

Coal can be shipped from producer to consumer regions through either of two transport modes: land or sea. All sea routes include implicit land routes to move the coal to port. All of the physical transport constraints in the model are associated with the sea routes.

Because coal is valued for its heat content and transportation costs depend on the weight of the coal, only high heat content coal is traded in international markets. To account for these market realities, the demand for coal in each consuming region is expressed in terms of the energy (gigajoules of energy [GJ]) rather than in terms of the weight of the coal. Because producing coal requires digging up and transporting metric tons (tonnes) of coal, the marginal cost of production in each region is expressed in terms of dollars per tonne of coal produced. For the same reason, the cost of moving coal between consuming and producing regions is specified in terms of dollars per tonne. This distinction between the drivers of the cost of producing and moving coal versus the drivers of the demand for coal in the major consuming region is necessary to model the global market accurately because there is significant variation in the heat content of different coals produced around the world.[8]

A major challenge in specifying a model of the global coal market is the lack of sufficient data for all regions to estimate all of the parameters of the model econometrically. For those regions were the data is available econometric techniques are used to estimate the parameters of the model. In all other cases, parameter values are taken from sources in the literature. Then a calibration exercise is employed to adjust these parameters to reproduce as accurately as possible observed market outcomes in the global coal market in 2011, the last year before the impacts of the US shale gas boom began manifest in the global LNG and coal markets.

3.1 Model Overview

This section provides an overview of the model structure, the inputs to the model, and the outputs from the model solution. The actual equations used to solve the model are described in Appendix 2. Starting with **?** there is a growing literature specifying spatial equilibrium models of the global coal market that allow for strategic behavior by consumers and producers. **?** formulated a similar model to study competition in the international coking coal market. **?** constructs a model of the global steam coal trade and finds that a model that assumes price-taking suppliers appears to reproduce observed market outcomes better than a model based on quantity-setting behavior by coal producing regions. **?** explores the impact of bulk energy transport decisions within China, specifically whether to build additoinal domestic coal transportation infrastructure or additional electricity transmission

[8]**?** argues that a spatial equilibrium model based only on coal quantities is unable to match actual global trades flows as well as one based on the demand for coal-supplied energy in consuming regions.

infrastructure on the global coal market. These models are typically solved as nonlinear complementarity problems using the first-order conditions from optimizing consumer and producer behavior. The PATH software package described in **?** is used to solve all of the models described in this paper.

3.2 Model Outputs

The model outputs are prices and quantities in both producing regions and consuming regions, and flows of coal between producing and consuming regions. Because coal quantities in the consuming regions are expressed in terms of energy units rather than weight, all prices are expressed in terms of dollars per unit of energy, in this case dollars per GJ. Although there are other attributes such as sulfur content and ash content that coal consumers value, high sulfur or high ash content coal does not trade internationally. Consequently, the types of coal consumed domestically are far more heterogenous than the types of coal traded internationally. Another way for coal consuming regions and coal consumers to obtain their desired heat, sulfur and ash contents for the coal they burn is to mix coal from a variety of sources. For example, a consuming region could mix higher sulfur coal that has a higher heat content than what it requires with a lower sulfur content coal that has a lower heat content to obtain the desired heat and sulfur content.

The output variables from the model are:

- x_{mfc} = Quantity of coal bought by consuming region c from producing region f over transport mode m in Petajoules [PJ] (1,000,000 GJ = 1 PJ)
- p_c = Price paid for all coal in consuming region c in dollars per GJ
- p_f = Price received for all coal in producing region f in dollars per GJ

These model outputs can be used to compute the total amount of coal consumed or produced in any region.

3.3 Transport

The transportation of coal in the model is characterized by two types of parameters: the dollar per tonne cost to transport coal from producing region f to consuming region c using transport mode m, τ_{mfc}, and the maximum amount of tonnage on that route during the year, $tcap_{mfc}$. The model has two modes m of transport: *land* and *sea*. Domestic suppliers are connected to domestic or land-connected coal consumers by land routes. All other coal producing regions are linked to coal consuming regions by sea and pre-existing capacity constraints are accounted for by the value of $tcap_{mfc}$. Table 1A lists the 23 coal consuming regions and the transport mode to access these regions built into the model. Table 1B defines the composition of the consuming regions for the USA and China, each of which has five consuming regions.

3.3.1 Land Transport Data

Transport cost data is difficult to find for intra-country trade. Rail rates between coal producing regions and consuming regions in the US are confidential. A number of sources were used to obtain the transport cost estimates used as starting values for the model calibration procedure. For land transport links in the United States costs were computed based on data from the National Electricity Modeling System (NEMS) of the EIA. These values were checked for their reasonableness through informal telephone surveys of industry participants. For land transport costs in China, data from a Chinese coal consultancy provided route-specific transport costs on some key routes, and these costs and their associated distances were used to estimate the costs on other routes.

3.3.2 Sea Transport Data

The sea transport cost data consists of three different components: (1) the transport cost from the producing region to the port, (2) port fees and export taxes, and (3) the sea freight from the export port to the import port. For the land transport and port fee components for some key exporters, a variety of industry sources were used. For the freight rates, a sample of data from Reuters on waterborne freight rates and distances was used to estimate a nonparametric regression of coal transport costs on transport distance. This regression was then used to fill in gaps in the Reuters data on transport costs between certain producing and consuming regions.

3.4 Producers

Producers in the model represent the major coal mining regions of the world. Table 2 contains a list of the producing regions in the model. The coal from these producing regions has two possible destinations: local/domestic consumers (through land transport) or international consumers (through sea transport). Producing region marginal cost curves are modeled at the mine level, assuming a constant marginal cost of production up to mine capacity and allowing for different marginal costs for each mine. These step functions are coverted into continuously differentiable functions using the following smoothing procedure.

Order the marginal costs and annual mine capacity steps for the N mines in the producing region from the lowest marginal cost mine to the highest marginal cost mine, where (c_1, q_1) is the lowest marginal cost and q_1 is the annual capacity of this mine and c_N is the highest marginal cost and q_N is the annual capacity of the highest marginal cost mine. Define $c_j^* = c_j - c_{j-1}$ as the increase in the marginal cost between the j^{th} and $(j-1)^{th}$ mine, for $j = 2, ..., N$ and $q_j^* = q_{j-1}^* + q_j$ for $j = 2, ..., N$ is the amount of annual capacity that has a marginal cost of production at or below c_j. Mathematically, the smoothed marginal cost function for a producing region can be written as:

$$MC(Q_f) = \left\{ c_1 + \sum_{j=2}^{N} c_j^* \cdot \Phi\left(\frac{\left(Q_f - q_j^*\right)}{h}\right)\right\}$$

where

- h = user selected smoothing factor for marginal cost curve
- Q_f = total amount of coal produced by producing region f in tonnes.

Figure 7 plots the step function marginal cost function and the smoothed version given above. Besides the marginal cost function, there are two other parameters that characterize production in each region of the model:

- $PCap_f$ = annual production capacity of the coal producing region in mega-tonnes (millions of tonnes)
- k_f = heat content of coal from producing region in tonnes per GJ

The heat content of the producing region's coal is assumed to be constant for each producing region, meaning that different mines within a producing region are assumed to produce coal with the same heat content. Obviously this does not perfectly reflect reality, but because of the global scope of the model and data availability constraints this simplifying assumption was necessary. The heat content parameter is used convert weight-based costs (transportation and production costs) to energy-related costs that are used to set the dollar per GJ prices that consuming regions pay and quantities of energy in GJs that consuming regions demand.

3.4.1 Producing Region Optimization Problem

Producing regions are paid the price of coal at the mine-mouth p_f. The demand for their coal comes from local consumers or distant consumers via sea routes. Regardless of the model of strategic behavior assumed for producers, the price of coal at the minemouth will be greater than or equal to the producer's marginal production cost of coal if any coal is produced in equilibrium. Even if a producing region is a price-taker, the minemouth price can be greater than its marginal cost of production if there is an export constraint from the producing region that sets the price at the willingness to pay of an importing region. Alternatively, if the amount produced in the region is at the annual capacity constraint for the region, then the price can be in excess of the marginal cost of production. A strategic producer can set a price that is greater than its marginal cost by withholding output to exploit a downward sloping demand function for its output.

The delivered price of a unit of coal is made up of: (1) the minemouth price for the producing region, and (2) the transportation cost to move coal from producing region f to consuming region c. If the minemouth price of coal, p_f, is greater than the marginal cost of production, a price-taking producing region will continue to supply coal until the marginal cost is equal p_f, unless there is a physical constraint on the amount of coal that can be exported from the producing region. In terms of the above notation, the first-order conditions for a price-taking producing region is:

$$-p_f \;+\; k_f \cdot [MC(Q_f) \;+\; \alpha_f] \;\geq\; 0 \quad \perp \quad Q_f \;\geq\; 0$$

where " $\perp$ " denotes the complementarity condition that one of the weak inequalities holds as equality if the other holds as a strict inequality and α_f is the dollar per tonne shadow price on the annual production capacity constraint for producing region f. If the producing regions reaches it annual production capacity then the shadow price, α_f, on that constraint will be positive instead of zero. The shadow price is the amount of scarcity rents added to the marginal cost of production to arrive at p_f.

3.5 Consuming Region Optimization Problem

Consuming regions are aggregates of sub-countries, countries, or broader regions. China and the US are both broken into five different consuming regions. With the exception of Europe and the demand regions in the US, all consumers are modeled as having a perfectly price inelastic demand for coal for the reasons discussed in Section 2. These fixed-demand regions must purchase a fixed amount of energy from coal to meet their electricity production needs. The US and EU are modeled as own-price and cross-price elastic consumers of coal because of the prevalence of natural gas-fired generation capacity in both regions and the availability of pipeline-supplied natural gas allows them to switch between coal and natural gas in their electricity sectors on time scales less than a year.

3.5.1 Price Elastic Consuming Regions

Price-elastic, consuming-region demand is modeled using constant-elasticity conditional (on total fossil fuel generation) factor demand curves. The own-price elasticity of the demand for coal and cross-price elasticity with respect to the price of natural gas are estimated econometrically for both the US and European Union. The functional forms for these econometric models take the following form:

$$ln(QCoal_{rt}) \ = \ \beta_{r1} \cdot ln(coalp_{rt}) \ + \ \beta_{r2} \cdot ln(gasp_{rt}) \ + \ \beta_3 \cdot ln(fossilgen_{rt}) \ + \ \alpha_r \ + \ \epsilon_{rt}$$

where $QCoal_{rt}$ is the quantity of coal in GJ consumed in region r in quarter t, $coalp_{rt}$ is the price of coal in dollars per GJ in region r in quarter t, $gasp_{rt}$ is the price of natural gas in dollars per GJ in region r in quarter t, $fossilgen_{rt}$ is the total amount of fossil-fuel generation in terawatt-hours (TWh) in region r in quarter t, α_r is a region-specific fixed-effect, and ϵ_{rt} is a mean zero disturbance term. The coefficients β_{r1} and β_{r2} are, respectively, the own-price elasticity and cross-price elasticity of coal demand for region r.

US Consuming Regions For US consuming regions, quarterly data from January 2001 to April 2013 on the quantity of coal consumed to produce electricity, coal prices, natural gas prices, and the total amount of electricity produced by fossil fuels by state are taken from the EIA. State-level-quantity-weighted averages of the state-level coal and natural gas prices within each region are computed to obtain the coal and natural gas price variables for each region. Coal consumption values for each region are obtained by summing the coal consumption over all states within the region. A similar process is followed for state-level electricity production from fossil fuels to obtain the total amount of electricity produced from fossil fuels in each region. This process yields a panel dataset that can be used to estimate own-price elasticities and cross-price elasticities of the demand for coal for all US consuming regions. The results for the all US consuming regions are shown in Table 3. In all regions coal is inelastically demanded, but there is considerable heterogeneity across regions in the own-price elasticity. **?** standard errors that are robust to heteroscedasticity and autocorrelation of an unknown form are reported below the coefficient estimates. Similarly, in all regions natural gas is found to be a substute for coal, but there is considerable heterogeneity in the value of the cross-price elasticity. The most price-responsive consuming regions are the East Region and the Gulf Region, two places with considerable amounts of natural gas and coal-fired generation capacity available for coal-to-natural gas switching.

European Consuming Regions For the EU consuming region, yearly data from 2005 to 2011 from the OECD on the quantity of coal consumed in the electricity sector, coal prices, natural gas prices, and total fossil generation in each country was compiled. The same conditional factor demand model is estimated with country-specific fixed-effects. The panel dataset was unbalanced because of missing data for some countries for some years of the sample. The regression results are shown in Table 4. **?** standard errors are reported below the coefficient estimates. Coal is inelastically demanded in Europe, with an elasticity near the midpoint of the values obtained for the US. Natural gas has a positive cross-price elasticity near the mid-point of the values in the US, consistent with it being a substitute for coal in the electricity sector.

These own-price and cross-price elasticities will be used to assess the impact of different conditions in the global LNG market on market outcomes in the global natural gas market. Converting the deterministic portion of the regression equation into a demand function yields $QCoal_{rt} = A_{rt}(coalp)^{\beta_{r1}}$, where $A_{rt} = (gasp_{rt})^{\beta_{r2}}(fossilgen_{rt})^{\beta_{r1}}exp(\alpha_r)$. Assuming a counterfactual price of natural gas, $gaspcounter_{r,t}$, the new demand curve for coal in region r in period t becomes $QCoal_{rt} = A_{rt}(gaspcounter_{rt}/gasp_{rt})^{\beta_{r2}}(coalp)^{\beta_{r1}}$. Because the value of β_{r1} is positive, if $gascounter_{rt}$ is greater that $gasp_{rt}$ then the demand curve is uniformly higher for all prices of coal and if $gascounter_{rt}$ is less that $gasp_{rt}$ the demand curve is lower for all coal prices. By adjusting the counterfactual prices of natural gas in the US and EU, the demand for coal in each consuming region of the US and in the EU will shift by a different amount because the cross-price elasticities of the damand for coal differs across US regions and from the those in the EU.

3.5.2 Consumer optimization problems

As shown in Table 2, the model has three types of consuming regions: perfectly price inelastic, price-setting monopsony consumers in China, and price elastic consuming regions of the US and in Europe.

Inelastic consumer problem The inelastic consuming regions's first-order condition is:

$$p_f + k_f \cdot (\tau_{mfc} + \beta_{mfc} + \theta_{f,c} \cdot \pi_{Ch}) \; - \; p_c \geq 0 \quad \perp \quad x_{mfc} \geq 0,$$

where τ_{mfc} the dollar per tonne cost of transport between producing region f and consuming region c over mode m, β_{mfc} is the shadow price on the transport constraint between producing region f and consuming region c over mode m, $\theta_{f,c}$ is a binary variable indicating if an export restriction applies between a producing region and a consuming region (such those that exist between Chinese producers and non-Chinese consumers), π_{Ch} is the dollar per tonne shadow price on the Chinese export restriction, and x_{mfc} is the quantity of coal in GJ sent from producer f to consumer c over mode m.

Note that p_c can be higher than the sum of transport costs and p_f. If there are binding capacity constraints, then the scarcity rent of the transport constraint is reflected in the shadow price of the constraint. For example, the shadow price on the transport capacity from producing region f to consuming region c, $\beta_{f,c}$, raises the price in the consuming region to reflect the scarcity of transportation capacity between the two regions.

Chinese consumer problem The Chinese consuming region problem accounts for these regions acting as a monopsony. The behavioral assumption is that these consuming regions choose how much coal purchase from each Chinese producing region taking into account the impact of these decisions on the price they will pay. The first-order conditions take the form:

$$p_f + k_f(\tau_{mfc} + \beta_{mfc} + \theta_{f,c} \cdot \pi_{Ch}) + \gamma_{f,c}(MC'_f(Q_f)k_f[\sum_{m,china} x_{mfc}]) - p_c \geq 0 \quad \perp \quad x_{mfc} \geq 0,$$

where the "m,china" subscripts in the summation denotes the fact that the summation is only over modes of transport that serve Chinese consuming regions from each Chinese producing region f and $MC'_f(Q_f)$ is the slope of the marginal cost curve for Chinese producing region f. The variable $\gamma_{f,c}$ is a binary variable that equals 1 if a consuming region c is exercising monopsony power on the producing region f. We use this parameter to switch from the price-taking to the monopsony scenario for Chinese consuming regions. Note that when $\gamma_{f,c}$ is zero, the expression is the same as that for the inelastic demand consumers.

Elastic consumer problem The third type of consuming region is a price-taker, but has a price elastic demand. These are the US consuming regions and EU consuming region. The first-order condition for these consuming regions is:

$$p_f + k_f \cdot (\tau_{mfc} + \beta_{m,f} + \theta_{f,c} \cdot \pi_{Ch}) \; - \; P_c(\sum_{m,f} x_{mfc}) \geq 0 \quad \perp \quad x_{mfc} \geq 0,$$

where $P_c(\sum_{m,f} x_{m,f,c})$ is the inverse demand for consuming region c, obtained by inverting the demand curve for consuming region c defined above. As noted above, this inverse demand curve can change depending on the value of the counterfactual prices of natural gas relative to the actual price of natural gas.

4 Monopsony in the Chinese Coal Market

This section discusses the empirical evidence for China acting as a monopsony buyer from its domestic suppliers of coal and the implications of this behavior for equilibrium in the global coal market. Since 2000, China's consumption of coal has increased at double-digit growth rates, and virtually all of the growth has occurred in the electricity sector. The Chinese government is extremely concerned about raising electricity prices and has instituted caps on retail electricity prices to promote economic growth, industrial goods exports, and to control nominal price inflation. However, the vast majority of domestically produced coal in China is priced through a national market. Consequently, if the price of coal increases electricity producers are unable to pass this price increase on to consumers in the form of higher electricity prices because of the cap on retail prices. This logic implies that minimizing the power sector's total procurement cost of coal is essential for it to operate without government subsidies or increasing retail electricity prices.

One option the Chinese government has to keep total coal costs lower would be to have Chinese coal buyers exercise market power against domestic coal suppliers. In our model, China's demand for coal in each consuming region is fixed, so when they are treated as a monopsony their total consumption of coal will not decrease. Instead, these regions will reduce their consumption from domestic producers and cover the difference on the export market in order to reduce their total procurement costs for coal. This behavior and its implications for the total price China pays for its coal is displayed in Figure 8. Chinese consuming regions reduce their consumption from domestic producing regions to drive down market prices at home and therefore pay a lower price for all their domestically produced coal consumption. They then make up the difference by purchasing more from producing regions outside of the China. Looking at Figure 8, total expenditure on coal is lower in the case where the buyer exercises monopsony power. This is represented by the sum of the two purple-lined boxes being smaller than the two red-lined boxes. This diagram for the case of China is likely to be far more extreme than is represented in Figure 8 because imports typically make up less than 5 percent of domestic consumption and China's marginal sources of domestically produced coal are very expensive.

4.1 Evidence of Chinese Monopsony Buying

Because the Chinese government maintains a cap on the price that producers can charge for electricity, the cost of acquiring coal cannot be passed through to consumers by electricity producers. This creates an incentive for domestic coal consumers and the government to exercise monopsony power. The structure of the coal market in China enhances the ability of the consumers to act as monopsonists. First, coal producing regions in China are relatively isolated from any markets besides the domestic market in China. All the producing regions are inland and face land transport and freight costs in order to export coal. Second, there are five large electricity producers in China, and they are each operate across many provinces in China. This means that each individual power producer has the ability to buy from abroad or domestically and the small number of buyers of substantial amounts of coal makes government coordinated purchasing easier to facilitate.

Several policies in China are conducive to large coal consumers acting as a monopsony. First, there is an annual coal trade conference where consumers negotiate the price paid for coal supplied from the major coal producers in China. Second, coal exports are capped using a permit system, and the number of permits has been decreasing steadily as shown in Figure 9. Finally, the Chinese government has even imposed coal export quotas. The time series of coal imports to and coal exports from China are consistent with a shift from price-taking behavior to the exercise of monopsony power by reducing purchases from domestic suppliers and increasing imports.

4.2 Predicted Impacts of Chinese Monopsony Power

As explained above, lower domestic coal production and increased imports are likely if domestic buyers in China exercise monopsony power rather than act as price-takers. The total procurement cost of coal by China should also be lower. These are the predicted first-order impacts of the exercise of monopsony power. If China imports more from the global market, then the price of coal on the world market should increase. This has the interesting implication from a climate policy perspective that more coal-to-gas switching should take place in the consuming regions where it is possible, currently the US and EU.

5 Model Scenarios and Results

To explore the impact of monopsony buying by Chinese coal consumers two versions of the model are constructed. The first assumes that Chinese consumers act as price-takers and buy internationally traded coal at the same price as domestic coal. The model was calibrated so that outcome from this version of the model produced outputs that matched the actual market observations in 2011 as closely as possible. The calibration process is described in Appendix 1. The second version of the model assumes that Chinese consuming regions act cooperatively as a monopsony. This model was also calibrated to match the same observed market outcomes from 2011. With each version of the model a number of scenarios were run to assess the impact of different future prices in the global natural gas market on market outcomes in the global coal market. A second set of counterfactual scenarios considered the impact of relaxing the export port capacity constraint from the US west coast on global coal market outcomes under both the price-taking and monopsony buyer models for the Chinese consuming region behavior.

5.1 Modeled Scenarios

Three types of modeling scenarios are analyzed: (1) the assumed behavior of Chinese consuming regions for the calibration of the model parameters, (2) the modeled behavior of Chinese consumers used to solve model, and (3) the state (on or off) of the coal port export constraint on the west coast of the United States (where Powder River Basin coal would exit the US).

5.1.1 Calibrating Model to Assumed Chinese Buying Behavior

"Assumed Chinese buying behavior" means what model of behavior is assumed to produce the observed market outcomes in 2011, price-taking buyers or a monopsony buyer in China. With the same input data, the model solves very differently depending on which assumption is made. The model is calibrated by changing the input paramters so that both the price-taking consumers and monopsony consumer assumptions yield very similar outputs but are generated from different parameter inputs. Appendix 1 shows how the input parameters differ for the two base cases. This process yields two base cases relative to which natural gas and export constraint scenarios are compared. The first base case assumes that Chinese consumers are price-takers. The second assumes they exercise monopsony power to reduce China total expenditures on coal. For each base case, a number of US and EU natural gas price scenarios are run. Then another set of natural gas price scenarios are run removing the export constraint on coal from the US west coast.

The natural gas price scenarios are chosen by the following logic. Figure 6 shows that in early 2011 natural gas in the US was trading in the range of \$4.50/MMBTU, whereas the price of natural gas in Europe was trading at roughly double that amount at around \$9.00/MMBTU. By June of 2016, prices in the US had fallen to 1/2 to 3/4 of what they were in 2011 and prices in Europe fell to approximately \$5/MMBTU or approximately 1/2 of what they were in 2011. This logic suggests considering ratios of the counterfactual natural gas price to the actual price of natural gas, $(gaspcounter_{r,t}/gasp_{r,t})$ in terms of the notation of the previous section, for US regions of 0.50, 0.75, 1, and 1.25 and values for the EU equal to 0.50 and 1. The price ratios 0.50 and 0.75 span the ratio of prices in 2016 relative to prices in 2011, the year the model was calibrated to. The ratio of 1.25 reflects the scenario that the shale gas boom ends and natural gas prices in the US return to the levels that existed before 2007. The ratio of 0.50 for Europe reflects the ratio of the 2016 price to the 2011 prices in the EU and 1 is the pre-shale gas boom price in the EU.

5.2 Scenario Output Analysis

Because there are four counterfactual prices in the US and two in the EU, this yields a total of eight counterfactual natural gas price scenarios for each set of model parameters, model solution concept (price-taking demand or monopsony in China) and state of the west coast coal export constraint. The four sets of results reported are the percent change in coal consumption relative to the baseline in each US coal consuming region and Europe, the percent change in the delivered price of coal relative to the baseline price in each coal consuming region, the percent change in the price of coal relative to the baseline price in each coal producing region, and the percent change in coal production relative to baseline in each coal producing region.

The first baseline model equilibrium considered uses the set of parameters calibrated to the price-taking China consuming regions solution (Cmp), solved assuming pricing-taking China consuming regions (Cmp), and keeping the western US port capacity at its current level of 11 million tonnes per year (Cons). This scenario is referred to as the Cmp-Cmp-Cons model scenario. For the remainder of the paper, scenarios are referred to using this three-part naming convention where the first part gives the model parameters used to solve the model, the second gives the model solution concept used, and third part states whether or not the western US port constraint is active or not. The other baseline model equilibrium considered uses the set of parameters calibrated to the monopsony China consuming regions solution (Mnp), solved assuming monopsony China consuming regions (Mnp), and keeping the western US port capacity at its current level of 11 million tonnes per year (Cons). This scenario is referred to as the Mnp-Mnp-Cons model scenario.

Table 5A presents the US region and EU coal consumption percentage changes relative to the Cmp-Cmp-Cons solution for the eight natural gas scenarios. In all cases, lower prices in the US and no change in prices in the EU led to reduced coal consumption in all US consuming regions except the Rocky Mountain region, which has access to extremely inexpensive coal, which means that significant coal-to-natural gas switching is unlikely even at 2016 natural gas prices. Reducing natural gas prices in the US with no change in the EU increases coal consumption in the EU, which is consistent with what was observed immediately following the fall in natural gas prices in the US in the 2010 to 2012 timeframe. Reducing natural gas prices only in the EU reduces coal consumption in the EU, and increases consumption in the Eastern US region. Reducing natural gas prices in both the US and EU and reduces coal consumption in both the US and EU.

The (.5,.5) natural gas price is the most representative of current natural gas conditions in the US and EU. The reduction in US consumption under this scenario are uniformly smaller than it is for the (1,.5) scenario that leaves the natural gas price in the EU unchanged, and the reduction in EU consumption under the (.5,.5) scenario is smaller than it is for the (.5,1) scenario that leaves natural gas prices in the US unchanged.

Table 5B presents the percentage change in the delivered price of coal relative to the baseline price in each consuming region for each natural price scenario. The largest percent delivered price reductions from natural gas price reductions in the US occur in the USA_South consuming region. The other consuming regions experience a small percentage delivered coal price reduction from the decline in natural gas prices in the US. The EU also does not experience very substantial delivered price reductions from declines in the price of natural gas in the EU.

Table 5C presents the percentage change in the producer price of coal relative to the baseline price in each coal producing regions. Here the producer region coal price changes from different natural gas prices in the US and EU are minimal. Even the most likely (.5.,5) natural gas price scenario finds small reductions in the price of coal in US producing regions.

Table 5D gives the percentage change in coal productoin relative to the baseline in each coal producing region. Natural gas price reductions in the US reduce production from all US coal-producing regions, the hardest hit on a percentage basis being the USA_Rocky region. The (.5,.5) scenario yields reductions in the US producing regions very similar to the (1,.5) scenario, but it has significantly larger reductions from producing regions that serve the EU. Figures 10-16 present the delivered price percent changes, the coal consumption percent changes, coal production percent changes in graphical format.

Tables 6A to 6B report the same results for the Cmp-Cmp-Open scenario that uses the price-taking calibrated parameters to solve the price-taking China consuming regions model, but with western US coal port constraint unrestricted. The US and EU coal consumption percent reductions for the same natural gas price scenarios in the US and EU are larger if the western US coal port constraint is relaxed. This result occurs because US coal price reductions are smaller in absolute value or even increase because of the substantial increase in US coal production from relaxing the western US coal port constraint. Figures 17 to 24 present the delivered price percent change, coal consumption percent change and coal production percent change graphically.

Comparing the results in Tables 5A-5D to those in Table 6A-6D yields the following conclusions about the likely impact of the shale gas boom in the US on global coal markets. First, the June 2016 prices of natural gas in the US and EU which are broadly consistent with the (.5,.5) natural gas price scenario, imply a substantial reduction in coal consumption in all regions of the US except the Rocky mountain region. The these consumption reductions are less than would occur from unilateral reductions in natural gas prices in the US or EU separately, the (.5,1) or (1,.5) scenarios, respectively. The slight increase in coal consumption in the Rocky mountain region is not surprising given that this part of the US is where extremely cheap surface mined coal is readily available, primarily from the Powder River Basin in Montana and Wyoming, and even natural gas at June 2016 prices does not yield a lower variable cost for natural gas-fired electricity than coal-fired electricity in these regions. Second, very similar reductions in US coal consumption and EU coal consumption occur if the US west coal port constraint is relaxed. In fact, coal consumption even falls in the Rocky mountain region for June 2016 natural gas prices, the (.5,.5) natural gas price scenario. However, this scenario also illustrates the capability of the western and midwest US coal producing regions to scale up production with little impact on producer region prices in order to export substantial amounts of coal from west coast ports. Despite the fact that eastern coal production falls under the June 2016 natural gas price scenario, coal production in the remaining US producing regions increases, with little or no impact on producing region prices. Finally, comparing the production declines in other parts of the world under the constrained west coast port capacity solution and the unconstrained west coast port solution suggests an additional benefit from expanding west coast port capacity, coal production in China and India, two regions that produce significantly higher sulfur and ash content coal than western US coal, falls as a result of the constraint on west coast port capacity being relaxed. Burning lower sulfur and ash content coal in Asia implies less sulfur dioxide and particulate emissions in these regions and local environmental damage from coal-buring in China and India.

The (1.25,1) and (1.25,.5) pricing scenarios (prices in the US are 25 percent higher than 2011 levels and prices in the EU remain at their 2011 levels and US prices are 25 percent higher than 2011 levels and prices in the EU are half of their 2011) for the Cmp-Cmp-Cons counterfactuals illustrate how coal to natural switching in the US electriciy sector could be reversed if the shale gas boom in the US ended and natural gas prices return to global LNG levels before the US shale gas boom. In all coal consuming regions but the Rocky mountain region, coal consumption would increase. These coal consumption increases under the (1.25,1) and (1.25,.5) pricing scenarios for the Cmp-Cmp-Open counterfactuals are lower, consistent with expanded production in US producing regions leading to higher coal prices which reduces US coal consumption.

All of these counterfactual market outcomes suggest a possible win-win situation for US coal producers and the global environment from expanding west coast coal port capacity. Current US and EU natural gas prices cause US and EU coal consumption to fall, but US coal production does not fall nearly as much as would be the case with if the west coast coal port constraint was at its current annual 11 MT level. Because the remaining countries of the world have an inelastic demand for coal, the reduction in coal consumption in the US and EU reduces global greenhouse gas emissions. As noted above, the low sulfur and ash content coal produced in the western US displaces the higher sulfur and ash content coal produced in China and India, which yields local environmental benefits consumers in these countries. Even if one assumed a price elastic demand for coal in other countries of the world, the impact of expanded western US coal production on coal prices in Asia is extremely modest because of the ability of western coal producers to expand production without significant increases in US producing region prices of coal. Simulations of the model (not reported here) with modest own-price elasticities of demand for the Asian countries did not change the basic conclusion about the global environmental benefits of expanding western US coal port capacity.

The (1.25,1) and (1.25,.5) pricing scenarios illustrate an additional economic and environmental benefit from expanding west coast coal port capacity. if the shale gas boom does end and natural gas prices in the US increase. By allowing an additional outlet for western US coal, the increase in domestic coal consumptoin that is likely to result from increased natural gas prices in the US are smaller than would be the case with the west coast coal port constraint imposed, because increased west coast coal exports increases US coal prices which reduces US coal consumption. Under the reasonable assumption that all of the coal-fired power plants built in Asia over the past 10 years will continue to operate for the next 20 years, expanding west coast coal ports allows US coal producers to serve this market and thereby maintain higher US prices which reduces coal consumption in the US, and indirectly reduces coal consumption in Europe, because it is a major consumer of eastern US coal exports.

Tables 7A-7D repeats the same set of scenarios as Tables 5A-5D with the baseline model equilibrium that uses the parameters calibrated to monopsony China consuming regions solution (Mnp), solved assuming monopsony China consuming regions (Mnp), and keeping the western US port capacity at its current level of 11 million tonnes per year (Cons)–the Mnp-Mnp-Cons model scenario. Figures 25-31 presents the same information as Figures 10-16 for the Mnp-Mnp-Cons model scenario. Tables 8A-8D repeats the same set of scenarios as Tables 6A-6D with the baseline model equilibrium that uses the parameters calibrated to monopsony China consuming regions solution (Mnp), solved assuming monopsony China consuming regions (Mnp), and relaxing the west coast port constraint (Open)–the Mnp-Mnp-Open model scenario. Figures 32-39 presents the same information as Figures 17-26 for the Mnp-Mnp-Open model scenario.

The same qualitative conclusions as described above for the Cmp-Cmp-Cons and Cmp-Cmp-open counterfactual scenarios holds for the comparison of the Mnp-Mnp-Cons to the Mnp-Mnp-open scenarios. The quantitative effects of opening up the west coast port constraint are more muted than for for the Cmp-Cmp-Cons to Cmp-Cmp-open comparison. This follows from the fact that Chinese consuming regions are assumed to be acting as a monopsony under the baseline model solution and are using coal imports as way to reduce their total coal supply costs. This implies that the demand for imports from Chinese consuming regions is not as responsive to supply increases in the global market as is the case under the price-taking assumption for Chinese consuming regions. Comparing the (.5,.5) natural gas prices scenario results in Table 8D to those in Table 6D shows that the percentage production reductions in China under the Mnp-Mnp-open scenario relative to baseline are roughly one-half the percent reduction under the Cmp-Cmp-open scenario relative to baseline. Comparing the (.5,.5) natural gas prices scenario results in Table 8B to those in Table 6B illustrates the impact of the monopsony assumption on how Chinese consuming regions respond to relaxing the west coast port constraint. Prices in three Chinese coal consuming regions fall relative to baseline for the Mnp-Mnp-Open scenario, versus the price in only one Chinese coal-consuming region falls relative to baseline for the Cmp-Cmp-Open scenario, which is consistent with the Chinese coal consuming regions responding to the elmination of the west coast US port constraint by using their monopsony power to lower their total coal procurement costs.

Note that the benefits of acting as a monopsony on domestic producers are not evenly distributed across the Chinese consuming regions. From Table 1A, the Chinese consuming regions C_CHN_Northeast, C_CHN_SIS, and C_CHN_Main do not have access to ocean-supplied imported coal. Consequently, these regions only indirectly benefit from the exercise of monopsony power, whereas the C_CHN_Eastern does have access to ocean-supplied imported coal and coal consumers in this region can increase their imports thereby reducing their domestic purchases and reducing delivered prices for all Chinese consumers.

The monopsony assumption for Chinese consuming regions also has implications for the impact of the end of the shale gas boom for US and EU coal consumption. Both the "Cons' and "Open" monopsony solutions for the "Mnp" equilibrium imply larger US and EU coal consumption increases in response to increases in US and EU natural gas prices consistent with an end of the US shale gas boom, the (1.25,1) and (1.25,.5) pricing scenarios. Comparing these natural gas prices scenario columns in Tables 5A and 7A shows that coal consumption in the US increases by slightly more and EU coal consumption falls by less under these pricing scenarios if Chinese consumers behave as a monopsony. Under the scenarios that relax the US west coast port constraint in Tables 6A and 8A, once again US coal consumption rises more under the "Mnp" equilibrium relative to the "Cmp" equilibrium and EU coal consumption falls by less under the "Mnp" versus "Cmp" scenario.

Although it is an open question whether Chinese consuming regions actually act as a monopsony relative to Chinese producing regions, the main conclusions to draw from comparing the "Cmp" Chinese consuming region assumption to the "Mnp" Chinese consuming region assumption are: (1) the impacts of the shale gas boom on coal consumption are slightly mitigated under the "Mnp" versus "Cmp" assumption, (2) the win-win economic benefit to US coal producers and the global climate if the the US west coast coal constraint is relaxed are maintained under the "Mnp" solution, but the absolute magnitude of the impacts are smaller, and (3) the impact on US and EU coal consumption from an end to the US shale gas boom are slightly more extreme for "Mnp" versus "Cmp" model equilibrium.

6 Conclusions

The results of these modeling scenarios presented demonstrate that the shale gas boom in the US has had a significan impact of US and EU coal consumption and the geographic distribution of global coal production. Other counterfactual results suggest that these reductions in US and EU coal consumption could be easily erased and global coal consumption increase if the shale gas boom in the US ends. The modeling results also demonstrate that expanding the western US coal export could benefit US coal producers, as well as the global climate. Some lost US coal production is preserved of relaxing the west coast port constraint and there is unlikely to be significant short-term change in coal consumption outside of the US because of limited opportunities for electricity sectors outside of the US and EU to substitute away from coal in the short and medium term. The increased coal production in the US that results from expanding the west coast coal port capacity raises US coal prices, which increases coal-to-natural gas switching in the US, and indirectly in the EU, which further reduces greenhouse gas emissions in the US and EU, little or no impact on greenhouse gas emissions in other parts of the world because they have little or no ability to switch from coal to natural gas. Moreover, even allowing for modest price elasticities of demand for coal in other parts of the world still preserves the basic result that expanding the western US coal port capacity reduces global greenhouse gas emissions.

It is important to emphasize that these results are short to medium-term, because they implicitly assume a fixed stock of generation capacity around the world and do not account for changes in new generation investment behavior that result from these price changes. However, given current natural gas prices, it is unlikely that many regions of the world would expand their installed capacity of coal-fired generation in response to the US expanding its west coast port capacity. As these model simulation demonstrate there are plenty of sources of supply of coal outside of the US that can replace the western US coal supplied to the global market with a very limited impact, if any, on delivered coal prices to the major coal consuming regions. Essentially, western US coal suppliers are infra-marginal suppliers to the Asian market so their increased supply from expanding west coast coal port capacity is indirect in the sense that the marginal supplier to Asia only produces less coal.

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Appendix 1: Calibration Description

A Overview

The model outputs depend on transport and production costs, but those costs are difficult or prohibitively expensive to obtain. Data on model outputs like region-level production, region-level consumption, region-level delivered prices, and region-to-region trade flows, is typically available from public sources. The International Energy Agency (IEA), United States Energy Information Administration (EIA), and other governments publish this type of data on at least an annual basis. Other industry news services report some of this data, most notably delivered prices, on a monthly or weekly basis.

Given the asymmetry of available information, the more readily available and more certain data is used to estimate the more uncertain or more difficult to obtain data by adjusting these parameters to match, as closely as possible, actual model outputs to the predicted model outputs based on these and all of the other parameters of the model. The calibrated parameters are adjusted within pre-defined "reasonableness bounds" so that the model's outputs (coal production, flows, and prices) match the observations from that year as closely as possible. The baseline year chosen for the calibration is 2011.

The first step in the calibration process is to identify which of the model's outputs to match. The outputs chosen are: key country-level export and import quantities, and prices shown in Table 1. Most of these observed values come from the IEA Coal Information 2013 Edition using the values given for the year 2011.[9] The EIA data mentioned in the table comes from the U.S. Coal Imports by Year and U.S. Coal Exports by Year publications. Because coal buying behavior of Chinese consuming regions and its impact on the global coal market is a focus of this modeling effort, total exports from major export-oriented producers, import quantities into China, and delivered prices into major importing regions are included in the set variables used to calibrate the model parameters.i

As noted in Section 4, the model is calibrated to model solutions with Chinese consuming regions acting as price-takers in the global coal market and Chinese consumers actings as monpsony with respect to Chinese producing regions.

[9] http://wds.iea.org/wds/pdf/Documentation%20for%20Coal%20Information%202013.pdf

Table 1: Observed Values Used in Calibrations

Model Output	Goal value	Source
Appalachian Exports abroad	30 Mt	EIA (US Exports by Year)
Powder River Basin Exports abroad	11.6 Mt	IEA
Imports to US Gulf states	9 Mt	IEA & EIA (US Imports by Year)
Colombian exports	74.6 Mt	IEA
Russian Exports	95.4 Mt	
South African Exports	67 Mt	
Indonesian Exports	297 Mt	
Australian (Queensland and New South Wales) Exports	163 Mt	
Imports into India	81 Mt	
Imports into China	137 Mt	
CIF price in Japan	110 $/t	Platts and McCloskey coal reports (2011)
CIF price into Europe	104 $/t	
CIF price into China	104 $/t	

B Optimization description

The calibriation process uses two MATLAB optimization routines. Within each routine the coal model is solved using PATH for the current values of the calibrated parameters and then the objective function (described below) measuring the match between the actual data and model solutions at the current parameter values is computed. The first routine is the *fminsearch* algorithm and the second is the *patternsearch* algorithm. Both are attractive for this application because both rely only on objective function values to minimize the objective function. These routines allow for constrained optimization using user-supplied lower and upper bounds of the parameter values. The "reasonableness bounds" on the parameters described above are imposed using this capability. These two optimization routines are run iteratively, alternating between having each routine vary a subset of the parameter types (see table 2) or the entire set of parameter types. After some initial experimental, alternating between optimizing a subset of input parameters and all input parameters and switching between the two routines appears to perform better (terminate at lower objective function values and run more quickly) than using one routine and optimizing all parameters at once.

B.1 Optimization process details

The optimization process is as follows:

1. Run these steps 25 times

    (a) *fminsearch* algorithm in MATLAB varying all the model's input parameters

    (b) *patternsearch* algorithm in MATLAB varying all the model's input parameters

Table 2: Sets Calibrated

Parameter type	Notes
Producer cost intercepts int_f	All are calibrated
Producer quality factors k_f	
Transport costs τ_{mfc}	Only selected routes are calibrated
Freight rate adder	Scalar quantity added to all sea transport.
Producer cost curve intercept adder	Scalar quantity added to all production costs

2. Then we run the following steps 25 times

   (a) *fminsearch* algorithm in MATLAB varying the following subsets of input parameters in order

      i. First step of marginal cost curves
      ii. transportation costs
      iii. Producer quality factors
      iv. Freight rate adder
      v. Marginal cost step adder (adds a fixed $/tonne amount to each step)

   (b) *patternsearch* algorithm in MATLAB varying the following subsets of input parameters in order

      i. First step of marginal cost curves
      ii. transportation costs
      iii. Producer quality factors
      iv. Freight rate adder
      v. Marginal cost step adder (adds a fixed $/tonne amount to each step)

   (c) *fminsearch* algorithm in MATLAB varying all the model's input parameters

   (d) *patternsearch* algorithm in MATLAB varying all the model's input parameters

This procedure tends to reach an acceptably small value of the objective function in around 48 hours. More iterations of either of the algorithms the process takes longer without much additional benefit. The number of iterations settled on strikes a balance between increased run time and a closer match to reality.

B.2 Objective function

The optimization routines attempts to match the model's outputs for a given solution concept to the observed outputs. This requires choosing a measure of closeness between the model output's and the observed outputs, which is the objective function minimized. The objective function is the sum of squared differences of the model's output and the actual observation. Summing the squares of the difference between the model outputs and goal outputs is attractive because it places a greater emphasis on extremel differences between model outputs and actual outputs.

$$Obj\_func(parameters) \quad = \quad \sum_i \left[(mode1(\_output_i(parameters) - model\_output_i)^2\right] \tag{1}$$

C Model Inputs

This section shows the bounds set for the input parameters in the calibrations for both the price-taking and monopsony model solutions. The values of the calibrated inputs and how they differ between the competitive and monopsony calibrations is discussed.

C.1 Parameter value calibration bounds

The following charts show the bounds set on the input parameters for each of the calibrations. Figure 1 shows the bounds of the first step of the marginal cost curve for both the price-taking and monopsony calibrations. Figures 2 and 3 show the bounds on the freight rate parameters for both calibrations. Note that the parameter bounds for the monopsony calibration are wider than for the competitive calibration. This because the monopsony calibration didn't bring the objective function to a level as low as the competitive calibration without widening the parameter input bounds.

C.2 Calibrated parameter values

Figure 4 provides an example of how the marginal cost curve for a Chinese producing region changed across calibrations for the price-taking relative to the monopsony solutions. This figure shows how the intercept of the cost curve changes for the producer P_CHN_SIS between the price-taking and monopsony solutions. The marginal cost curve resulting from

Figure 1: Cost curve intercept bounds ($/t)

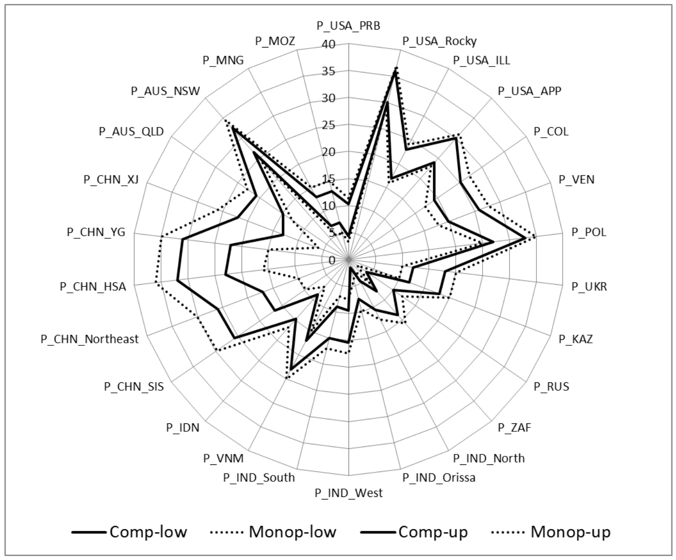
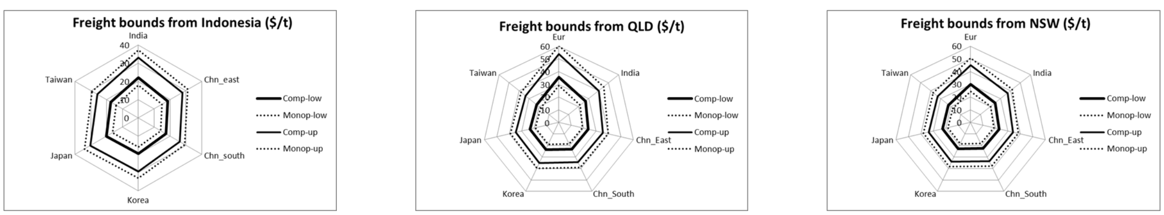


Figure 2: Freight rate bounds from selected major exporters



the calibration to the monopsony baseline is lower than the value for the price-taking calibration because Chinese domestic coal needs to be cheaper for Chinese imports to be at the observed level.

Figures 5 and 6 shows how transportation costs between major export-oriented producers and major import destinations differ from base case starting values for both calibrations, the values from the price-taking calibration, and the values from the moonopsony calibration. One result of note is that the delivery cost into Japan is higher for both of the calibrations than the base case. This is because the delivered price to Japan was too high in the base case, so the calibration pushed the price up by increasing the transport costs. The two Chinese import nodes (Chn_East & Chn_South) both also tend to have increased freight rates for delivery, especially from Indonesia. This is likely for two reasons: (1) the Chinese consuming regions were importing too much in total and (2) delivered prices into China in the base case were lower than the observed prices.

Figure 3: Freight rate bounds from selected major exporters cont.

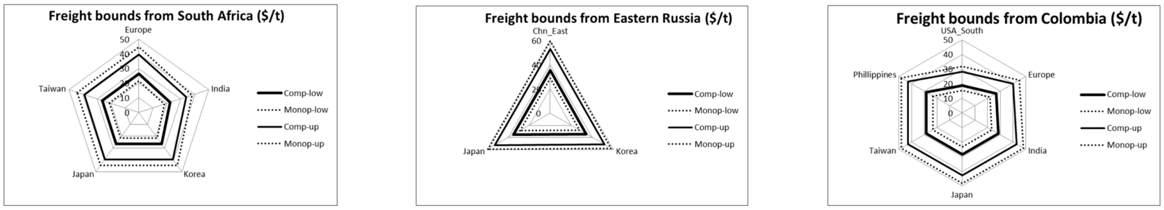


Figure 4: China cost curve example

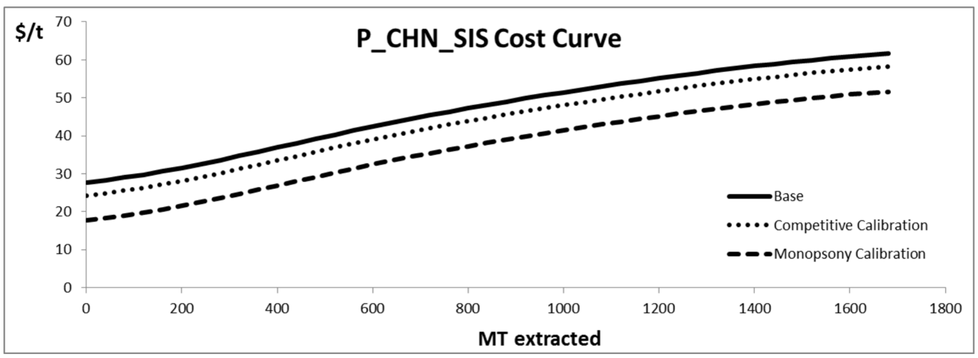


Figure 7 shows the values of the original first step of the producers' marginal cost curve and the calibrated first steps for both the monopsony and price-taking calibrations. The first thing to note is that both calibrations increase the value of the first step of the marginal cost curve relative to the original data. This is because delivered prices from the model solution are lower than the actual prices in Europe, China, and Japan. The first steps of the marginal cost curves in India also increase so that India will import the right amount of coal while the first step for the large export oriented producers were ralso increased in order to increase prices and keep these producers from exporting more than the observed amounts.

D Calibration Results

Table 3 shows how the price-taking calibration's start and end values compare to the observed values, and 4 shows how the monopnsony calibration's start and end values compare to the observed values. Both calibrations brought the objective functions to similar levels. As explained earlier, the bounds on the input parameters in the monopsony calibration had to be increased relative to those for the price-taking solution to obtain this outcome.

Figure 5: Freight rates from selected major exporters

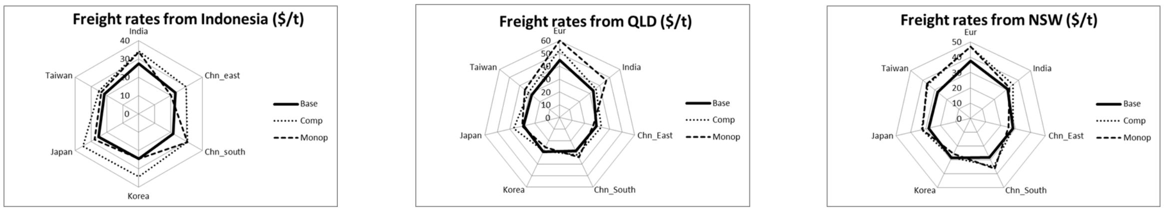
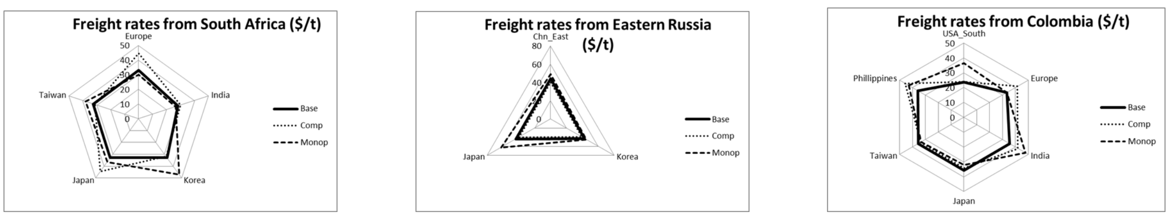


Figure 6: Freight rates from selected major exporters cont.



Appendix 2: Detailed Model Description

E Sets

Table 5 shows the sets of indeces used in the model. Note that there are three main sets–producing regions, consuming regions, and modes of transport. Other sets are subsets of these sets.

F Variables and Parameters

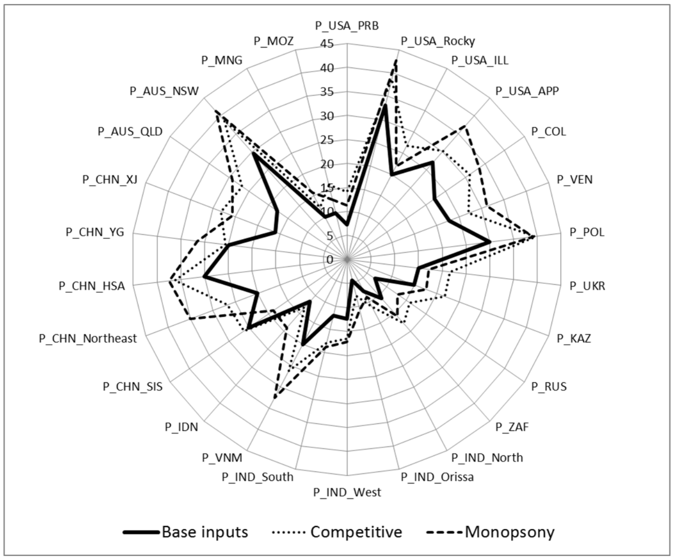
F.1 Exogenous Parameters

Table 6 shows the input parameters in the model. The subscripts on each parameter's symbol show what set(s) it belongs to.

F.2 Endogenous Variables

Table 7 shows the variables generated by the model solution. The subscripts in each variable symbol show which set(s) it belongs to.

Figure 7: Cost curve intercepts–including adjustments for quality factors ($/t)



G Model Equations

G.1 Producer and Consumer equations

Producer Problem:

$$-p_f + k_f \cdot [MC_f(Q_f) \ + \ \alpha_f] \geq 0 \quad \perp \quad Q_f \geq 0$$

Producer Constraint:

$$PCap_f - k_f \cdot Q_f \geq 0 \quad \perp \quad \alpha_f \geq 0$$

Market Clearing Condition:

$$Q_f - \sum_{m,c} x_{mfc} \geq 0 \quad \perp \quad p_c \geq 0$$

Inelastic Consumer Problem:

$$p_f + k_f \cdot (\tau_{mfc} + \beta_{mfc} + \theta_{f,c} \cdot \pi_{Ch}) - p_c \geq 0 \quad \perp \quad x_{mfc} \geq 0$$

Monopsony Consumer Problem:

$$p_f + k_f \cdot (\tau_{mfc} + \beta_{mfc} + \theta_{f,c} \cdot \pi) + \gamma_{f,c} \cdot (MC'_f(Q_f) k_f [\sum_{m,china} x_{mfc}] - p_c \ \geq \ 0 \quad \perp \quad x_{mfc} \geq 0$$

Table 3: Comparison of observed values and price-taking scenario calibration results

Parameter	Goal Value	Unit	Competitive Base (pre-calibration)	Calibrated competitive model
Appalachian Exports abroad	30	Mt	33	2
Powder River Basin Exports abroad	11	Mt	11	11 (capacity constraint)
Imports to US Gulf states	9	Mt	0	0
Colombian exports	75	Mt	87	76.5
Russian Exports	95	Mt	97	97
South African Exports	67	Mt	76	76
Indonesian Exports	297	Mt	320	320
Australia (Queensland and New South Wales) Exports	163	Mt	197	161
Imports into India	98	Mt	162	112.5
Imports into China	137	Mt	183	145
CIF price in Japan	110	$/t	89	95
CIF price into China	104	$/t	78	84
CIF price into Europe	104	$/t	85	87
			ObjFncVal = 9694	ObjFncVal= 2673

Table 4: Comparison of actual values and monopsony scenario calibration results

Parameter	Goal Value	Unit	Monopsony Base (pre-calibration)	Calibrated monopsony model
Appalachian Exports abroad	30	Mt	50	0
Powder River Basin Exports abroad	11	Mt	11	11 (capacity constraint)
Imports to US Gulf states	9	Mt	0	0
Colombian exports	75	Mt	87	74
Russian Exports	95	Mt	97	86
South African Exports	67	Mt	76	76
Indonesian Exports	297	Mt	320	281
Australia (Queensland and New South Wales) Exports	163	Mt	226	151
Imports into India	98	Mt	80	90
Imports into China	137	Mt	403	144
CIF price in Japan	110	$/t	95	95
CIF price into China	104	$/t	87	85
CIF price into Europe	104	$/t	91	87
			ObjFncVal = 76,971	ObjFncVal= 2532

Inelastic Demand Constraint:

$$\sum x_{mfc} - Q_c^{base} \geq 0 \quad \perp \quad p_c \geq 0$$

Elastic Consumer Problem:

$$p_f + k_f \cdot (\tau_{mfc} + \beta_{m,f,gas} + \theta_{f,gas} \cdot \pi_{Ch}) - P_c(\sum_{m,f} x_{mfc}) \geq 0 \quad \perp \quad x_{m,f,gas} \geq 0$$

Table 5: Model Sets

Parameter	Description
f	Coal producing regions
c	Coal consuming regions
$gas \in c$	The subset of consumers c that have significant gas power generation
$mon \in f$	The subset of Chinese consumers c that we model possibly exerting market power.
$monf \in f$	The subset of coal producers f that possibly face monopsony power. (Chinese and Vietnamese)
$C \in c$	The subset of coal consumers f that have monopsony power
m	Modes of transport: land or sea
$china \in f$	All Chinese producers that face export restriction

Elastic Consumer Constraint:

$$\sum_f x_{f,c} \; - \; QC_c(p_c) \geq 0 \quad \perp \quad p_c \geq 0$$

where $QC_c(p_c) \; = \; A_r(p_c)^{\beta_{r1}}$ and $A_r \; = \; (gasp_r)^{\beta_{r2}}(fossilgen_r)^{\beta_{r1}}exp(\alpha_r)$.

G.2 Transport constraint equations

Transport Constraint:

$$tcap_{mfc} - k_f \cdot x_{mfc} \geq 0 \quad \perp \quad \beta_{mfc} \geq 0$$

Chinese export restriction constraint:

$$\pi_{Ch} - \sum_{mfc} k_f \cdot x_{m,f,nochina} \geq 0 \quad \perp \quad \upsilon \geq 0$$

Table 6: Exogenous Parameters

Parameter	Description
int_f	Parameters making up the cost curve for producer f ($\frac{\$}{t}$) where i denotes the steps on each cost curve
p_f^i	Cost increase of coal produced at producer f on step i
q_f^i	Quantity where price increases by p_f^i for producer f on step i
σ_f	Smoothing factor for price jumps for consumer f
k_f	Coal quality for producer f ($\frac{t}{GJ}$)
$PCap_f$	Production capacity for producer f (Mt)
Q_{gas}^{base}	Baseline quantity consumed by consumers
P_{gas}^{base}	Solved price of coal form the inelastic model for consumers $gas \in c$
η_{gas}^c	Elasticity of coal consumption with respect to the coal price (Defined as the absolute value of the empirically estimated elasticity)
η_{gas}^g	Elasticity of coal consumption with respect to the gas price
γ_f	Binary variable that equals 1 if a consumer can exercise monopsony power on producer f
τ_{mfc}	Land transportation costs from producer f to consumer c using mode m ($\$/t$). This includes transport costs, taxes, and port fees.
$tcap_{mfc}$	Transport capacity between producer f and consumer c using mode m (Mt)
θ_c	Binary variable for if consumer c is subject to China's export constraint
π_{Ch}	Limit on the amount of Chinese coal exports (Mt)

Table 7: Endogenous Variables

Variable	Description
p_f	Mine-mouth price for producer f ($\frac{\$}{GJ}$)
Q_f	Total coal energy produced by producer f (PJ)
x_{mfc}	Coal from producer f to consumer c delivered through mode m (PJ)
p_c	Delivered price paid for coal by consumer c ($\frac{\$}{GJ}$)
α_f	Dual on production capacity constraint of producer f ($\$Million$)
β_{mfc}	Dual on the transport capacity from producer f to consumer c using mode m ($\$Million$)
υ	Dual on the export restriction on Chinese exports to non-Chinese importers ($\$Million$)

Table 1A: : Consuming Regions

Consumer Node	Demand type	Mode access	Monopsony capability
C_CANADA	Inelastic	land	No
C_USA_Rocky	Elastic	land	No
C_USA_Central	Elastic	land	No
C_USA_South	Elastic	land	No
C_USA_East	Elastic	land	No
C_USA_Gulf	Elastic	land, sea	No
C_EUR	Elastic	land, sea	No
C_USSR	Inelastic	land	No
C_INDIA	Inelastic	land, sea	No
C_THAILAND	Inelastic	sea	No
C_MAYALSIA	Inelastic	sea	No
C_VIETNAM	Inelastic	land	No
C_CHINA_Northeast	Inelastic	land	Yes
C_CHINA_SIS	Inelastic	land	Yes
C_CHINA_Main	Inelastic	land	Yes
C_CHINA_Eastern	Inelastic	land, sea	Yes
C_CHINA_South	Inelastic	land, sea	Yes
C_KOREA	Inelastic	sea	No
C_JAPAN	Inelastic	sea	No
C_TAIWAN	Inelastic	sea	No
C_PHILIPPINES	Inelastic	sea	No
C_MONGOLIA	Inelastic	land	No
C_CHILE	Inelastic	sea	No

Table 1B: : Coal Consuming Region Definitions

Consumer Node	States / Provinces
C_CHN_Eastern	Anhui, Hubei, JiangSu, Shanghai, Zhejiang
C_CHN_Main	Beijing, Hebei, Henan, Shandong, Tianjin
C_CHN_Northeast	Heilongjiang, Jilin, Liaoning
C_CHN_SIS	Inner Mongolia, Shaanxi, Shanxi
C_CHN_South	Fujian, Guangdong, Guangxi, Guizhou, Hong Kong, Hunan, Jiangxi, Macau, Chongqing, Sichuan
C_USA_Central	Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin
C_USA_East	Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont
C_USA_Gulf	Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Oklahoma, South Carolina, Tennessee, Texas
C_USA_Rocky	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming
C_USA_South	Delaware, DC, Kentucky, Maryland, North Carolina, Virginia, West Virginia

Table 2B: : Coal Producing Regions

Producer name	Region	Data Source for Marginal Cost Function
P_USA_PRB	Wyoming, North Dakota, Montana	Aggration of EIA mine-mouth prices by state
P_USA_Rocky	Colorado, New Mexico, Utah, Arizona	
P_USA_ILL	Illinois, Indiana, Western Kentucky, Tennessee	
P_USA_APP	Eastern Kentucky, West Virginia, Pennsylvania, Maryland, Ohio, Virginia	
P_COL	Colombia	Marston Mining Consultancy Presentation
P_VEN	Venezuela	
P_POL	Poland	PESD Estimate based on prices from IEA Coal 2013
P_UKR	Ukraine	
P_KAZ	Kazakhstan	
P_RUS	Russia	Marston Mining Consultancy Presentation
P_ZAF	South Africa	
P_IND_North	Assam, Chhatisgargh, Jarkhand, Madyha Pradesh, Uttar Pradesh, West Bengal	Government of India-Ministry of coal
P_IND_Orissa	Orissa	
P_IND_West	Maharashtra, Meghalaya	
P_IND_South	Andhra Pradesh	
P_VNM	Vietnam	PESD Estimate
P_IDN	Indonesia	Marston Mining Consultancy Presentation
P_CHN_XJ	Xianjiang	PESD Estimate
P_CHN_SIS	Shanxi, Shaanxi, Inner Mongolia, Hebei	PESD Estimate based on interviews and prices from Fenwei Consulting
P_CHN_Northeast	Liaoning, Jilin, Heilongjiang	PESD Estimate
P_CHN_HSA	Henan, Shandong, Jiangxi, Fujian, Jiangsu	
P_CHN_YG	Guizhou, Hunan, Chongqing, Sichuan	
P_AUS_QLD	Queensland	Marston Mining Consultancy Presentation
P_AUS_NSW	New South Wales	
P_MNG	Mongolia	PESD Estimate
P_MOZ	Mozambique	

Table 3B: : US Demand Parameters Regression Results

VARIABLES	(1) log_coal_consumption
Central Region log coal price	-0.0892
	(0.0110)
East Region log coal price	-0.524
	(0.0280)
Gulf Region log coal price	-0.282
	(0.0202)
Rocky Mountain Region log coal price	-0.308
	(0.0250)
South Region log coal price	-0.149
	(0.0159)
Central Region log gas price	0.0587
	(0.0105)
East Region log gas price	0.274
	(0.0293)
Gulf Region log gas price	0.185
	(0.0181)
Rocky Mountain Region log gas price	0.00616
	(0.0179)
South Region log gas price	0.124
	(0.0140)
Log total fossil gen	0.698
	(0.0178)
Constant	8.150
	(0.319)
Observations	740
R-squared	0.975

Arellano (1987) robust standard errors in parentheses

Table 4B: : Europe Demand Parameters Regression Results

VARIABLES	(1) ln_coal_consumption
log coal price	-0.304
	(0.116)
log gas price	0.182
	(0.0991)
log total fossil gen	1.520
	(0.390)
Constant	2.530
	(4.285)
Observations	112
R-squared	0.988

Arellano (1987) robust standard errors in parentheses

Table 5A:

		Percent Coal Consumption Change in Cmp-Cmp-Cons Counterfactual							
	Cmp-Cmp-Cons	[(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Consumption	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
C_USA_Rocky	2147.6	0.0	0.4	0.2	-0.2	0.0	0.4	0.2	-0.2
C_USA_Central	6259.3	0.0	-3.8	-1.6	1.3	0.0	-3.8	-1.6	1.3
C_USA_South	3535.4	0.0	-6.5	-1.8	2.8	0.0	-6.3	-1.7	2.8
C_USA_East	3269.4	0.0	-16.6	-7.4	5.7	0.3	-16.0	-6.9	5.7
C_USA_Gulf	2523.0	0.0	-11.8	-5.1	4.1	0.0	-11.8	-5.1	4.1
C_EUR	4052.9	0.0	0.3	0.1	-0.0	-11.7	-11.3	-11.6	-11.7

Table 5B:

	Cmp-Cmp-Cons	Percent Delivered Price Change in Cmp-Cmp-Cons Counterfactual							
		[(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Price	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
C_USA_Rocky	1.9	0.0	-1.0	-0.5	0.5	0.0	-1.0	-0.5	0.5
C_USA_Central	2.0	0.0	-1.0	-0.5	0.5	0.0	-1.0	-0.5	0.5
C_USA_South	3.2	0.0	-11.7	-10.8	0.3	0.0	-12.9	-11.7	0.3
C_USA_East	2.8	0.0	-1.5	0.0	1.1	-0.4	-2.5	-1.1	1.1
C_USA_Gulf	2.3	0.0	-0.9	-0.4	0.4	0.0	-0.9	-0.4	0.4
C_EUR	3.7	0.0	-1.1	0.0	0.3	-0.3	-1.9	-0.8	-0.3
C_CAN	2.6	0.0	-1.6	0.0	1.2	-0.4	-2.7	-1.2	1.2
C_USSR	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_IND	3.8	0.0	-1.1	-0.3	0.0	-0.5	-1.6	-1.1	-0.5
C_THA	3.6	0.0	-0.3	-0.3	0.0	-0.3	-0.5	-0.3	-0.3
C_MYS	3.6	0.0	-0.6	-0.3	0.0	-0.6	-0.8	-0.6	-0.6
C_VNM	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Northeast	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_SIS	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Main	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Eastern	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_South	3.6	0.0	-0.3	-0.3	0.0	-0.3	-0.6	-0.3	-0.3
C_KOR	3.7	0.0	-0.3	-0.3	0.0	-0.3	-0.5	-0.3	-0.3
C_JPN	3.8	0.0	-1.1	-0.3	0.0	-0.5	-1.3	-1.1	-0.3
C_TWN	3.6	0.0	-0.6	-0.3	0.0	-0.6	-0.8	-0.6	-0.6
C_PHL	3.6	0.0	-0.3	-0.3	0.0	-0.3	-0.8	-0.3	-0.3
C_MNG	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHL	3.4	0.0	-1.2	0.0	0.3	-0.3	-1.4	-0.9	-0.3

Table 5C:

	Cmp-Cmp-Cons	Percent Producer Price Change in Cmp-Cmp-Cons Counterfactual							
		[(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Price	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
P_USA_PRB	1.0	0.0	-2.1	-1.0	1.0	0.0	-2.1	-1.0	1.0
P_USA_Rocky	1.5	0.0	-1.3	-0.6	0.6	0.0	-1.3	-0.6	0.6
P_USA_ILL	1.4	0.0	-1.5	-0.7	1.5	0.0	-1.5	-0.7	1.5
P_USA_APP	2.2	0.0	-1.8	-0.5	1.4	-0.9	-3.7	-1.8	1.4
P_COL	2.1	0.0	-1.9	-0.5	0.0	-1.0	-2.4	-1.9	-0.5
P_VEN	2.9	0.0	-1.0	0.0	0.3	-0.3	-1.7	-1.0	-0.3
P_POL	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_UKR	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_KAZ	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_RUS	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_ZAF	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_North	3.1	0.0	-1.3	-0.3	0.0	-0.7	-2.0	-1.3	-0.7
P_IND_Orissa	2.7	0.0	-1.1	0.0	0.4	-0.4	-1.9	-1.1	-0.4
P_IND_West	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_South	2.8	0.0	-1.4	-0.4	0.0	-0.7	-2.2	-1.4	-0.7
P_VNM	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IDN	2.5	0.0	-0.4	-0.4	0.0	-0.4	-1.2	-0.4	-0.4
P_CHN_SIS	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_Northeast	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_HSA	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_YG	2.6	0.0	-0.4	-0.4	0.0	-0.4	-0.8	-0.4	-0.4
P_CHN_XJ	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_AUS_QLD	2.5	0.0	-1.6	-0.4	0.0	-0.8	-2.0	-1.6	-0.4
P_AUS_NSW	2.4	0.0	-1.2	0.0	0.4	-0.4	-2.0	-1.2	-0.4
P_MNG	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_MOZ	2.7	0.0	-1.5	-0.4	0.0	-0.7	-2.2	-1.5	-0.7

Table 5D:

	Cmp-Cmp-Cons Production	Percent Coal Production Change in Cmp-Cmp-Cons Counterfactual [(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are: (1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
P_USA_PRB	9245.6	0.0	-2.8	-1.3	1.5	0.0	-2.8	-1.3	1.5
P_USA_Rocky	1685.2	0.0	-13.2	-5.8	5.7	0.0	-13.2	-5.8	5.7
P_USA_ILL	1648.9	0.0	-4.9	-2.3	2.5	0.0	-4.9	-2.3	2.5
P_USA_APP	5730.2	0.0	-2.1	-0.5	1.9	-1.0	-3.8	-2.0	1.9
P_COL	1860.4	0.0	-2.6	-0.5	0.2	-1.2	-3.6	-2.5	-1.1
P_VEN	233.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_POL	1507.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_UKR	1053.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_KAZ	2394.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_RUS	2993.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_ZAF	2152.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_North	5444.5	0.0	-1.9	-0.4	0.1	-0.9	-2.6	-1.8	-0.8
P_IND_Orissa	1540.4	0.0	-2.0	-0.4	0.1	-0.9	-2.8	-2.0	-0.8
P_IND_West	1783.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_South	1337.6	0.0	-4.8	-1.0	0.3	-2.2	-6.5	-4.7	-2.1
P_VNM	1225.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IDN	7839.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_SIS	28523.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_Northeast	3609.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_HSA	7426.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_YG	7603.1	0.0	-3.1	-2.2	0.7	-3.1	-5.8	-3.1	-3.1
P_CHN_XJ	206.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_AUS_QLD	2009.7	0.0	-4.3	-0.9	0.3	-2.0	-5.9	-4.2	-1.8
P_AUS_NSW	2178.5	0.0	-1.9	-0.4	0.1	-0.8	-2.6	-1.8	-0.8
P_MNG	57.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_MOZ	28.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 6A:

		Percent Coal Consumption Change in Cmp-Cmp-Open Counterfactual							
	Cmp-Cmp-Cons	[(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Consumption	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
C_USA_Rocky	2147.6	-0.4	-0.1	-0.2	-0.6	-0.4	-0.1	-0.2	-0.6
C_USA_Central	6259.3	-0.1	-4.0	-1.7	1.1	-0.1	-4.0	-1.7	1.1
C_USA_South	3535.4	-0.1	-6.4	-1.7	2.6	-0.1	-6.3	-1.6	2.6
C_USA_East	3269.4	0.1	-16.2	-7.0	5.7	0.4	-15.9	-6.4	5.7
C_USA_Gulf	2523.0	-0.3	-12.1	-5.4	3.7	-0.3	-12.1	-5.4	3.7
C_EUR	4052.9	0.1	0.5	0.3	-0.0	-11.4	-11.2	-11.4	-11.4

Table 6B:

	Cmp-Cmp-Cons Price	Percent Delivered Price Change in Cmp-Cmp-Open Counterfactual [(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are: (1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
C_USA_Rocky	1.9	1.6	0.0	1.0	2.1	1.6	0.0	1.0	2.1
C_USA_Central	2.0	1.5	0.5	1.0	2.1	1.5	0.5	1.0	2.1
C_USA_South	3.2	0.6	-12.6	-11.7	0.9	0.6	-13.2	-12.6	0.9
C_USA_East	2.8	0.0	-2.2	-1.1	1.1	-0.7	-2.9	-2.2	1.1
C_USA_Gulf	2.3	0.9	0.0	0.4	1.8	0.9	0.0	0.4	1.8
C_EUR	3.7	0.0	-1.6	-0.8	0.0	-1.4	-2.2	-1.6	-1.4
C_CAN	2.6	0.0	-2.3	-1.2	1.2	-0.8	-3.1	-2.3	1.2
C_USSR	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_IND	3.8	-0.3	-1.9	-1.1	0.0	-1.6	-2.4	-1.6	-1.6
C_THA	3.6	-0.5	-0.8	-0.5	-0.5	-0.8	-1.4	-0.8	-0.8
C_MYS	3.6	-0.6	-1.1	-0.6	-0.6	-0.8	-1.7	-1.1	-0.8
C_VNM	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Northeast	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_SIS	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Main	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Eastern	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_South	3.6	-0.6	-0.8	-0.6	-0.6	-0.8	-1.4	-0.8	-0.8
C_KOR	3.7	-0.5	-0.8	-0.5	-0.5	-0.8	-1.3	-0.8	-0.8
C_JPN	3.8	-1.9	-2.1	-1.9	-1.9	-1.9	-2.7	-2.1	-1.9
C_TWN	3.6	-0.6	-1.1	-0.6	-0.6	-0.8	-1.7	-1.1	-0.8
C_PHL	3.6	-0.6	-0.8	-0.6	-0.6	-0.8	-1.7	-0.8	-0.8
C_MNG	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHL	3.4	0.0	-1.7	-0.9	0.0	-1.4	-2.3	-1.7	-1.4

Table 6C:

	Cmp-Cmp-Cons	Percent Producer Price Change in Cmp-Cmp-Open Counterfactual							
		[(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Price	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
P_USA_PRB	1.0	3.1	0.0	2.1	4.2	3.1	0.0	2.1	4.2
P_USA_Rocky	1.5	1.9	0.0	1.3	2.6	1.9	0.0	1.3	2.6
P_USA_ILL	1.4	2.2	0.7	1.5	2.9	2.2	0.7	1.5	2.9
P_USA_APP	2.2	-0.5	-2.8	-1.8	1.4	-0.9	-4.1	-2.8	1.4
P_COL	2.1	-0.5	-2.9	-1.4	0.0	-2.9	-3.8	-2.9	-2.9
P_VEN	2.9	0.0	-2.1	-1.0	0.0	-1.7	-2.8	-2.1	-1.7
P_POL	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_UKR	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_KAZ	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_RUS	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_ZAF	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_North	3.1	-0.3	-2.3	-1.3	0.0	-2.0	-2.9	-2.3	-2.0
P_IND_Orissa	2.7	0.0	-2.2	-1.1	0.4	-1.9	-3.0	-2.2	-1.9
P_IND_West	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_South	2.8	-0.4	-2.5	-1.4	0.0	-2.2	-3.2	-2.5	-2.2
P_VNM	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IDN	2.5	-0.8	-1.2	-0.8	-0.8	-1.2	-2.4	-1.2	-1.2
P_CHN_SIS	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_Northeast	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_HSA	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_YG	2.6	-0.8	-1.2	-0.8	-0.8	-1.2	-1.9	-1.2	-1.2
P_CHN_XJ	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_AUS_QLD	2.5	-2.8	-3.3	-2.8	-2.8	-2.8	-4.1	-3.3	-2.8
P_AUS_NSW	2.4	-2.4	-3.3	-2.4	-2.4	-2.9	-4.1	-3.3	-2.9
P_MNG	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_MOZ	2.7	-0.4	-2.6	-1.5	0.0	-2.2	-3.4	-2.6	-2.2

Table 6D:

	Cmp-Cmp-Cons	Percent Coal Production Change in Cmp-Cmp-Open Counterfactual [(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Production	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
P_USA_PRB	9245.6	3.6	0.4	2.1	5.2	3.6	0.4	2.1	5.2
P_USA_Rocky	1685.2	12.6	1.7	7.9	17.3	12.6	1.7	7.9	17.3
P_USA_ILL	1648.9	5.9	0.7	3.6	8.4	5.9	0.7	3.6	8.4
P_USA_APP	5730.2	-0.4	-3.2	-1.8	1.9	-1.2	-4.1	-3.2	1.9
P_COL	1860.4	-0.5	-4.1	-2.2	0.1	-3.7	-5.5	-4.1	-3.7
P_VEN	233.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_POL	1507.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_UKR	1053.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_KAZ	2394.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_RUS	2993.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_ZAF	2152.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_North	5444.5	-0.3	-2.9	-1.6	0.0	-2.7	-3.8	-2.9	-2.7
P_IND_Orissa	1540.4	-0.4	-3.2	-1.8	0.0	-2.9	-4.2	-3.2	-2.9
P_IND_West	1783.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_South	1337.6	-0.9	-7.4	-4.2	0.1	-6.8	-9.6	-7.4	-6.8
P_VNM	1225.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IDN	7839.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_SIS	28523.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_Northeast	3609.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_HSA	7426.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_YG	7603.1	-5.0	-7.3	-5.0	-5.0	-6.2	-10.3	-7.2	-6.2
P_CHN_XJ	206.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_AUS_QLD	2009.7	-7.1	-8.3	-7.1	-7.1	-7.7	-10.2	-8.3	-7.7
P_AUS_NSW	2178.5	-3.2	-3.8	-3.2	-3.2	-3.5	-4.8	-3.8	-3.5
P_MNG	57.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_MOZ	28.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7A:

	Mnp-Mnp-Cons Consumption	Percent Coal Consumption Change in Mnp-Mnp-Cons Counterfactual [(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are: (1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
C_USA_Rocky	2147.8	0.0	0.8	0.3	-0.2	0.0	0.8	0.3	-0.2
C_USA_Central	6259.3	0.0	-3.7	-1.6	1.2	0.0	-3.7	-1.6	1.2
C_USA_South	3535.4	0.0	-8.1	-3.4	2.8	0.0	-8.1	-3.4	2.8
C_USA_East	3269.2	0.0	-14.6	-6.8	6.1	0.0	-14.6	-6.8	6.1
C_USA_Gulf	2523.0	0.0	-11.6	-5.0	4.1	0.0	-11.6	-5.0	4.1
C_EUR	4055.5	0.0	0.0	0.0	0.0	-11.5	-11.5	-11.5	-11.5

Table 7B:

	Mnp-Mnp-Cons	Percent Delivered Price Change in Mnp-Mnp-Cons Counterfactual [(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Price	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
C_USA_Rocky	1.7	0.0	-3.0	-1.2	0.6	0.0	-3.0	-1.2	0.6
C_USA_Central	1.6	0.0	-3.2	-1.3	0.6	0.0	-3.2	-1.3	0.6
C_USA_South	3.3	0.0	-1.5	-0.6	0.3	0.0	-1.5	-0.6	0.3
C_USA_East	3.1	0.0	-5.8	-1.6	0.6	0.0	-5.8	-1.6	0.6
C_USA_Gulf	2.5	0.0	-2.0	-0.8	0.4	0.0	-2.0	-0.8	0.4
C_EUR	3.7	0.0	0.0	0.0	0.0	-1.6	-1.6	-1.6	-1.6
C_CAN	2.9	0.0	-6.5	-1.7	0.3	0.0	-6.5	-1.7	0.3
C_USSR	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_IND	3.8	0.0	0.0	0.0	0.0	-1.3	-1.3	-1.3	-1.3
C_THA	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_MYS	3.6	0.0	0.0	0.0	0.0	-0.3	-0.3	-0.3	-0.3
C_VNM	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Northeast	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_SIS	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Main	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Eastern	3.7	0.0	0.0	0.0	0.0	-0.3	-0.3	-0.3	-0.3
C_CHN_South	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_KOR	3.7	0.0	0.0	0.0	0.0	-0.3	-0.3	-0.3	-0.3
C_JPN	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_TWN	3.6	0.0	0.0	0.0	0.0	-0.3	-0.3	-0.3	-0.3
C_PHL	3.6	0.0	0.0	0.0	0.0	-0.3	-0.3	-0.3	-0.3
C_MNG	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHL	3.5	0.0	0.0	0.0	0.0	-1.7	-1.7	-1.7	-1.7

Table 7C:

	Mnp-Mnp-Cons	Percent Producer Price Change in Mnp-Mnp-Cons Counterfactual							
		[(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Price	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
P_USA_PRB	0.9	0.0	-4.4	-1.1	1.1	0.0	-4.4	-1.1	1.1
P_USA_Rocky	1.6	0.0	-3.8	-3.8	0.6	0.0	-2.5	-1.3	-1.9
P_USA_ILL	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_USA_APP	2.5	0.0	-7.6	-2.0	0.4	0.0	-7.6	-2.0	0.4
P_COL	2.1	0.0	0.0	0.0	0.0	-2.9	-2.9	-2.9	-2.9
P_VEN	2.6	0.0	0.0	0.0	0.0	-2.3	-2.3	-2.3	-2.3
P_POL	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_UKR	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_KAZ	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_RUS	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_ZAF	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_North	3.0	0.0	0.0	0.0	0.0	-1.7	-1.7	-1.7	-1.7
P_IND_Orissa	2.7	0.0	0.0	0.0	0.0	-2.2	-2.2	-2.2	-2.2
P_IND_West	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_South	2.7	0.0	0.0	0.0	0.0	-2.2	-2.2	-2.2	-2.2
P_VNM	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IDN	2.4	0.0	0.0	0.0	0.0	-0.4	-0.4	-0.4	-0.4
P_CHN_SIS	1.7	0.0	0.0	0.0	0.0	-0.6	-0.6	-0.6	-0.6
P_CHN_Northeast	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_HSA	2.4	0.0	0.0	0.0	0.0	-0.4	-0.4	-0.4	-0.4
P_CHN_YG	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_XJ	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_AUS_QLD	2.4	0.0	0.0	0.0	0.0	-0.4	-0.4	-0.4	-0.4
P_AUS_NSW	2.4	0.0	0.0	0.0	0.0	-0.4	-0.4	-0.4	-0.4
P_MNG	2.7	0.0	0.0	0.0	0.0	-0.4	-0.4	-0.4	-0.4
P_MOZ	2.7	0.0	0.0	0.0	0.0	-1.8	-1.8	-1.8	-1.8

Table 7D:

	Mnp-Mnp-Cons Production	Percent Coal Production Change in Mnp-Mnp-Cons Counterfactual [(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are: (1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
P_USA_PRB	10794.4	0.0	-8.3	-4.1	4.1	0.0	-8.3	-4.1	4.1
P_USA_ILL	2106.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_USA_APP	5212.1	0.0	-7.1	-2.2	0.6	0.0	-7.1	-2.2	0.6
P_COL	1716.9	0.0	0.0	0.0	0.0	-3.5	-3.5	-3.5	-3.5
P_VEN	257.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_POL	1474.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_UKR	1000.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_KAZ	1890.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_RUS	3129.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_ZAF	1867.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_North	4700.2	0.0	0.0	0.0	0.0	-1.8	-1.8	-1.8	-1.8
P_IND_Orissa	1454.2	0.0	0.0	0.0	0.0	-2.2	-2.2	-2.2	-2.2
P_IND_West	1877.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_South	920.6	0.0	0.0	0.0	0.0	-4.5	-4.5	-4.5	-4.5
P_VNM	519.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IDN	5959.1	0.0	0.0	0.0	0.0	-0.5	-0.5	-0.5	-0.5
P_CHN_SIS	25054.9	0.0	0.0	0.0	0.0	-0.7	-0.7	-0.7	-0.7
P_CHN_Northeast	3110.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_HSA	5755.1	0.0	0.0	0.0	0.0	-0.5	-0.5	-0.5	-0.5
P_CHN_YG	2732.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_XJ	194.5	0.0	0.0	0.0	0.0	-0.4	-0.4	-0.4	-0.4
P_AUS_QLD	1613.5	0.0	0.0	0.0	0.0	-0.6	-0.6	-0.6	-0.6
P_AUS_NSW	1935.7	0.0	0.0	0.0	0.0	-0.4	-0.4	-0.4	-0.4
P_MNG	51.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_MOZ	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 8A:

		Percent Coal Consumption Change in Mnp-Mnp-Open Counterfactual							
	Mnp-Mnp-Cons	[(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Consumption	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
C_USA_Rocky	2147.8	-0.3	0.2	-0.1	-0.4	-0.3	0.2	-0.1	-0.4
C_USA_Central	6259.3	-0.1	-3.9	-1.7	1.2	-0.1	-3.9	-1.7	1.2
C_USA_South	3535.4	-0.1	-8.1	-3.5	2.7	-0.1	-8.1	-3.5	2.7
C_USA_East	3269.2	-0.2	-14.6	-6.8	5.9	-0.2	-14.6	-6.8	5.9
C_USA_Gulf	2523.0	-0.2	-11.9	-5.2	4.0	-0.2	-11.9	-5.2	4.0
C_EUR	4055.5	0.1	0.1	0.1	0.1	-11.4	-11.4	-11.4	-11.4

Table 8B: : Text Here

	Mnp-Mnp-Cons Price	Percent Delivered Price Change in Mnp-Mnp-Open Counterfactual [(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are: (1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
C_USA_Rocky	1.7	0.6	-0.6	0.0	1.2	0.6	-0.6	0.0	1.2
C_USA_Central	1.6	0.6	-0.6	0.0	1.3	0.6	-0.6	0.0	1.3
C_USA_South	3.3	0.3	-1.2	0.0	0.6	0.3	-1.2	0.0	0.6
C_USA_East	3.1	0.6	-5.8	-1.6	0.6	0.6	-5.8	-1.6	0.6
C_USA_Gulf	2.5	0.4	-0.4	0.0	0.8	0.4	-0.4	0.0	0.8
C_EUR	3.7	-0.3	-0.3	-0.3	-0.3	-1.9	-1.9	-1.9	-1.9
C_CAN	2.9	0.3	-6.5	-1.7	0.7	0.3	-6.5	-1.7	0.7
C_USSR	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_IND	3.8	-0.8	-0.8	-0.8	-0.8	-1.6	-1.6	-1.6	-1.6
C_THA	3.6	-0.8	-0.8	-0.8	-0.8	-1.6	-1.6	-1.6	-1.6
C_MYS	3.6	-1.1	-1.1	-1.1	-1.1	-1.9	-1.9	-1.9	-1.9
C_VNM	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_Northeast	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_CHN_SIS	2.8	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
C_CHN_Main	3.4	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
C_CHN_Eastern	3.7	-1.1	-1.1	-1.1	-1.1	-1.9	-1.9	-1.9	-1.9
C_CHN_South	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C_KOR	3.7	-0.8	-0.8	-0.8	-0.8	-1.9	-1.9	-1.9	-1.9
C_JPN	3.7	-0.8	-0.8	-0.8	-0.8	-1.6	-1.6	-1.6	-1.6
C_TWN	3.6	-0.8	-0.8	-0.8	-0.8	-1.9	-1.9	-1.9	-1.9
C_PHL	3.6	-1.1	-1.1	-1.1	-1.1	-2.0	-2.0	-2.0	-2.0
C_MNG	2.8	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
C_CHL	3.5	-0.3	-0.3	-0.3	-0.3	-2.0	-2.0	-2.0	-2.0

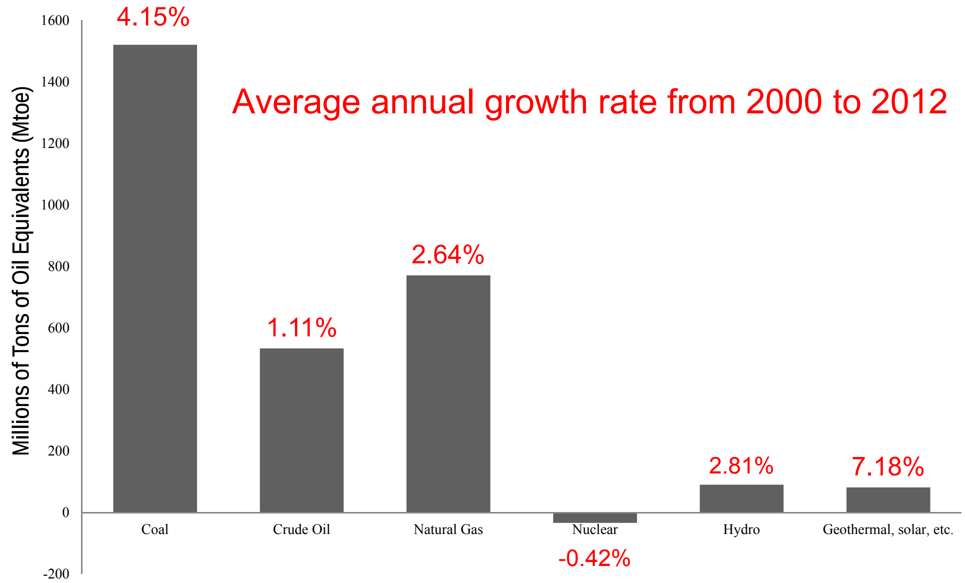
Table 8C:

		Percent Producer Price Change in Mnp-Mnp-Open Counterfactual							
	Mnp-Mnp-Cons	[(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are:							
	Price	(1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
P_USA_PRB	0.9	2.2	-1.1	1.1	2.2	2.2	-1.1	1.1	2.2
P_USA_Rocky	1.6	-1.9	-0.6	-2.5	-1.3	-1.9	-3.1	-2.5	-1.3
P_USA_ILL	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_USA_APP	2.5	0.4	-7.6	-2.0	0.8	0.4	-7.6	-2.0	0.8
P_COL	2.1	-0.5	-0.5	-0.5	-0.5	-3.3	-3.3	-3.3	-3.3
P_VEN	2.6	-1.5	-1.5	-1.5	-1.5	-2.7	-2.7	-2.7	-2.7
P_POL	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_UKR	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_KAZ	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_RUS	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_ZAF	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_North	3.0	-1.0	-1.0	-1.0	-1.0	-2.0	-2.0	-2.0	-2.0
P_IND_Orissa	2.7	-1.5	-1.5	-1.5	-1.5	-2.6	-2.6	-2.6	-2.6
P_IND_West	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_South	2.7	-1.5	-1.5	-1.5	-1.5	-2.6	-2.6	-2.6	-2.6
P_VNM	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IDN	2.4	-1.2	-1.2	-1.2	-1.2	-2.5	-2.5	-2.5	-2.5
P_CHN_SIS	1.7	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6
P_CHN_Northeast	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_HSA	2.4	-0.8	-0.8	-0.8	-0.8	-1.2	-1.2	-1.2	-1.2
P_CHN_YG	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_XJ	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_AUS_QLD	2.4	-1.7	-1.7	-1.7	-1.7	-3.0	-3.0	-3.0	-3.0
P_AUS_NSW	2.4	-1.3	-1.3	-1.3	-1.3	-3.0	-3.0	-3.0	-3.0
P_MNG	2.7	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
P_MOZ	2.7	-1.1	-1.1	-1.1	-1.1	-2.2	-2.2	-2.2	-2.2

Table 8D:

	Mnp-Mnp-Cons Production	Percent Coal Production Change in Mnp-Mnp-Open Counterfactual [(US Cftl./US Act.),(EU Cftl./EU Act.)] Gas Prices Are: (1,1)	(.5,1)	(.75,1)	(1.25,1)	(1,.5)	(.5,.5)	(.75,.5)	(1.25,.5)
P_USA_PRB	10794.4	5.6	-2.4	1.8	9.9	5.6	-2.4	1.8	9.9
P_USA_ILL	2106.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_USA_APP	5212.1	0.8	-7.1	-2.2	1.1	0.8	-7.1	-2.2	1.1
P_COL	1716.9	-0.6	-0.6	-0.6	-0.6	-4.2	-4.2	-4.2	-4.2
P_VEN	257.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_POL	1474.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_UKR	1000.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_KAZ	1890.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_RUS	3129.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_ZAF	1867.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_North	4700.2	-1.2	-1.2	-1.2	-1.2	-2.2	-2.2	-2.2	-2.2
P_IND_Orissa	1454.2	-1.4	-1.4	-1.4	-1.4	-2.7	-2.7	-2.7	-2.7
P_IND_West	1877.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IND_South	920.6	-2.8	-2.8	-2.8	-2.8	-5.4	-5.4	-5.4	-5.4
P_VNM	519.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_IDN	5959.1	-2.2	-2.2	-2.2	-2.2	-4.3	-4.3	-4.3	-4.3
P_CHN_SIS	25054.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9
P_CHN_Northeast	3110.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_HSA	5755.1	-2.1	-2.1	-2.1	-2.1	-4.3	-4.3	-4.3	-4.3
P_CHN_YG	2732.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_CHN_XJ	194.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
P_AUS_QLD	1613.5	-2.7	-2.7	-2.7	-2.7	-5.1	-5.1	-5.1	-5.1
P_AUS_NSW	1935.7	-1.7	-1.7	-1.7	-1.7	-3.4	-3.4	-3.4	-3.4
P_MNG	51.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_MOZ	30.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 1: Growth in Global Energy Supply 2000-2012 in MTOE



Source: International Energy Agency, 2014

Figure 2: World Coal Production in 2014 in MTOE

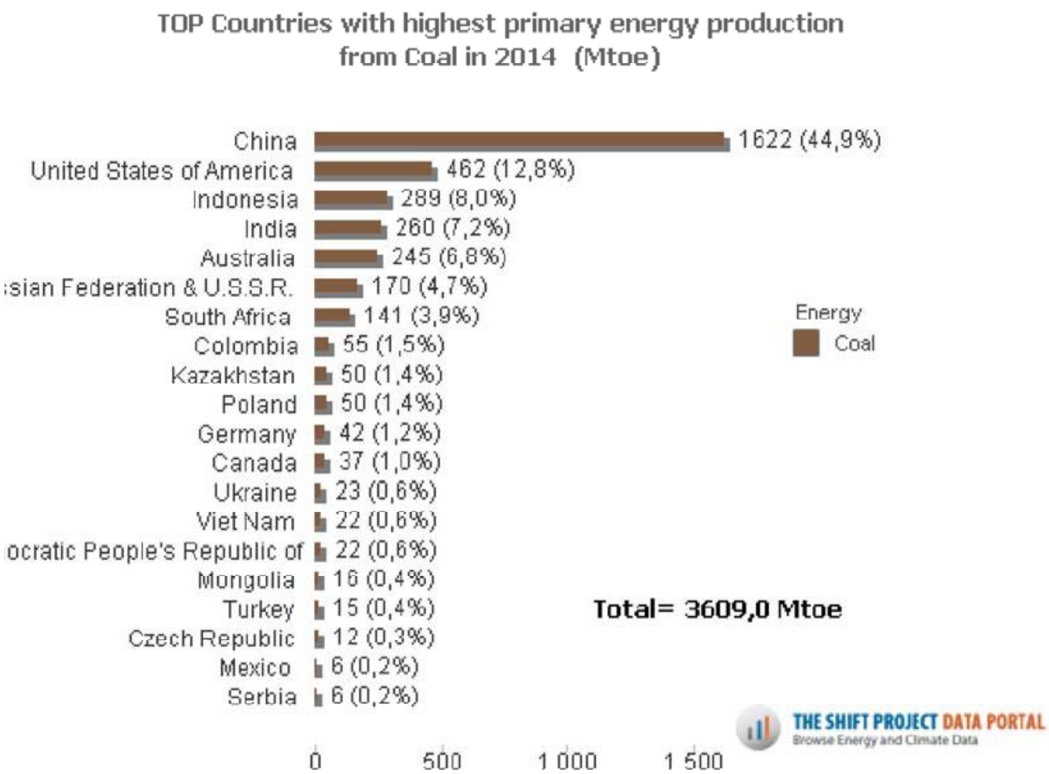


Figure 3: United States Electricity Supply Sources in 2014

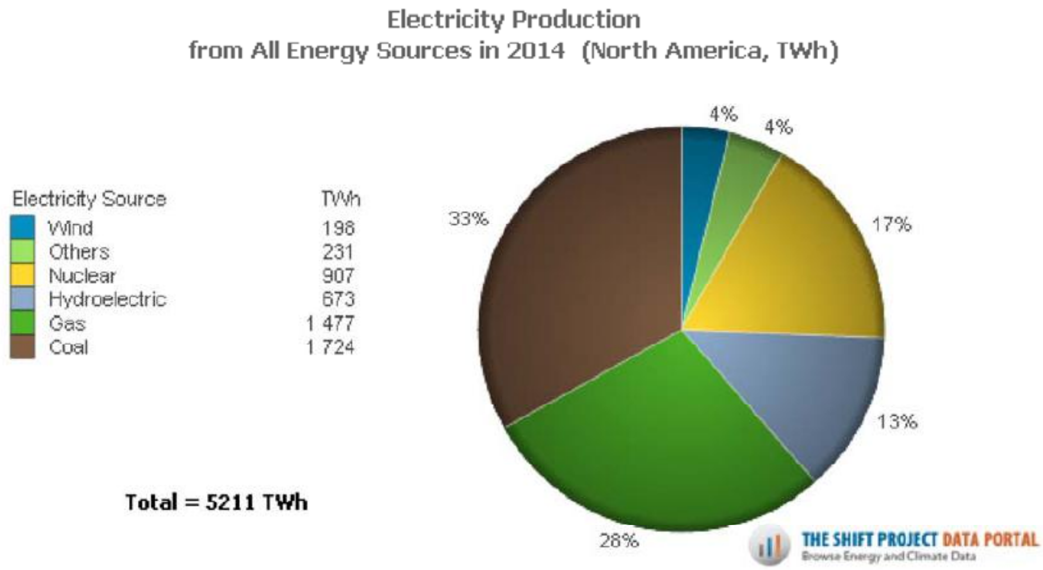


Figure 4: European Union Electricity Supply Sources in 2014

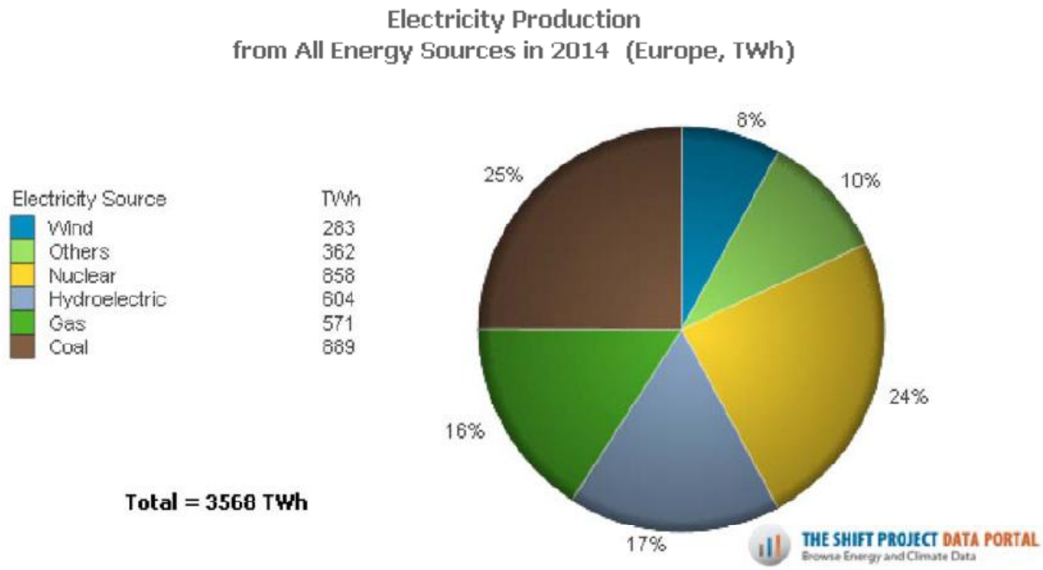


Figure 5: China Electricity Supply Sources in 2014

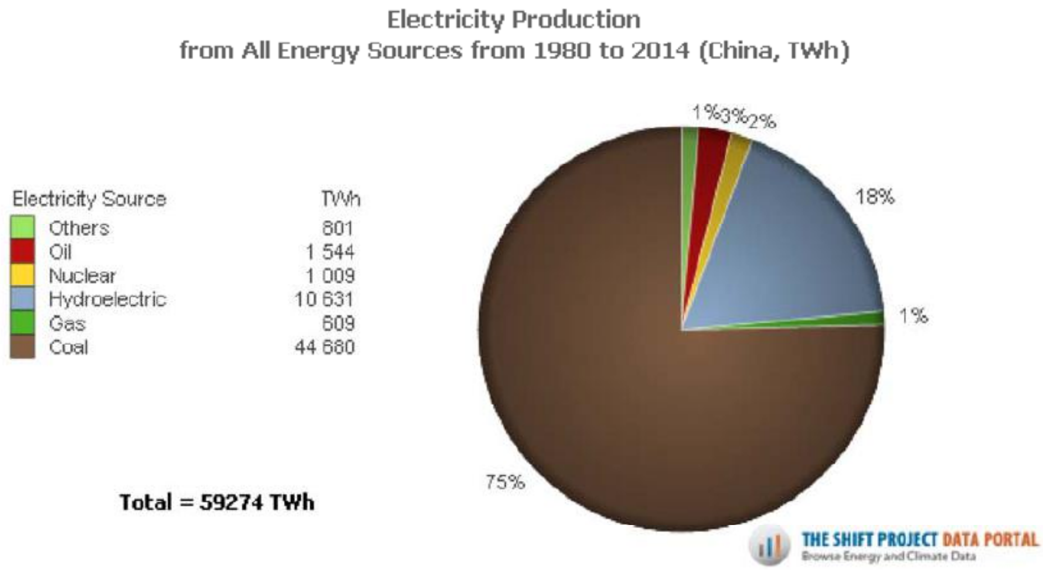
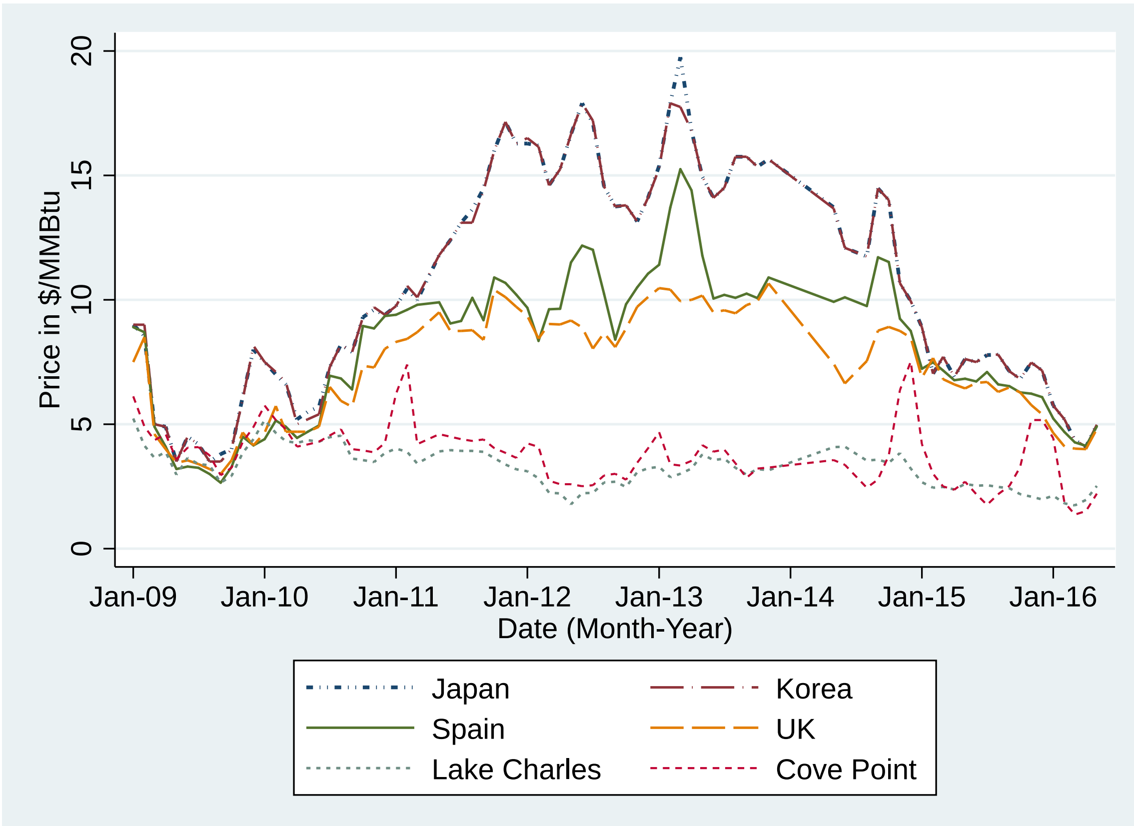


Figure 6: Global Landed LNG Prices in $/MMBTU from 2009 to 2016



Source: http://www.ferc.gov/market-oversight/mkt-gas/overview/archives.asp

Figure 7: Smoothing Step Function Marginal Cost Curve

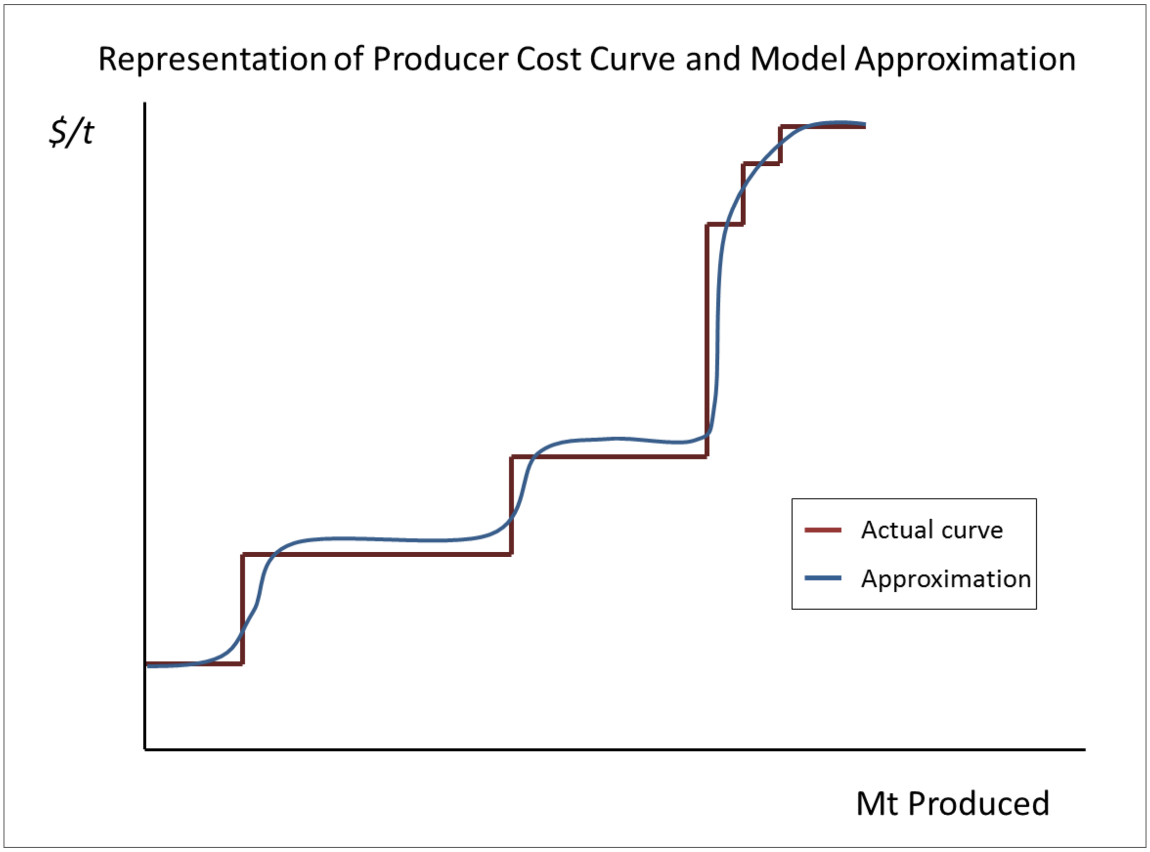


Figure 8: Exercising Monopsony Power Against Domestic Coal Suppliers

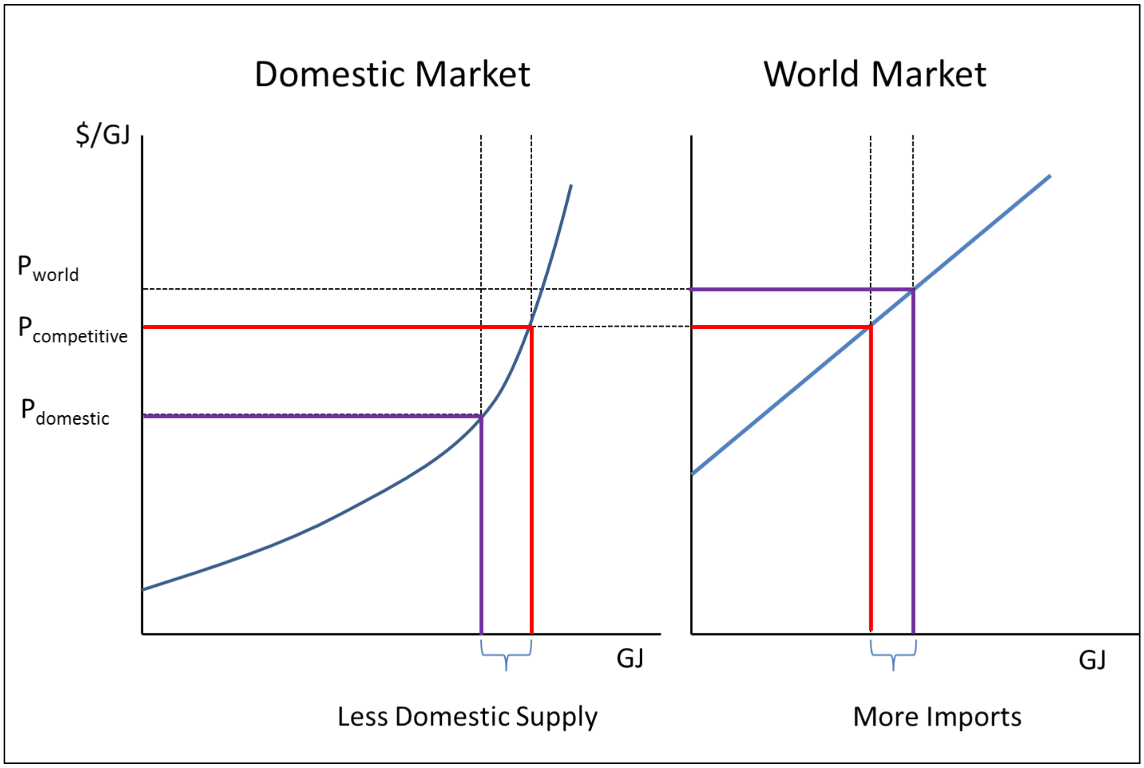
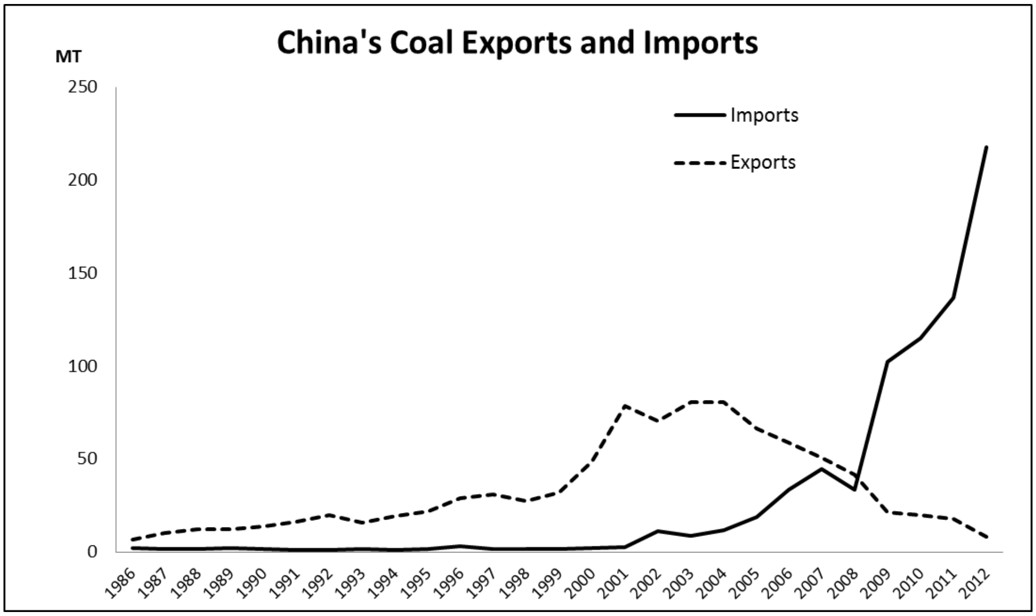


Figure 9: Chinese Coal Imports, Exports and Export Permits in Millions of Tonnes (MT)



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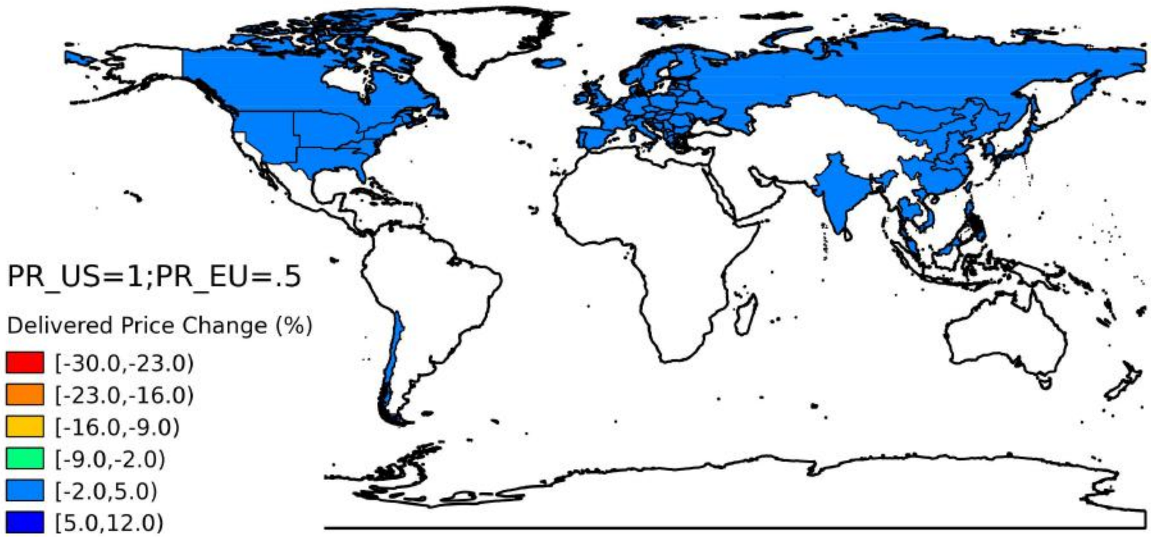

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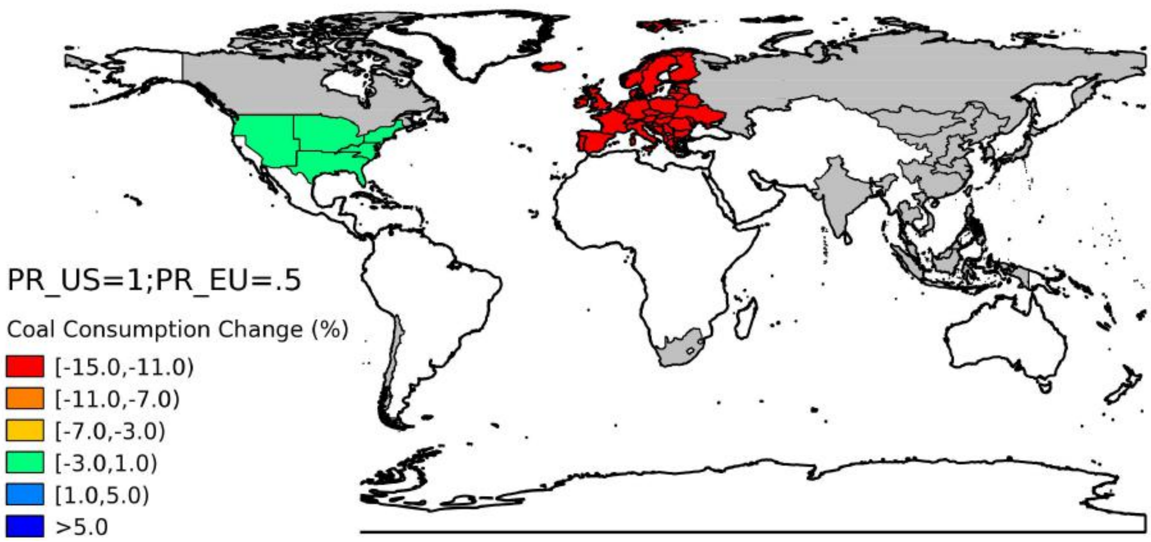

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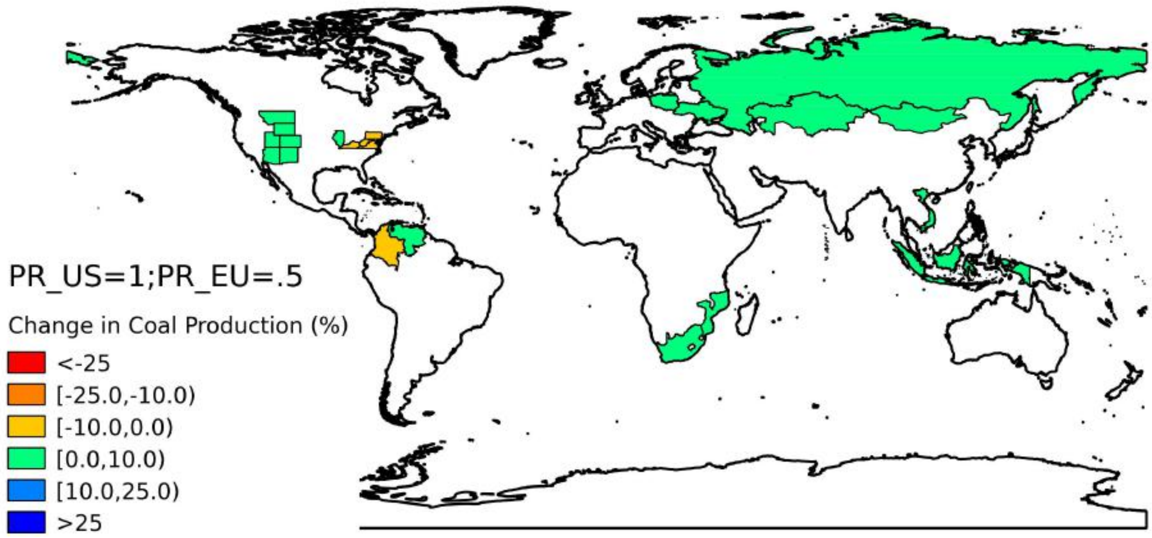

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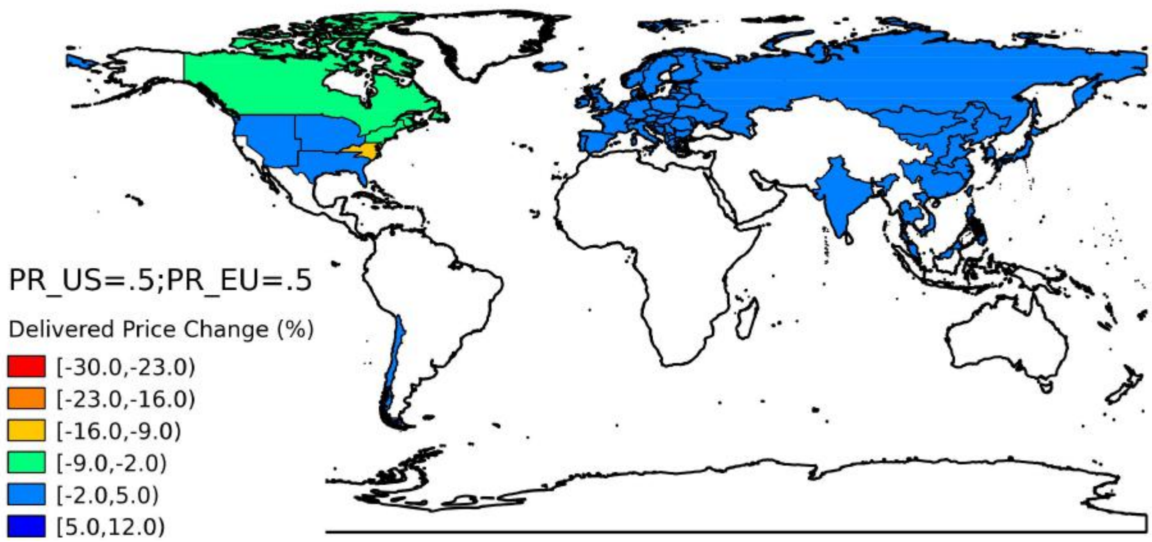

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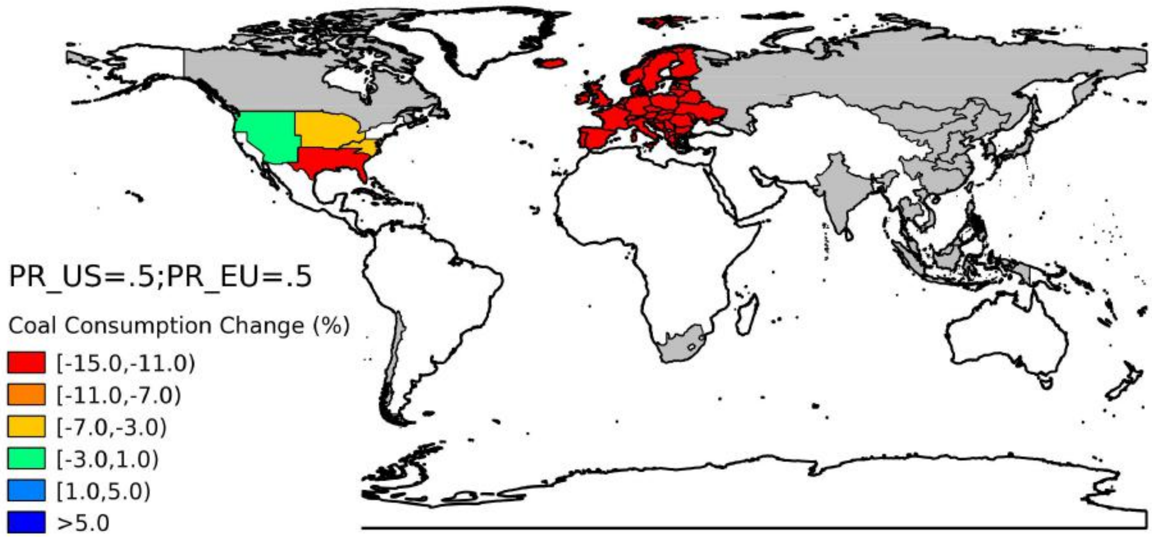

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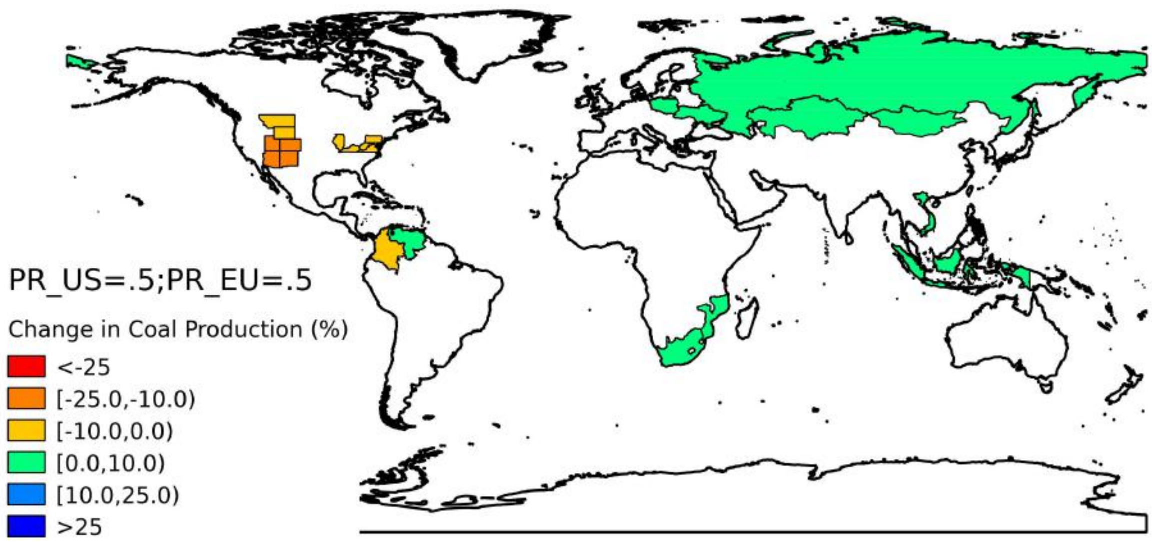

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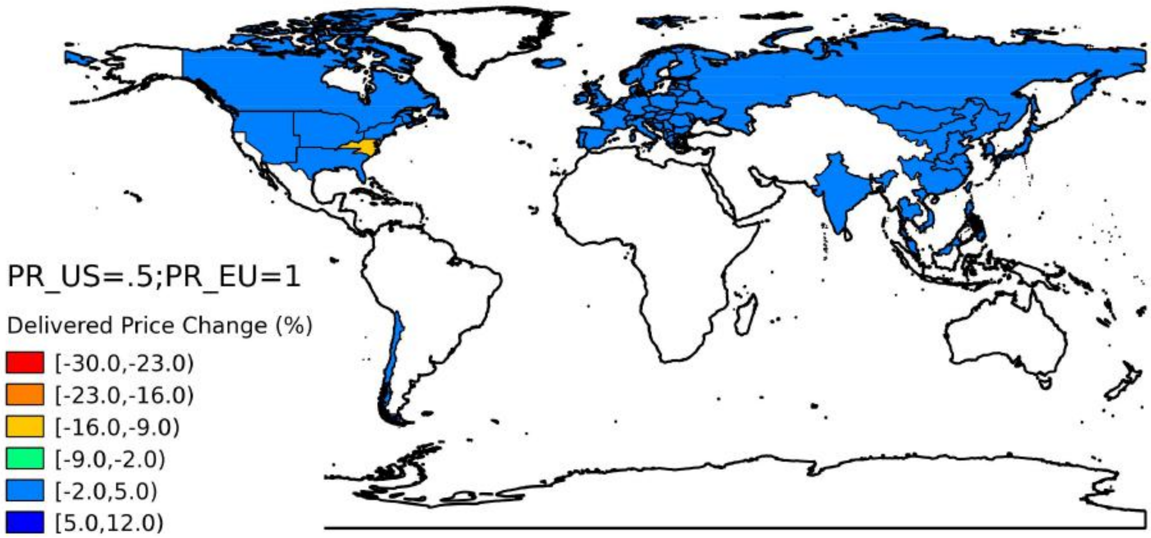

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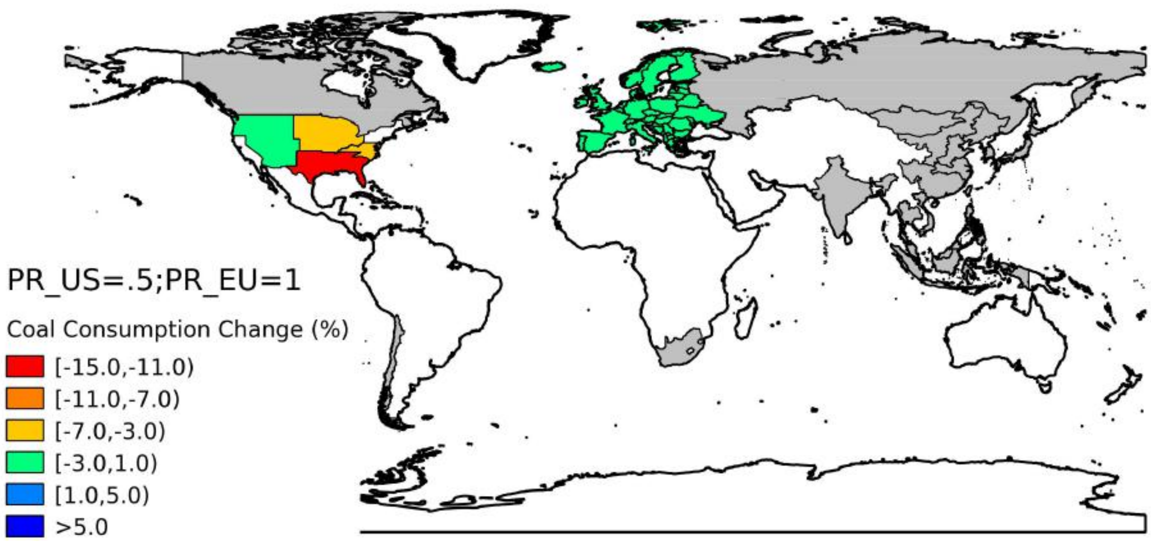

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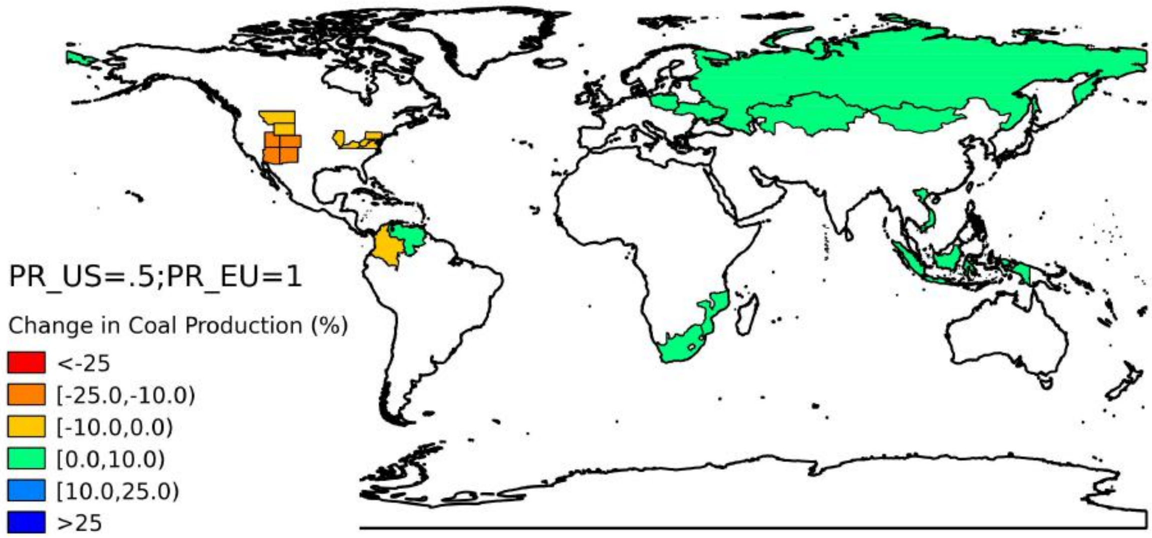

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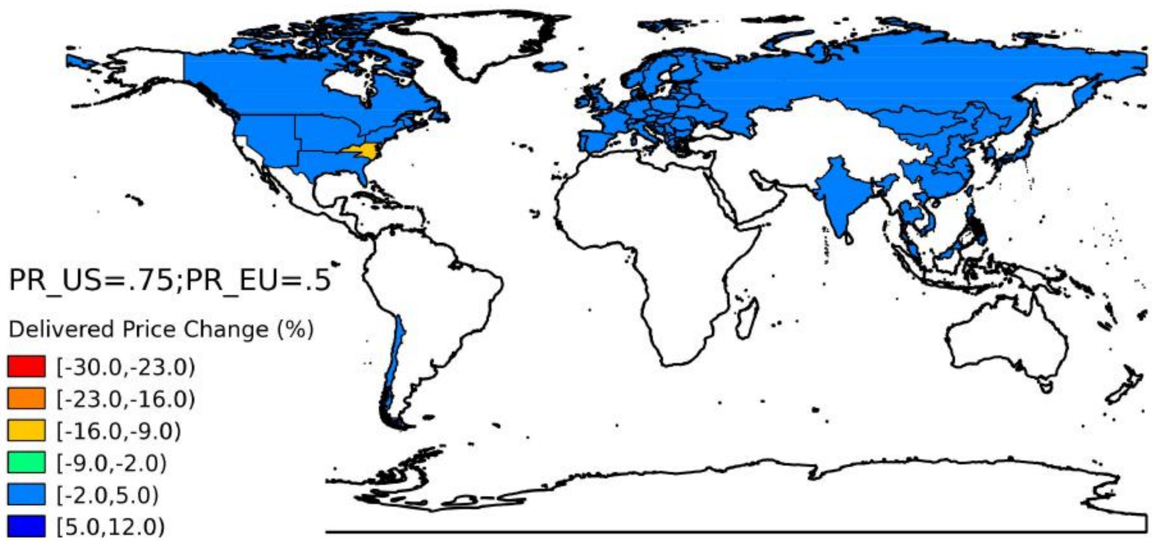

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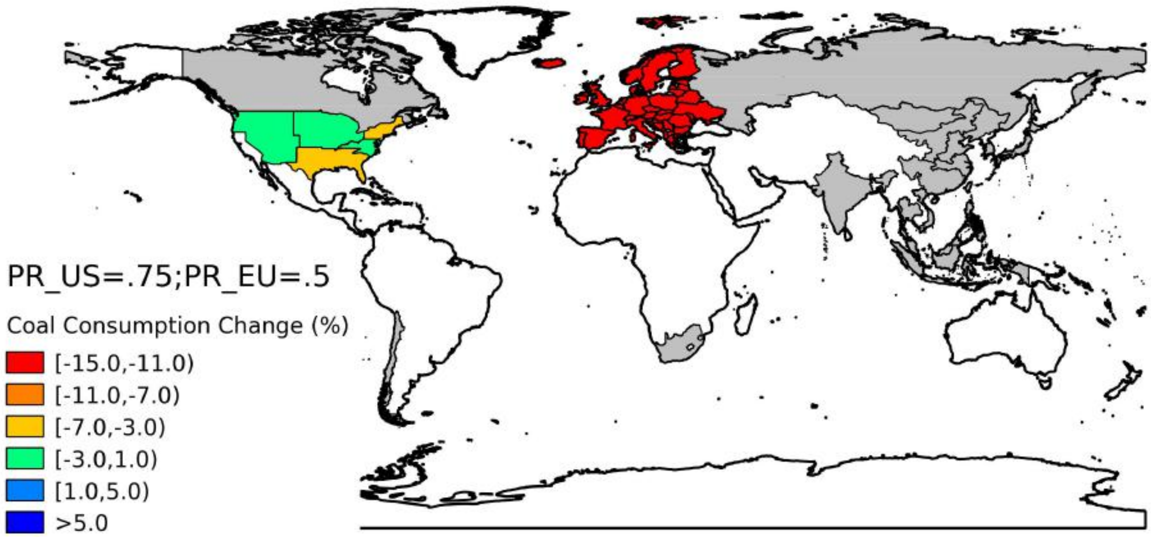

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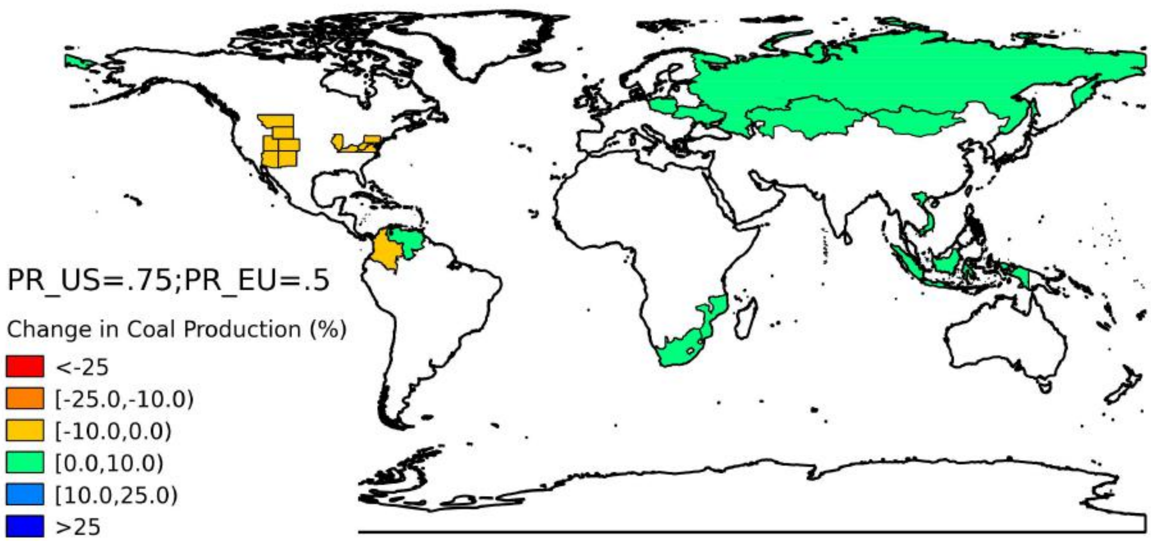

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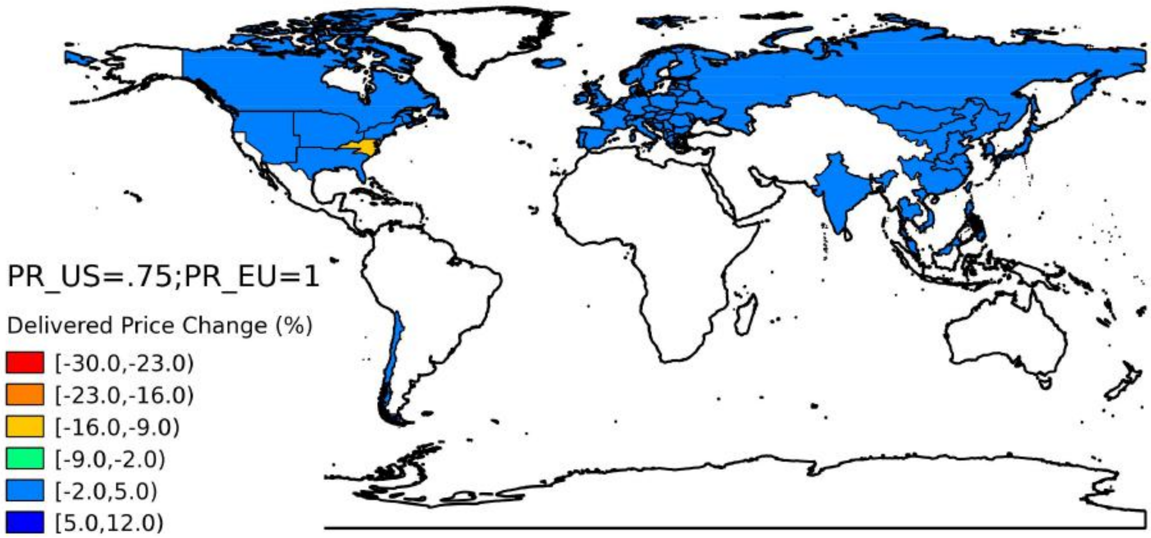

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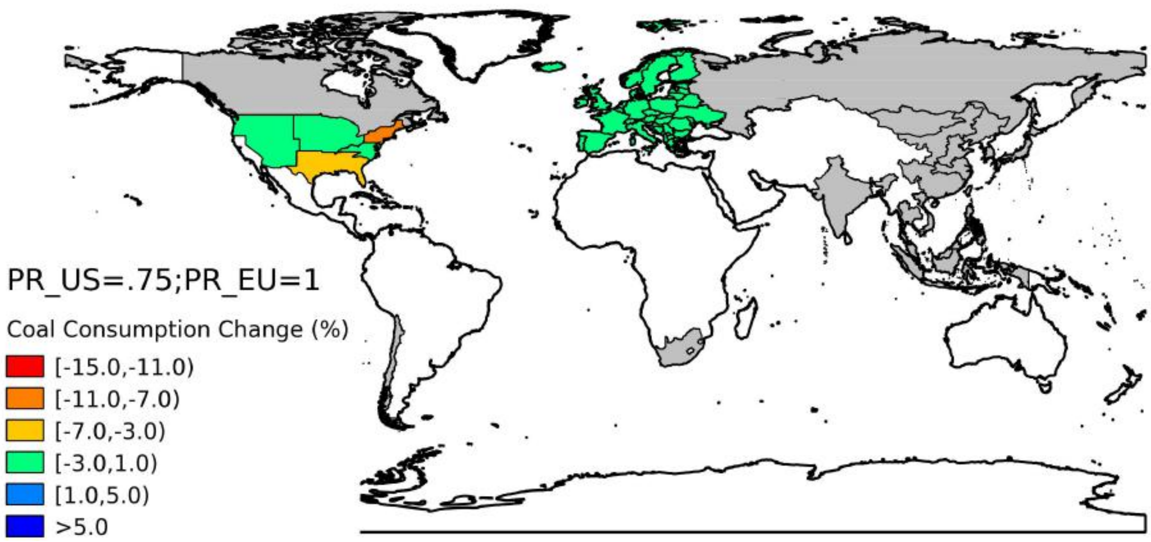

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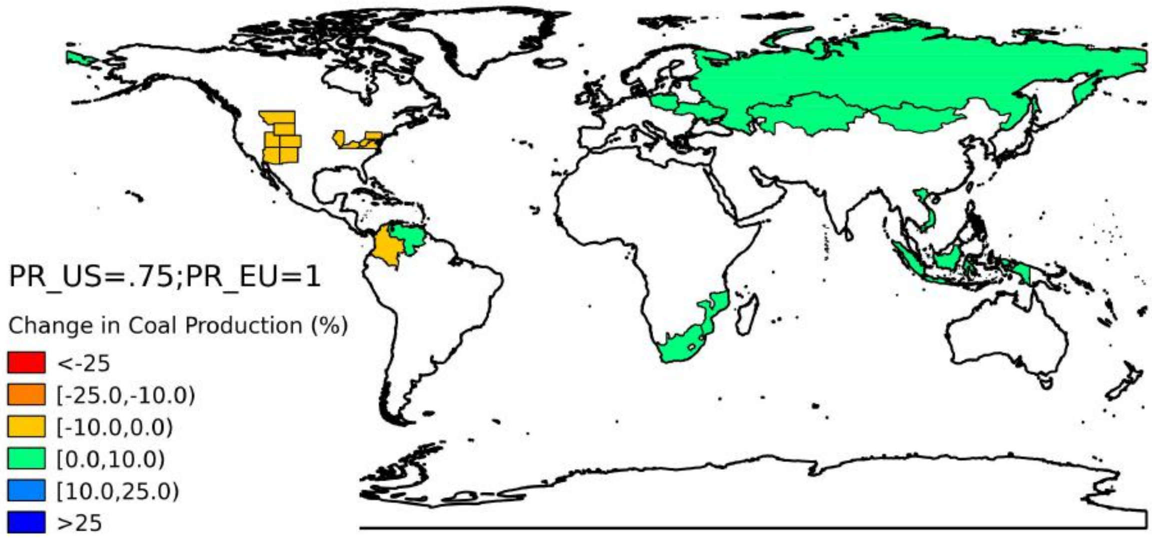

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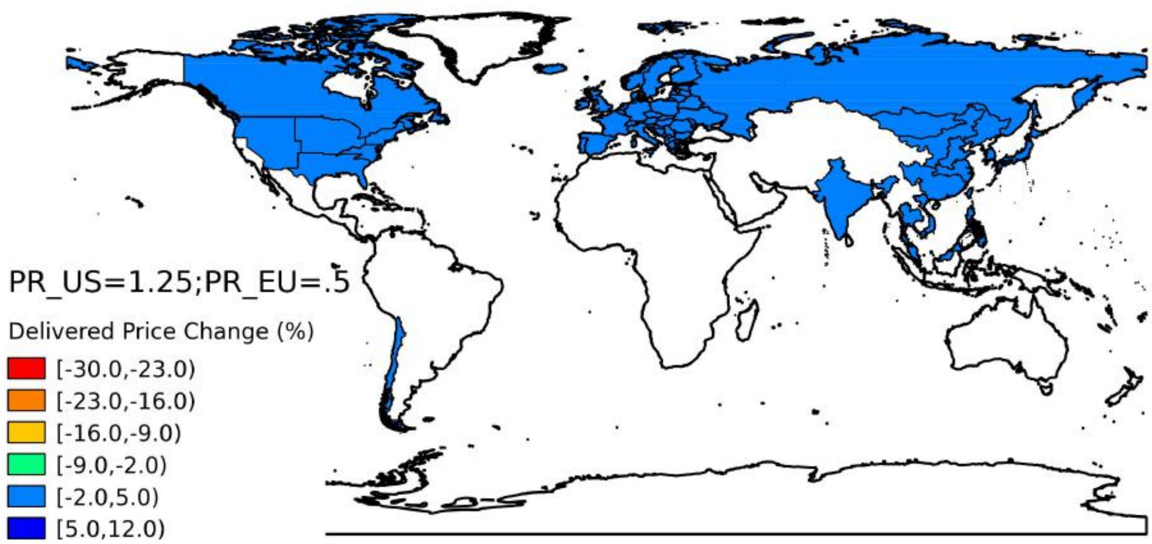

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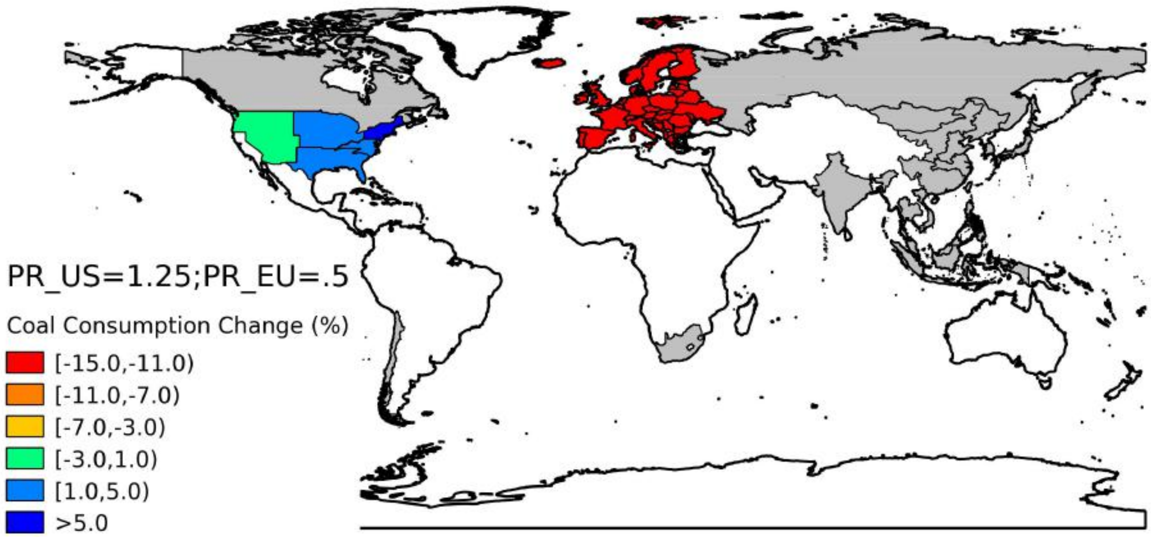

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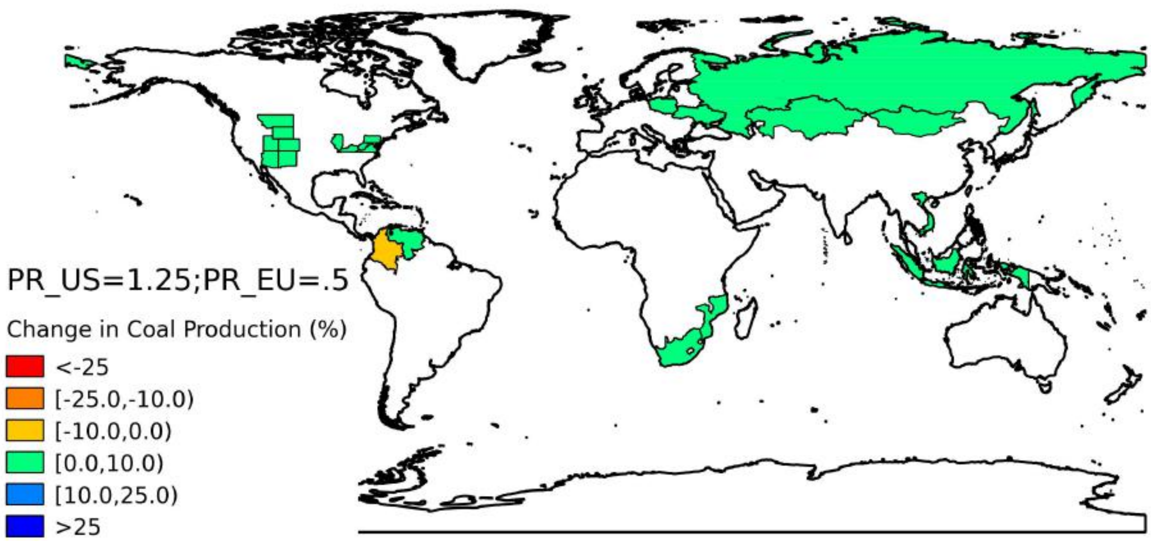

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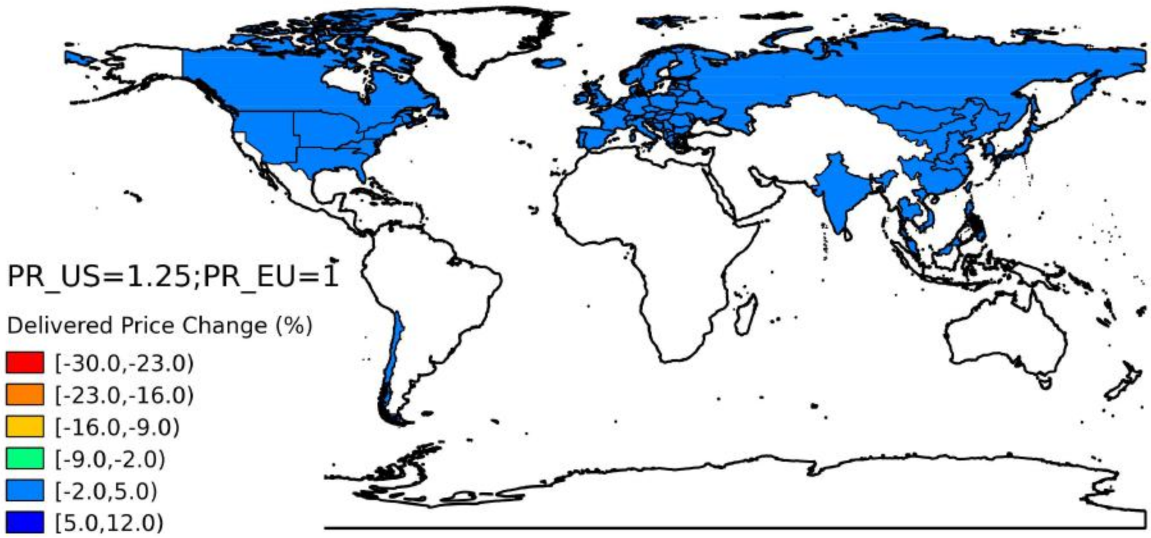

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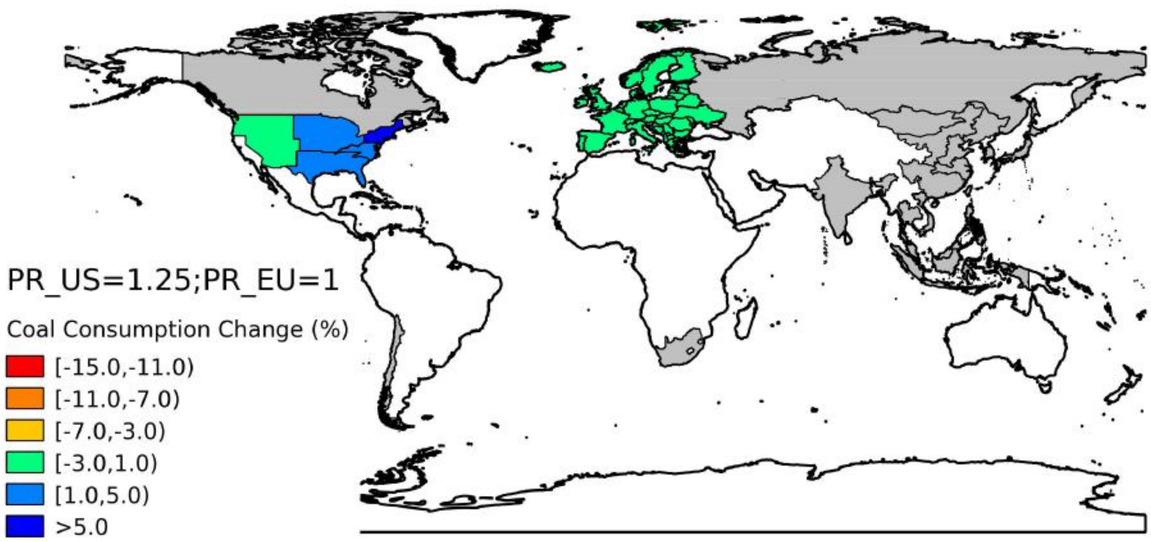

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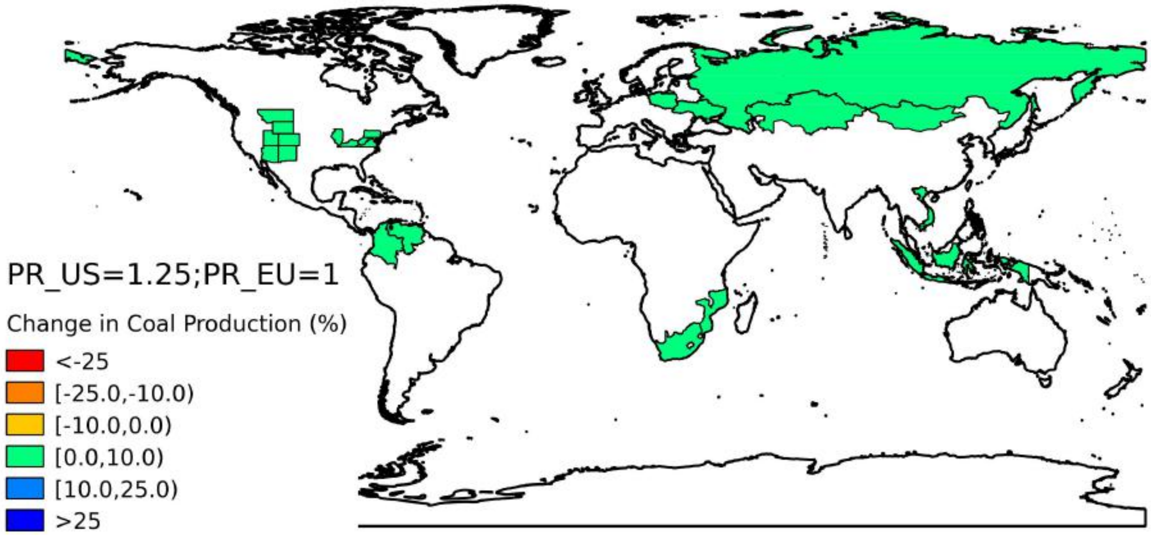

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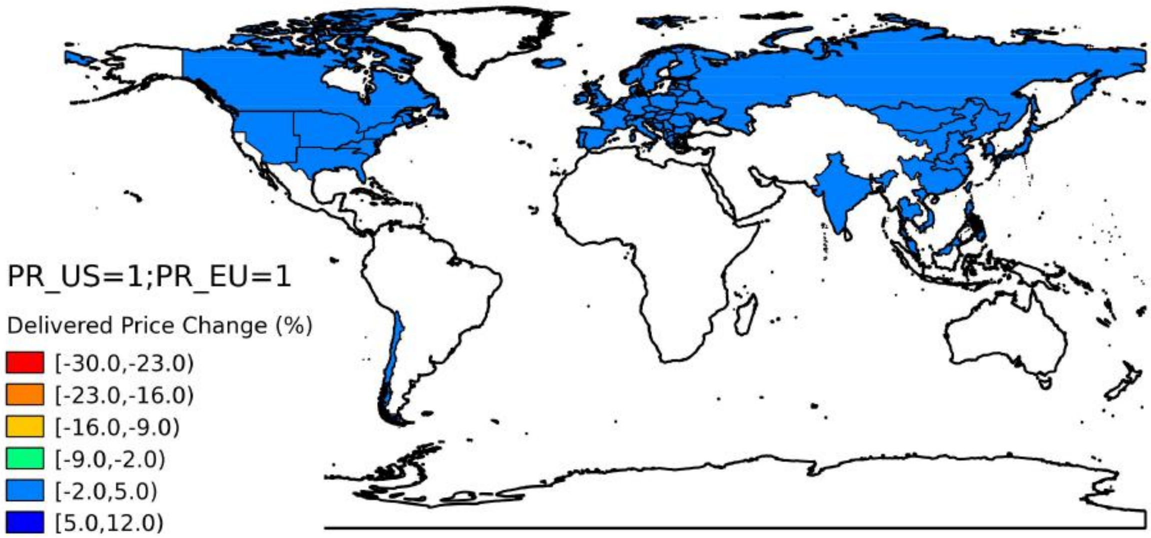

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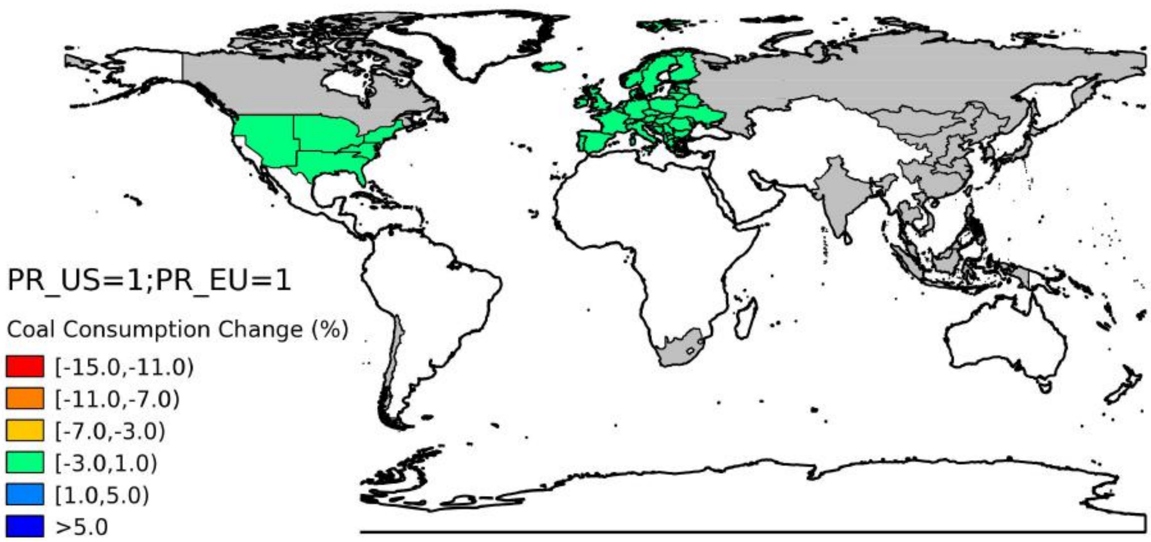

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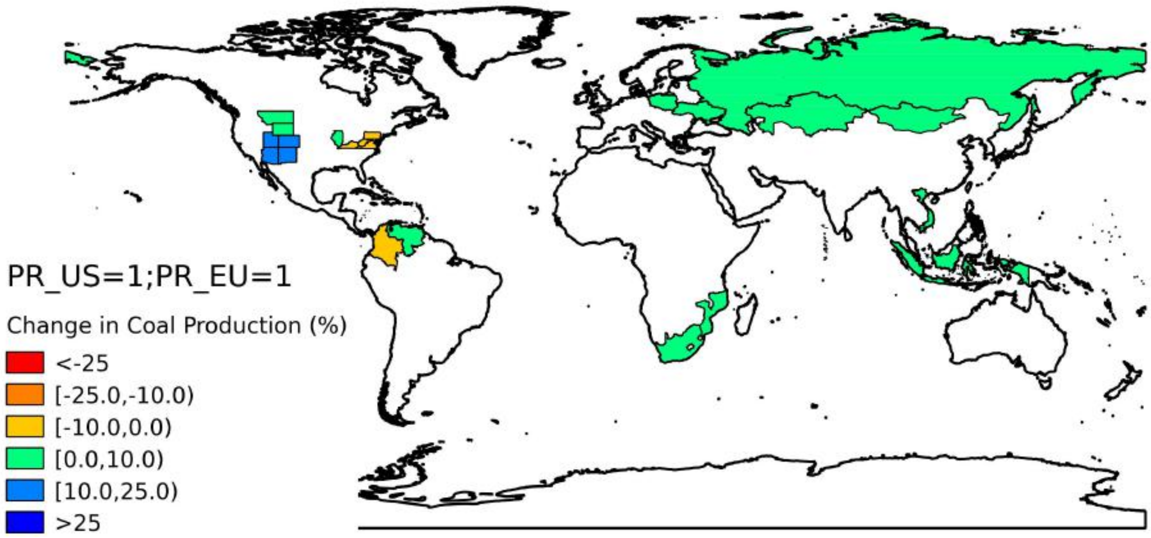

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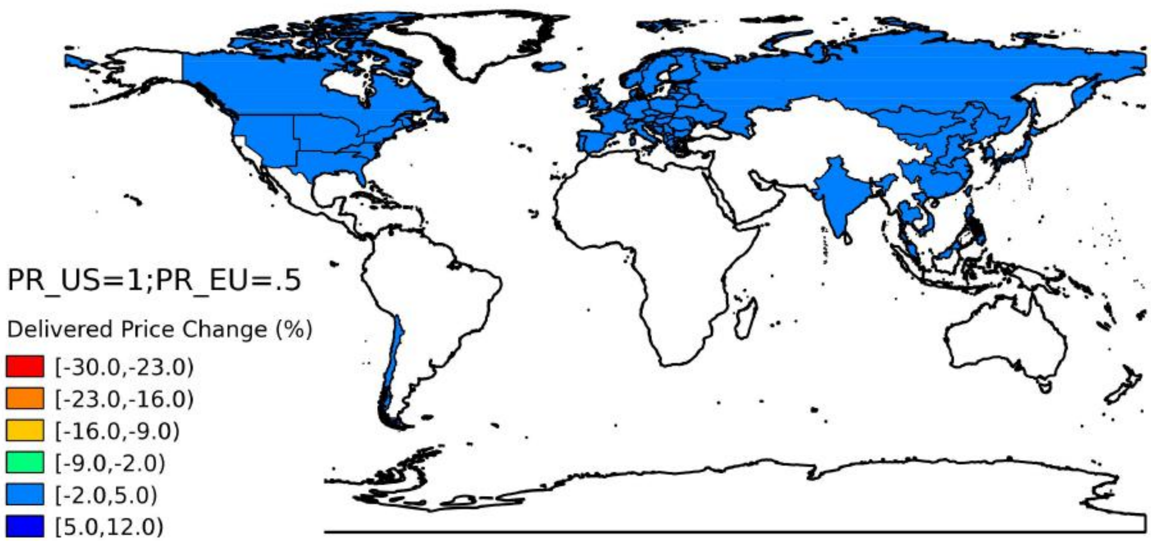

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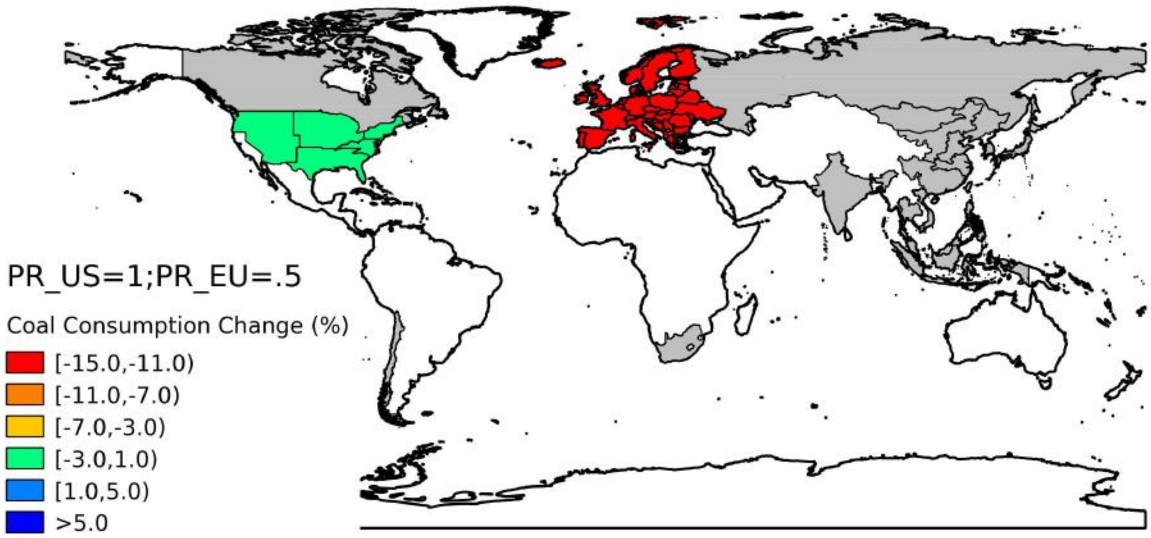

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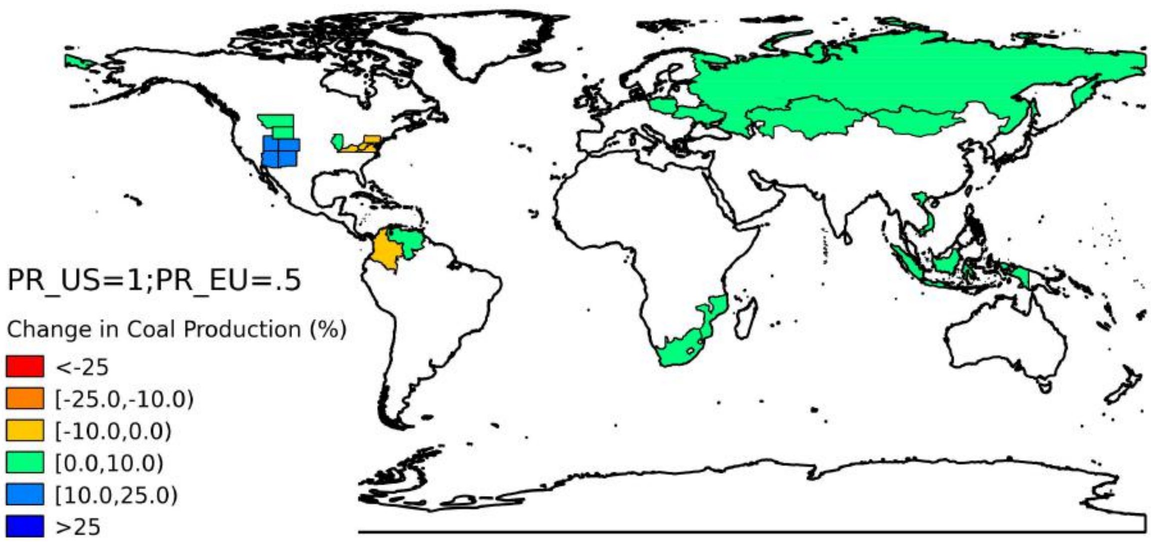

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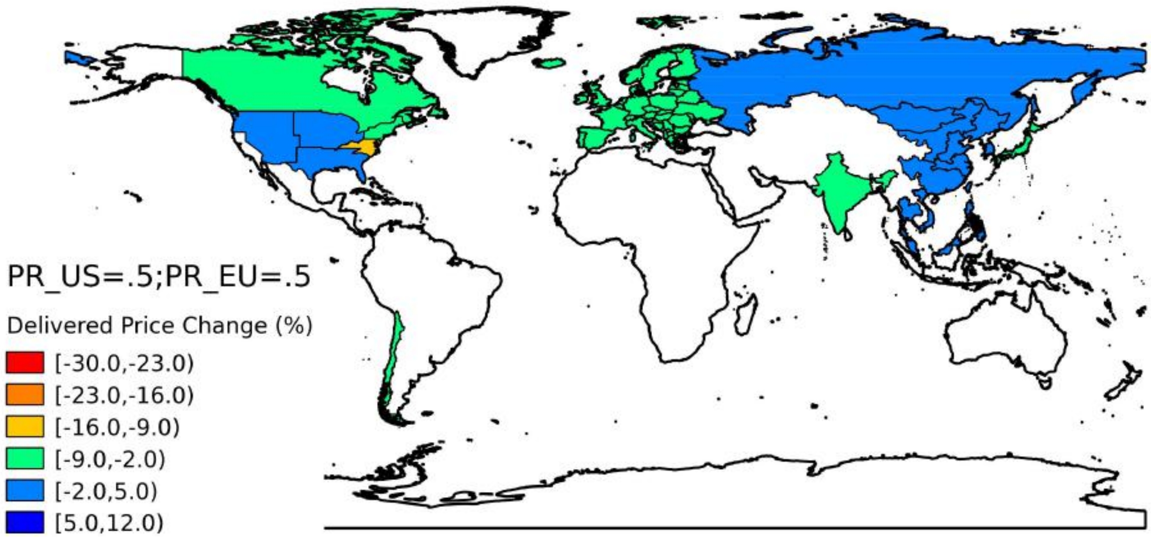

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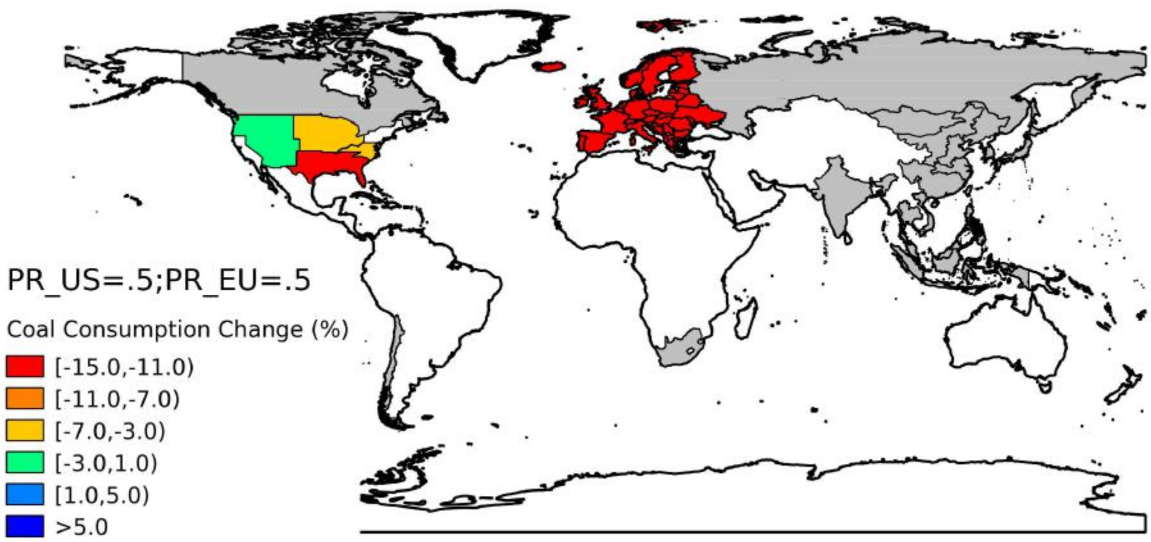

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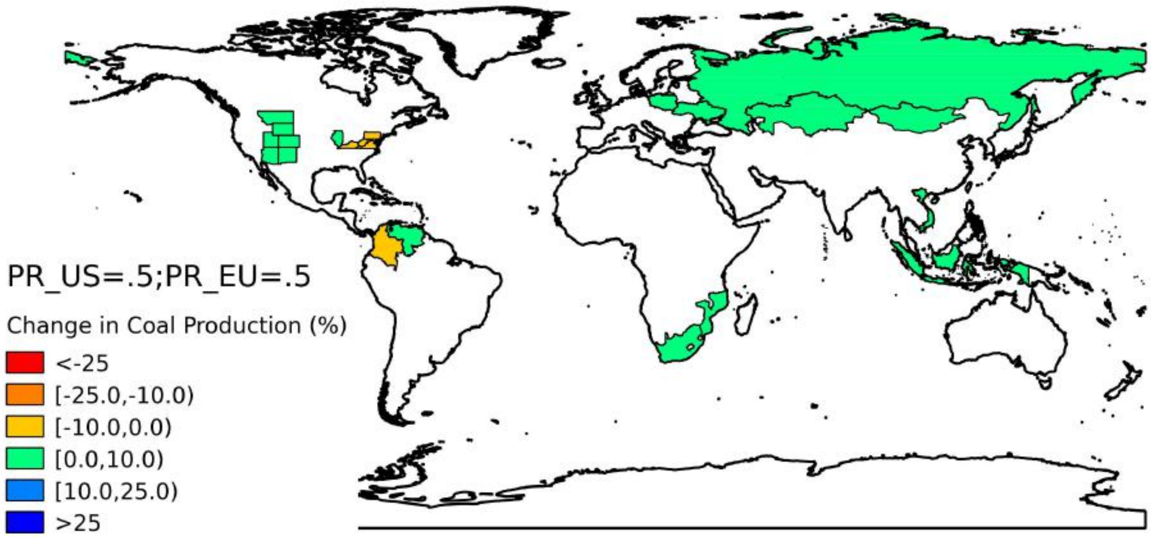

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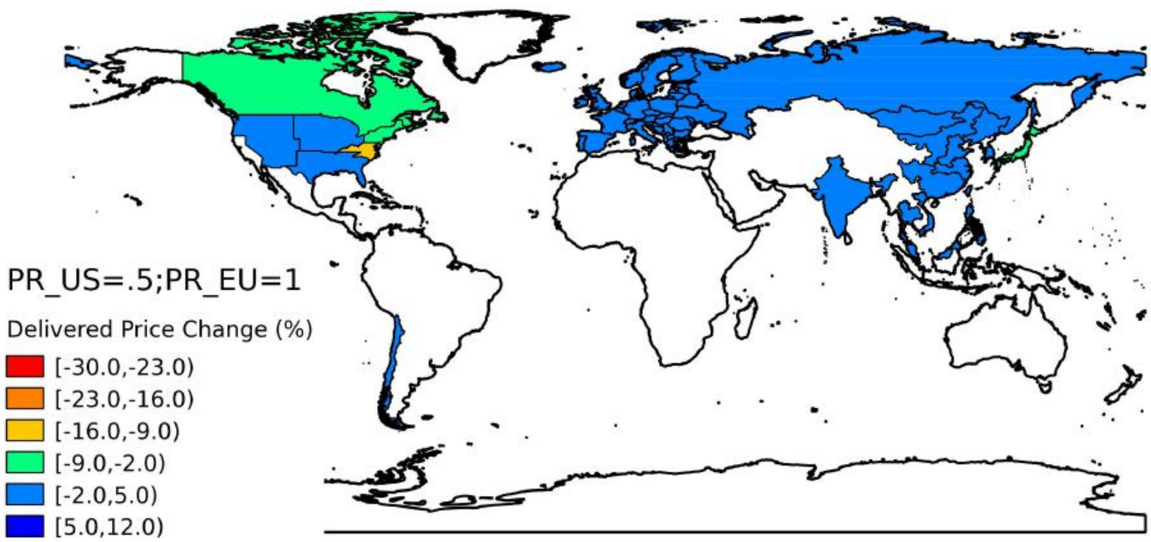

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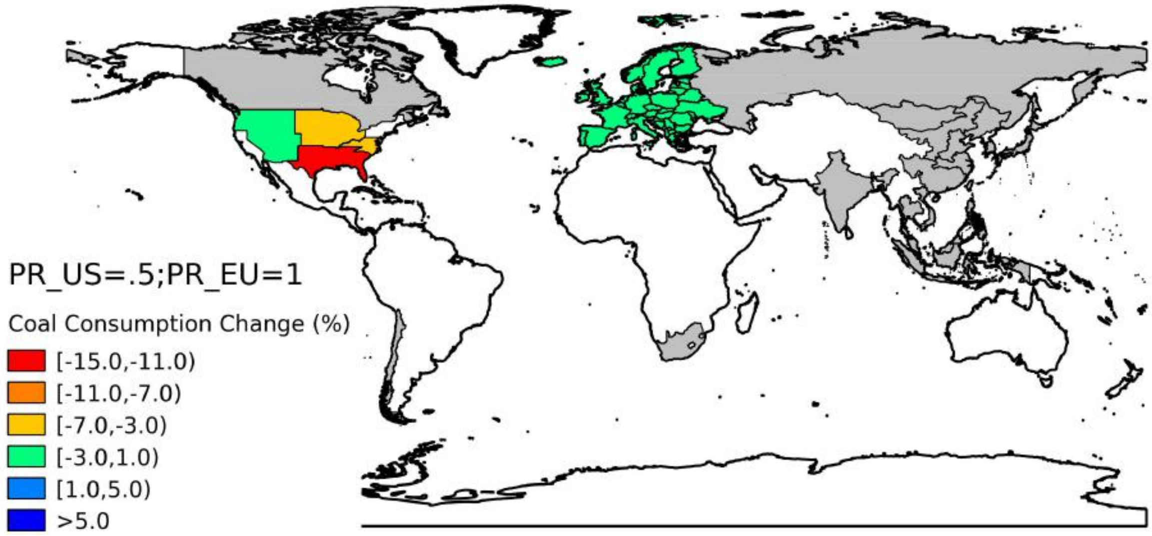

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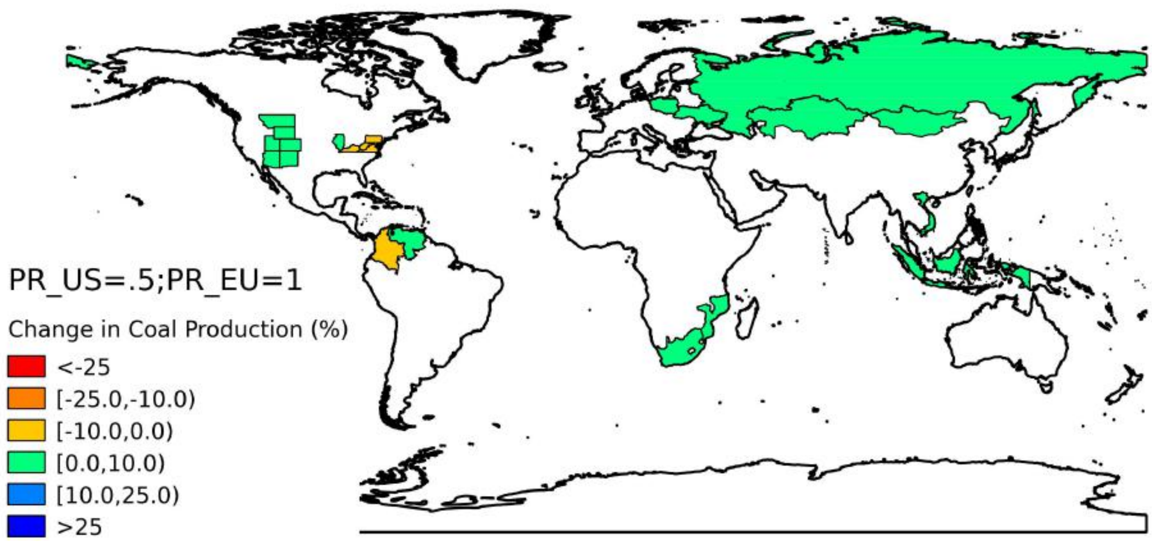

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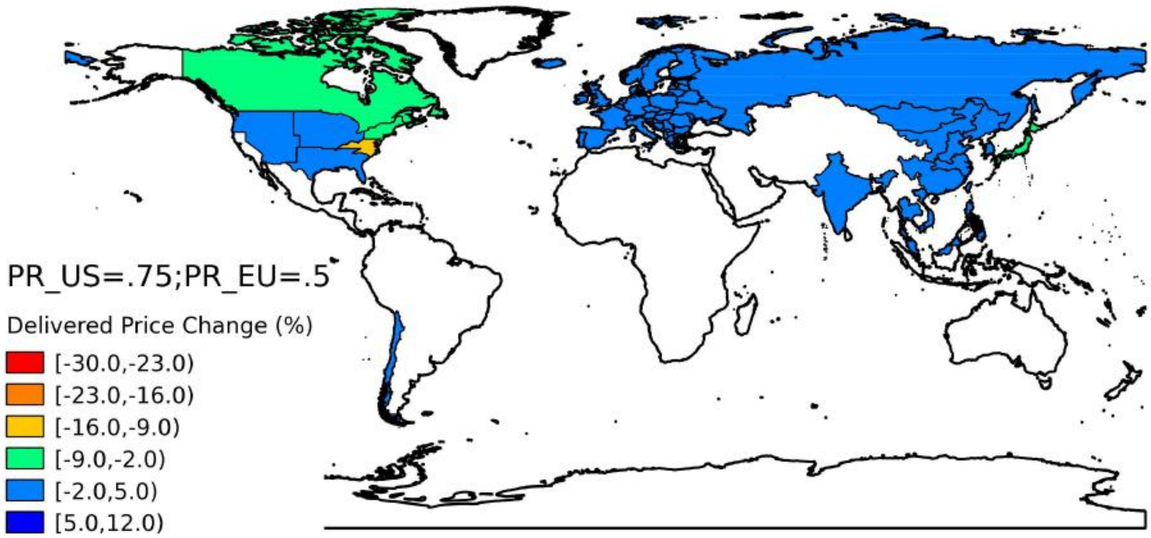

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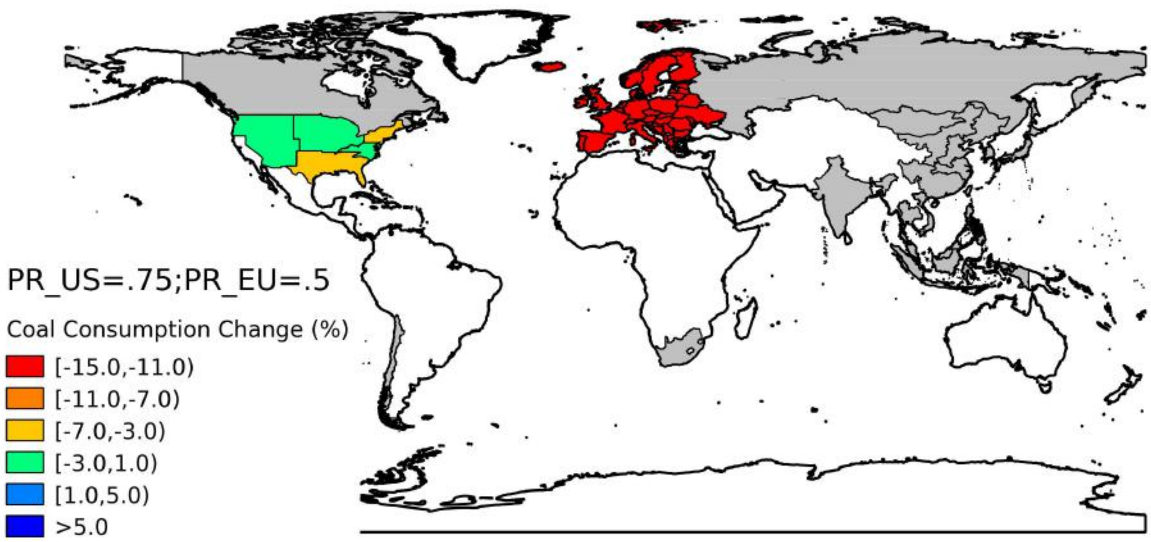

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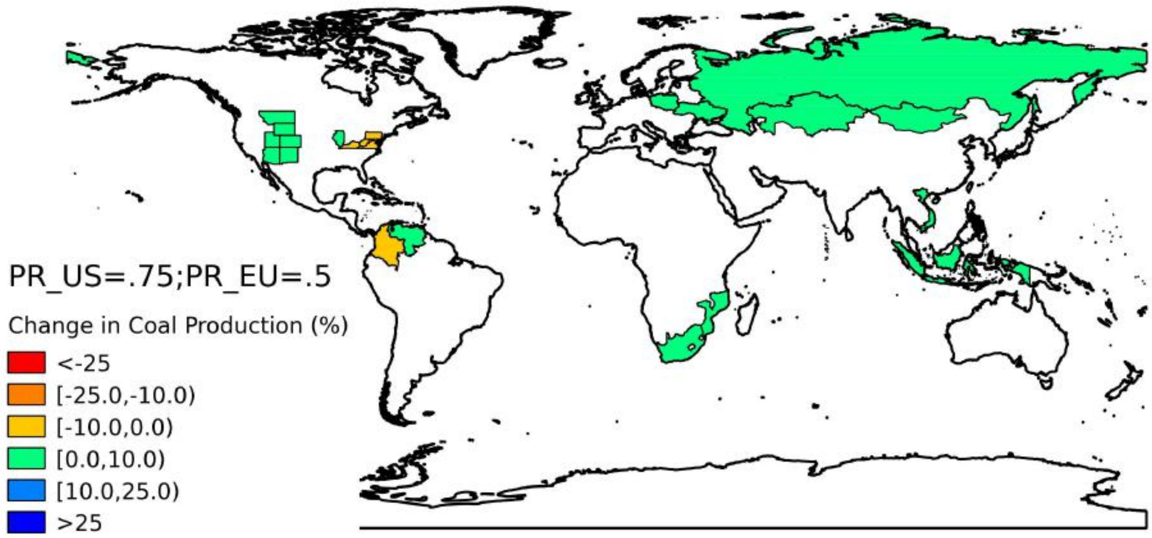

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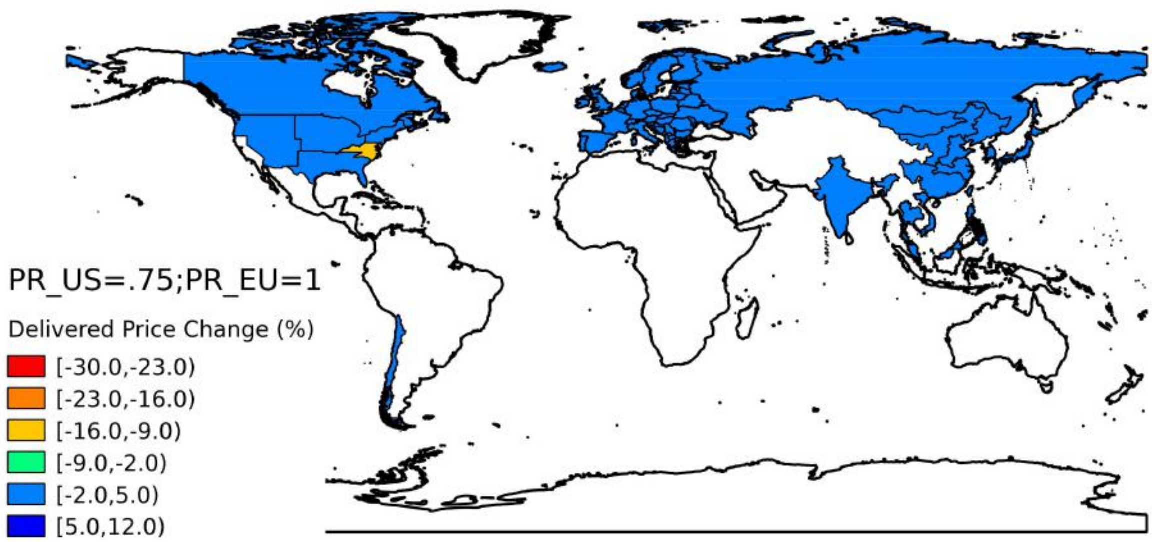

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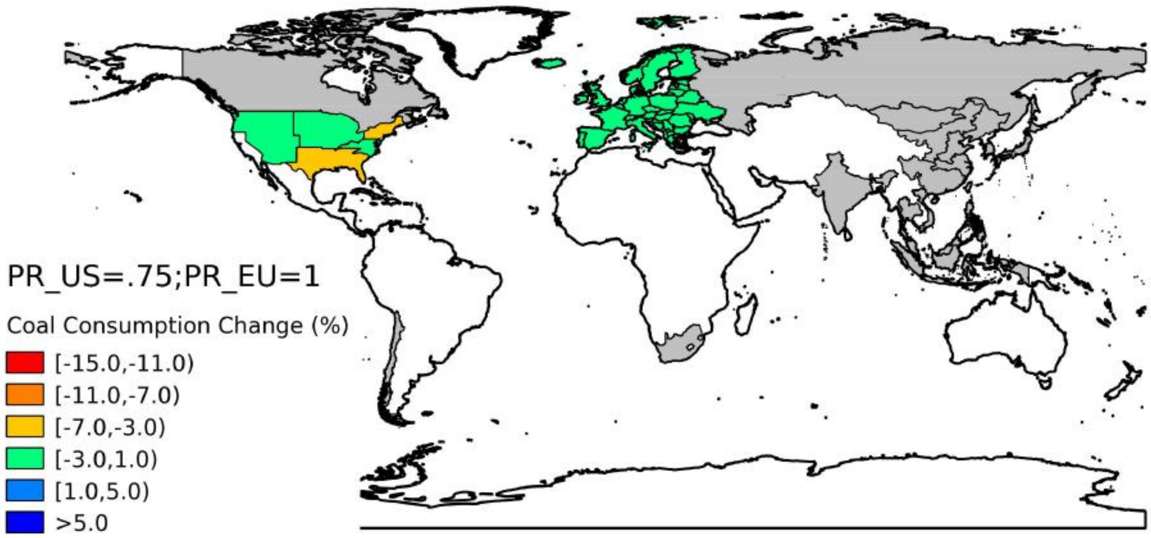

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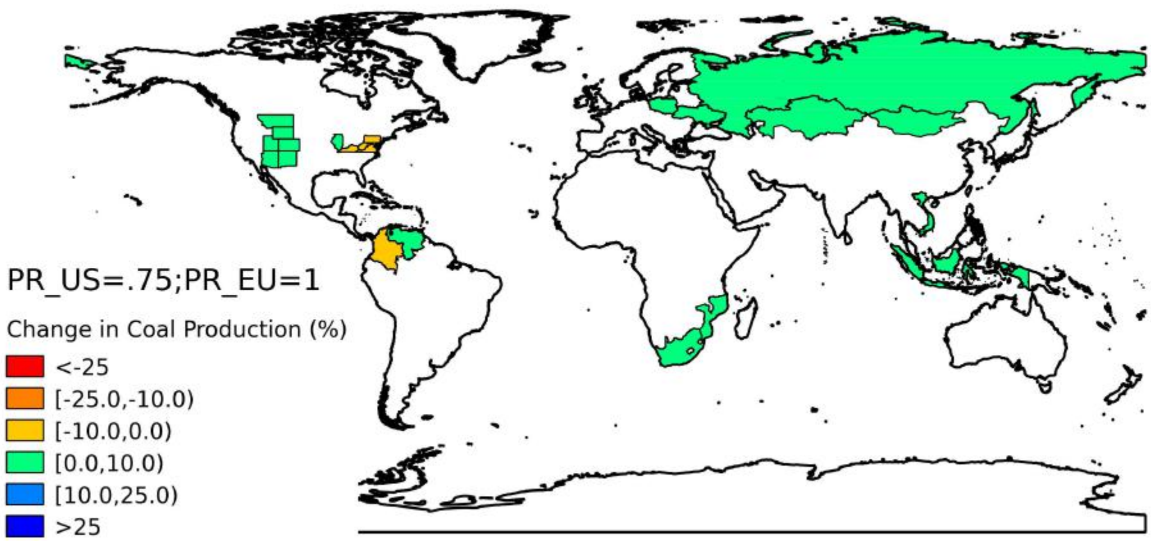

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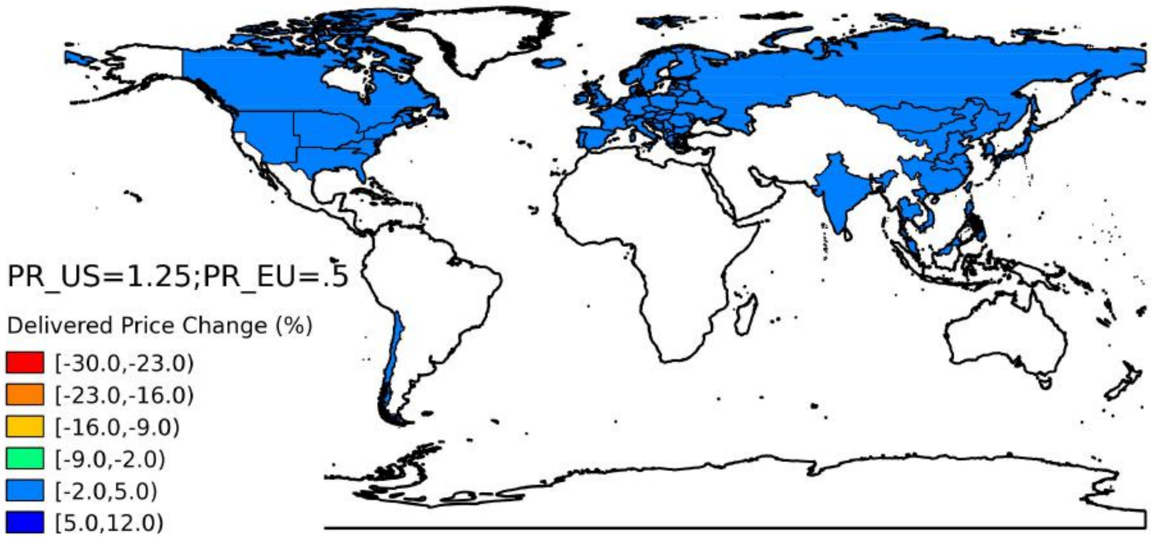

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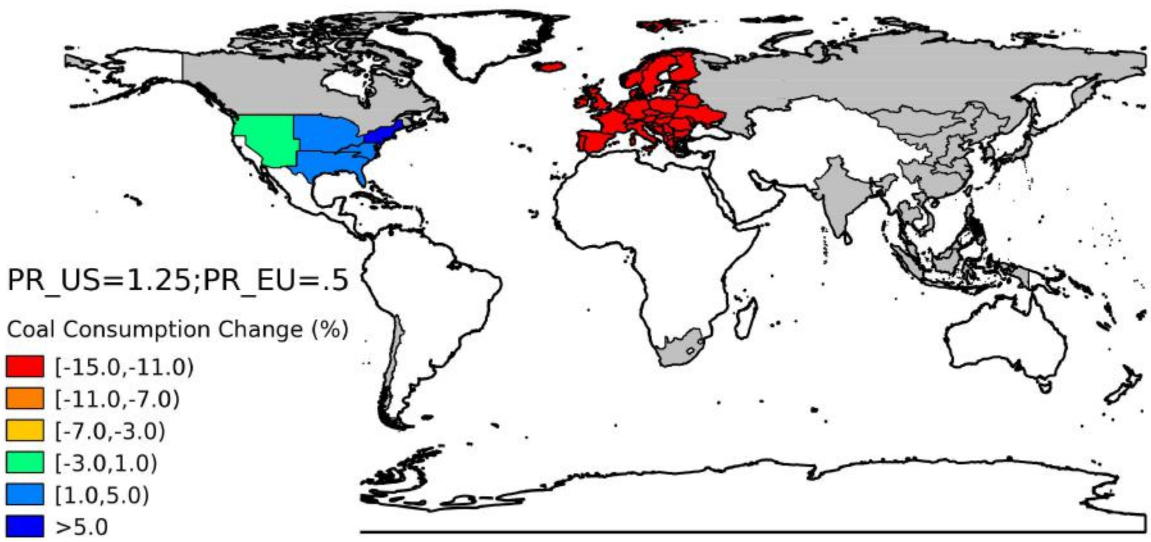

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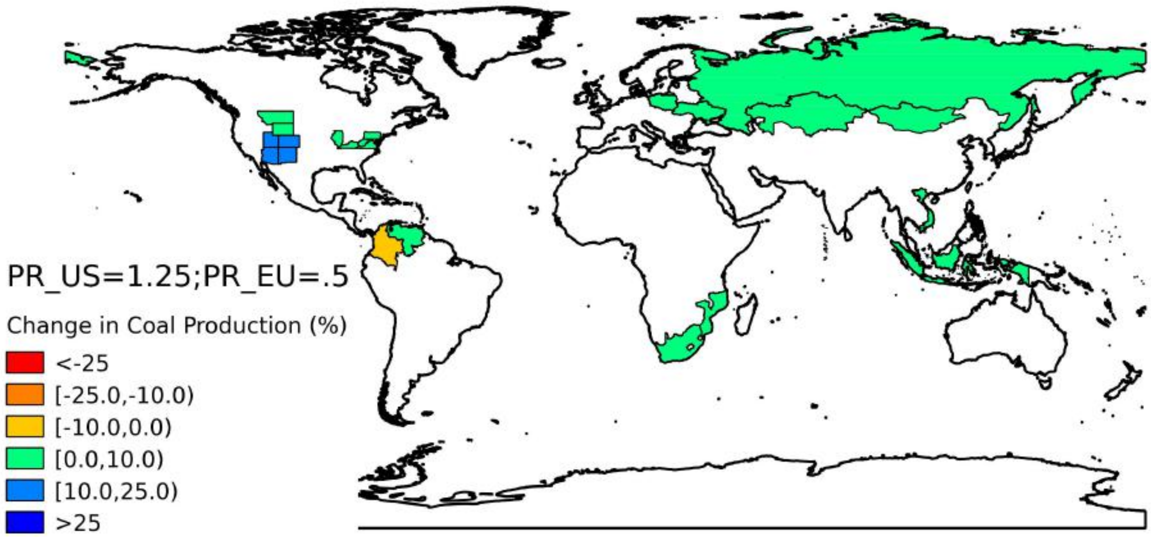

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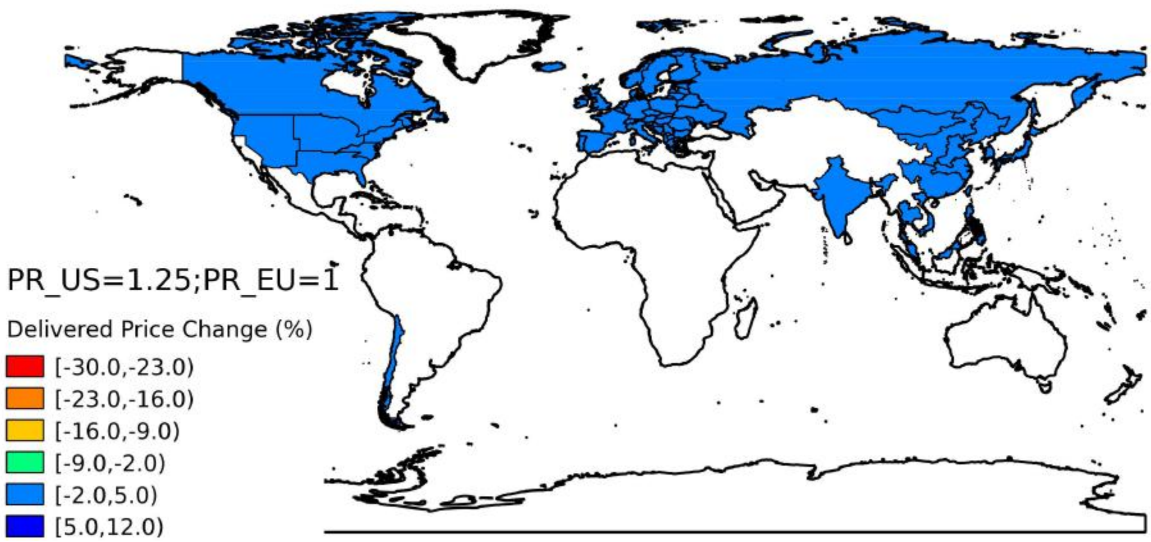

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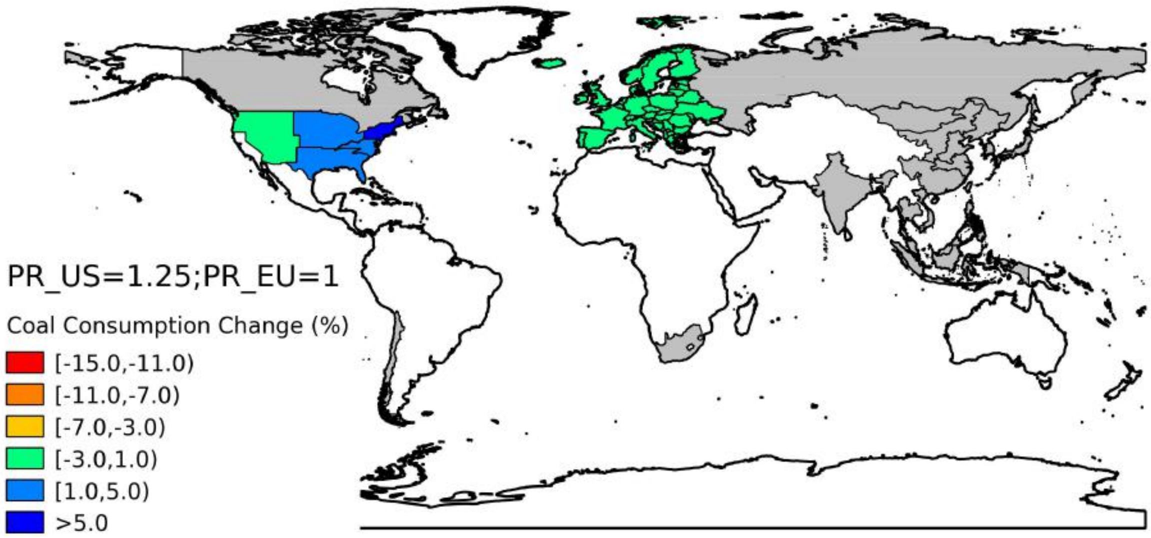

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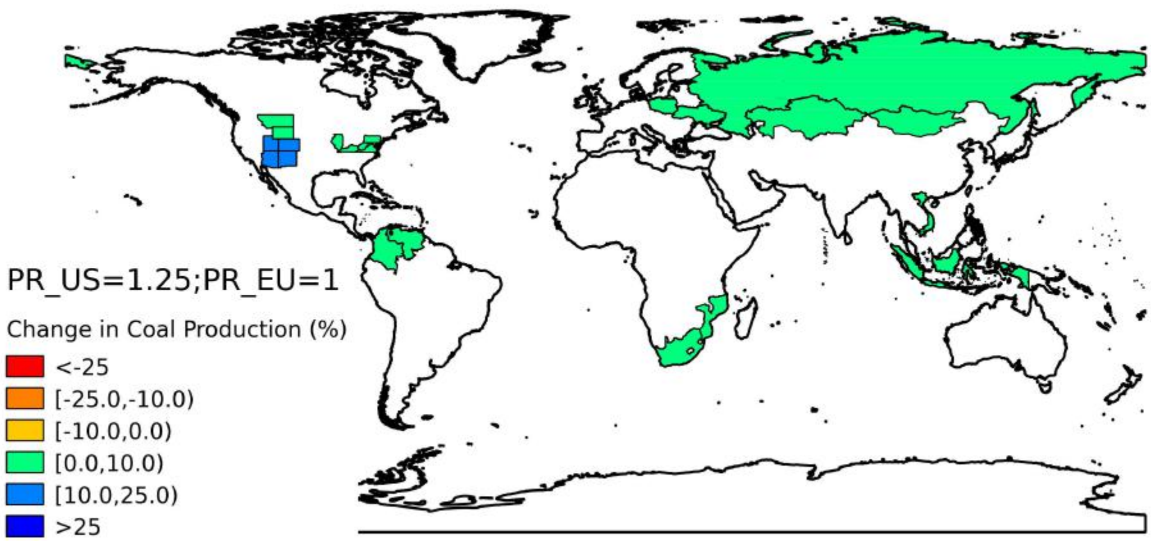

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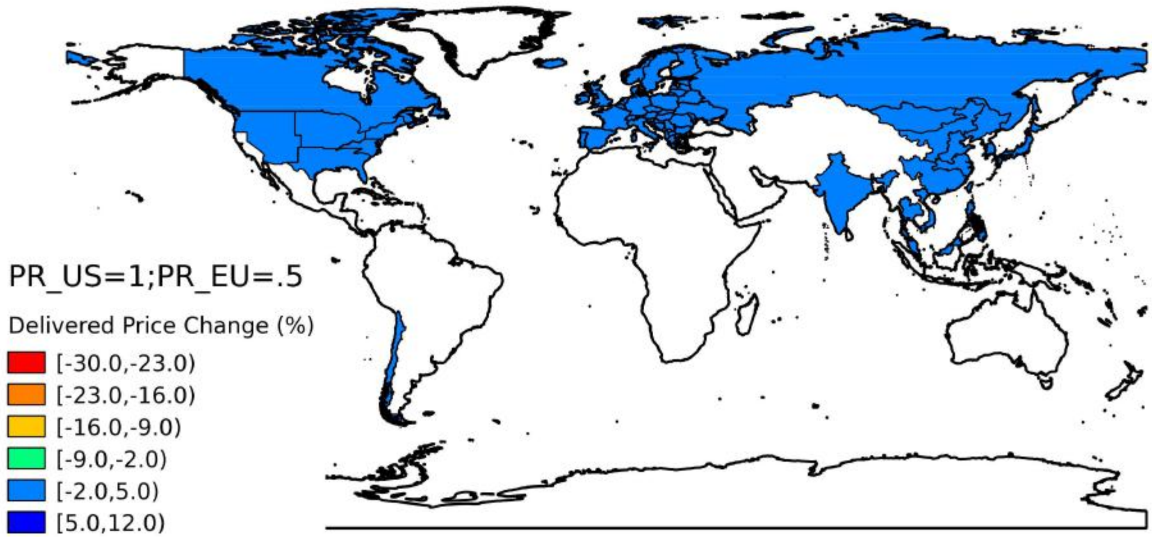

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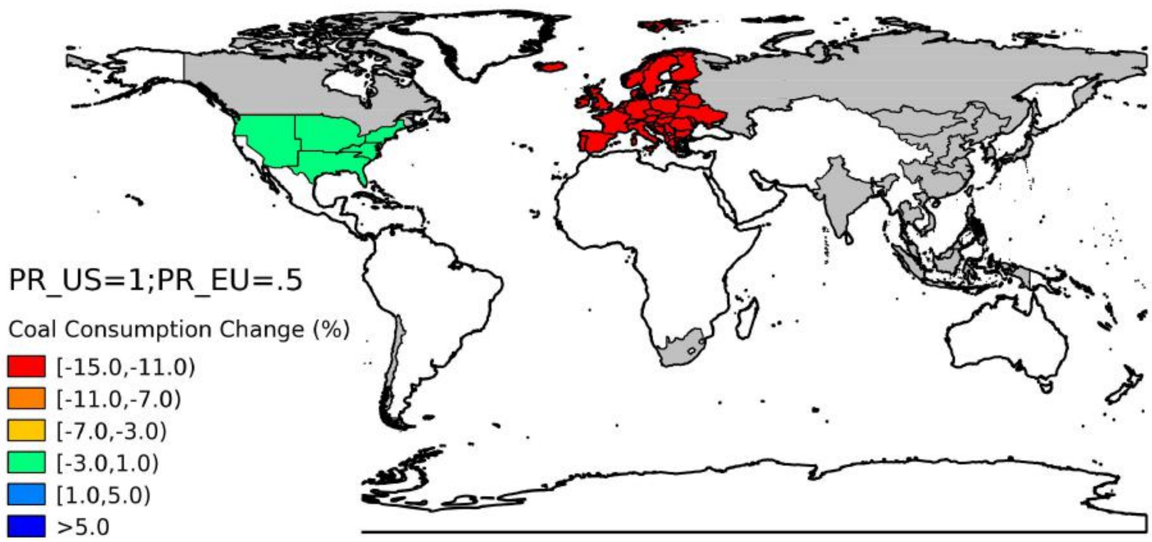

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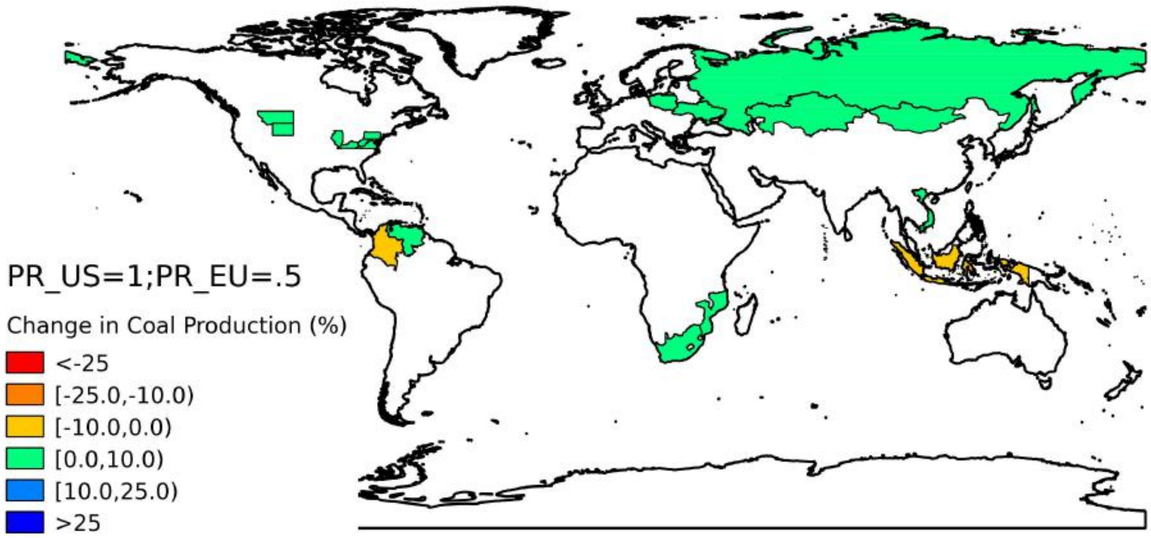

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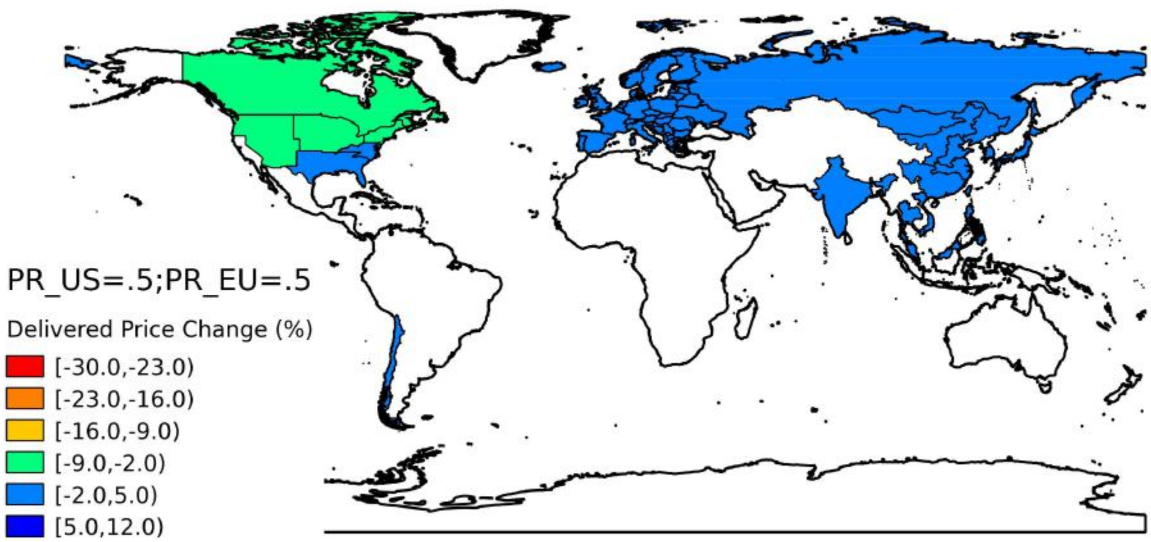

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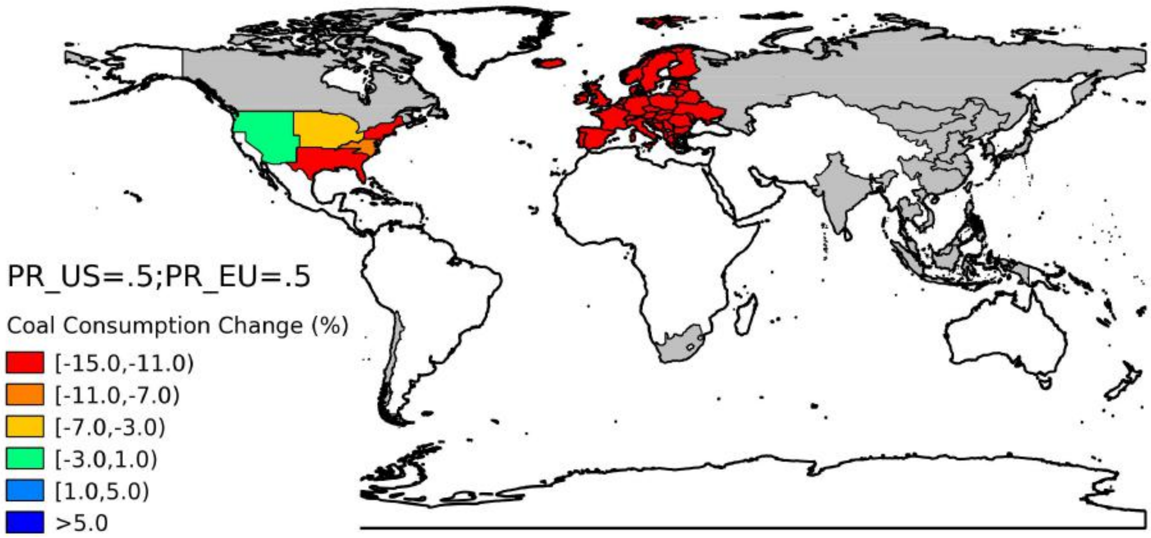

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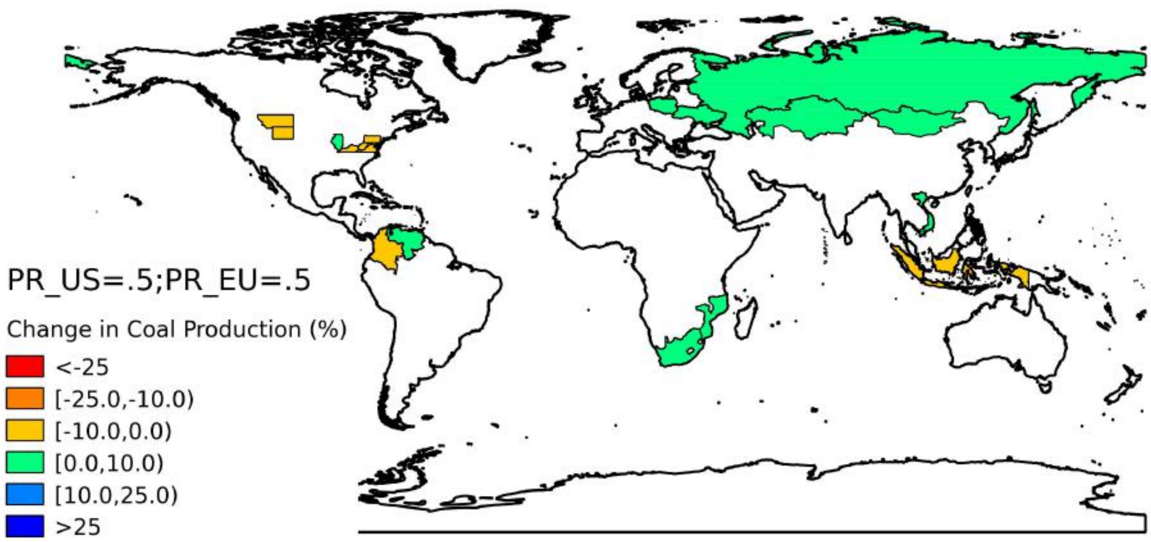

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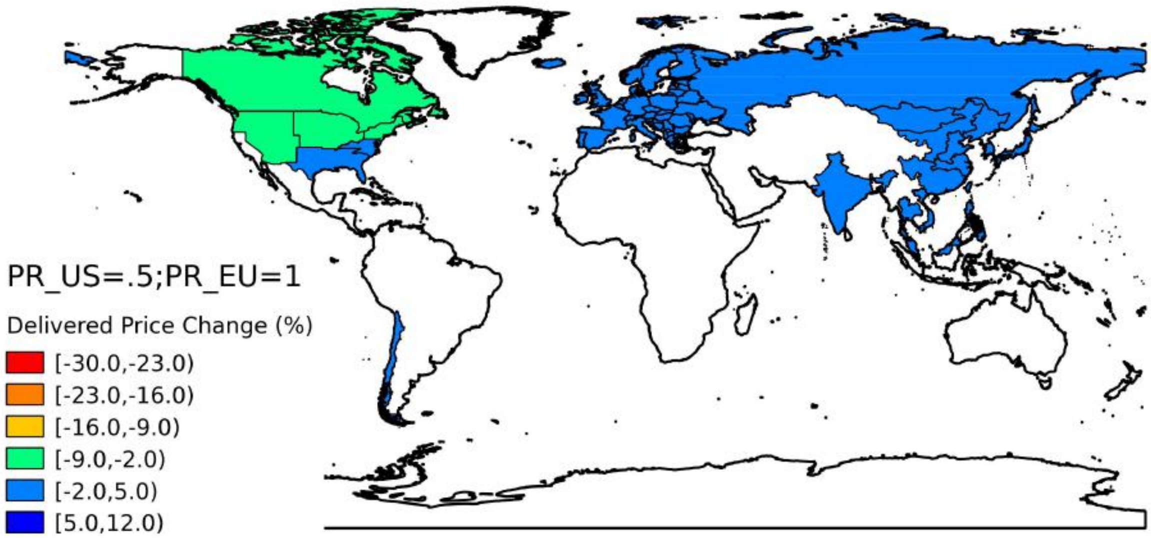

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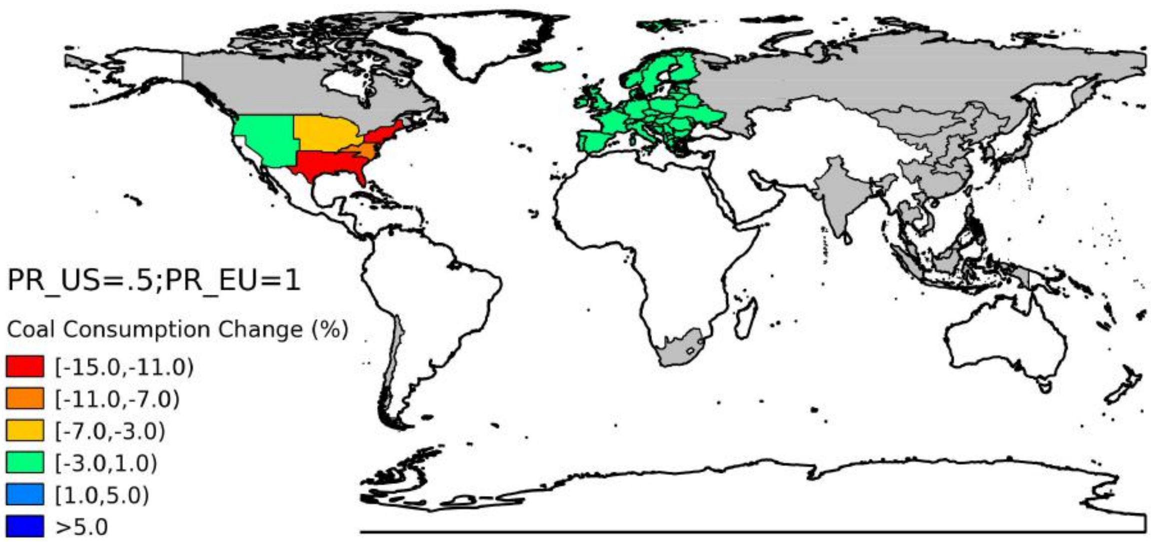

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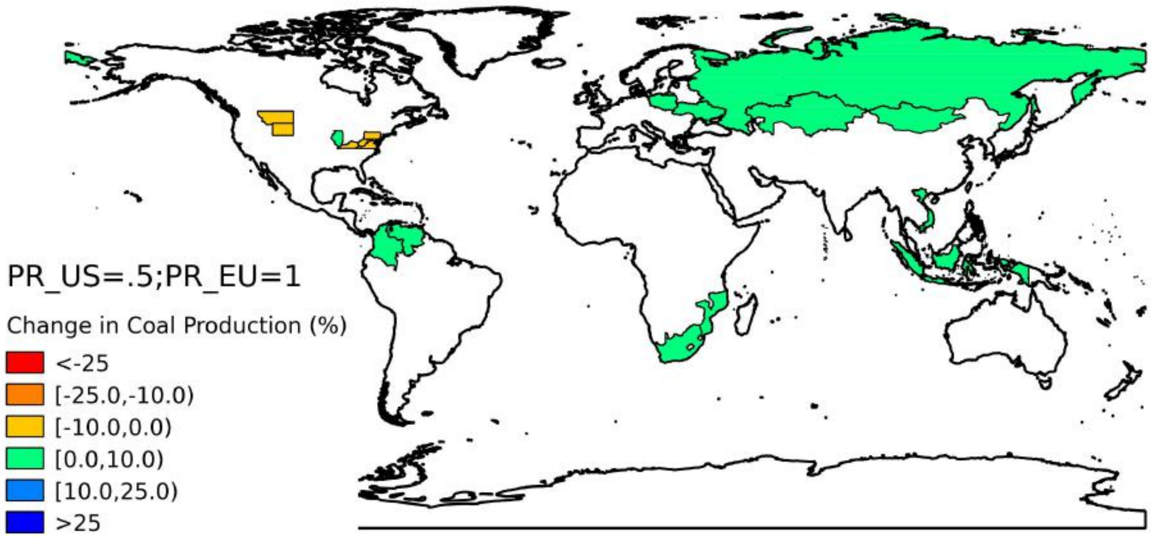

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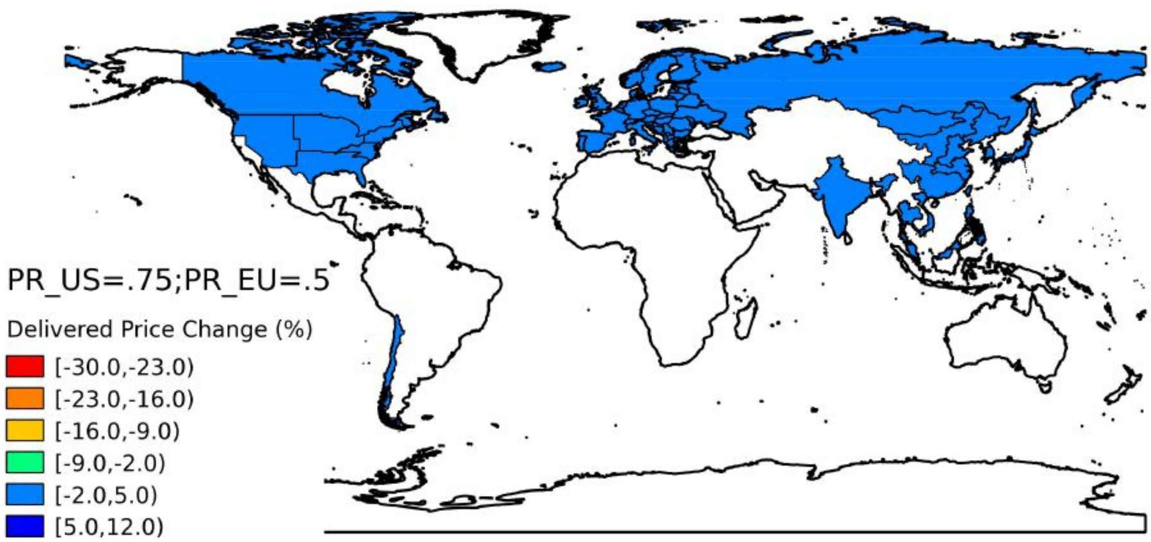

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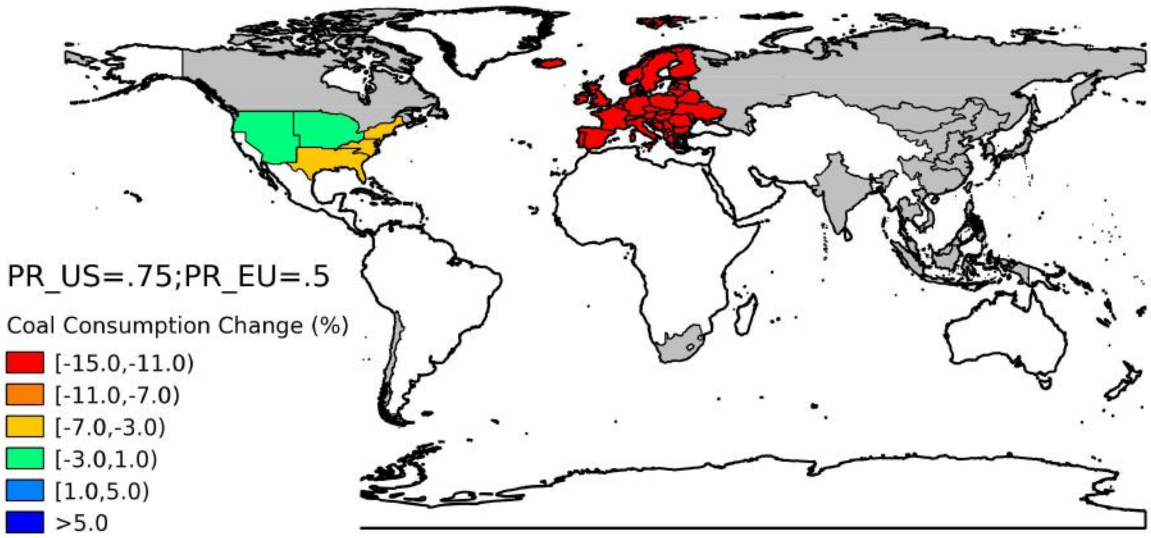

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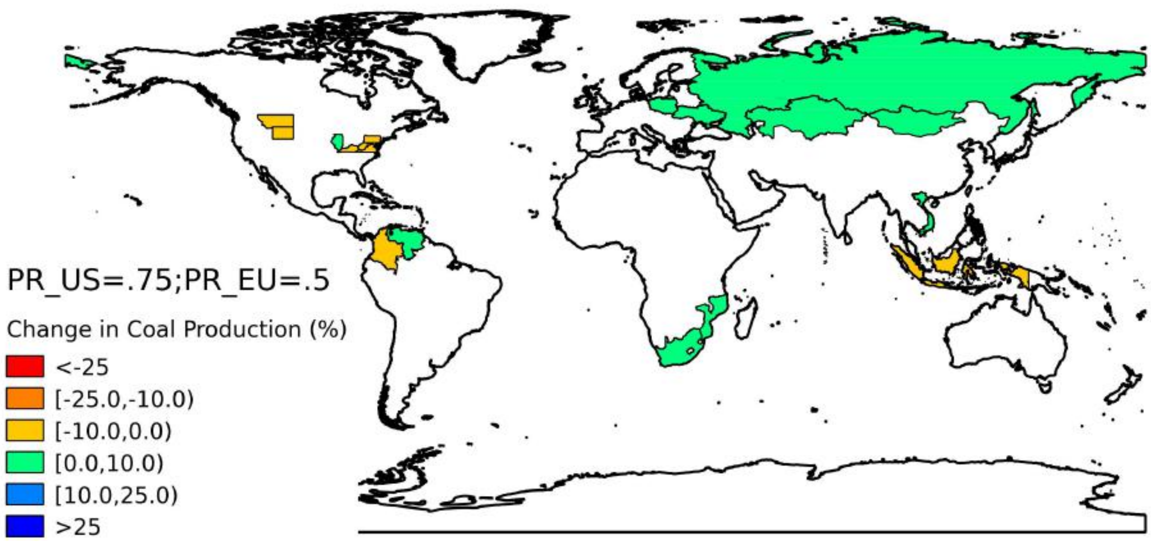

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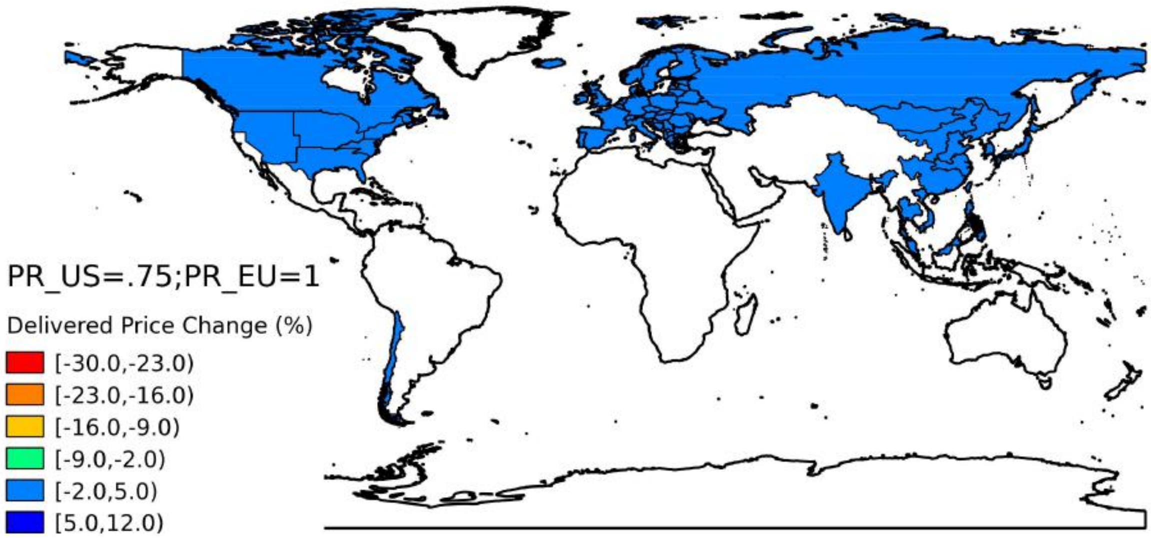

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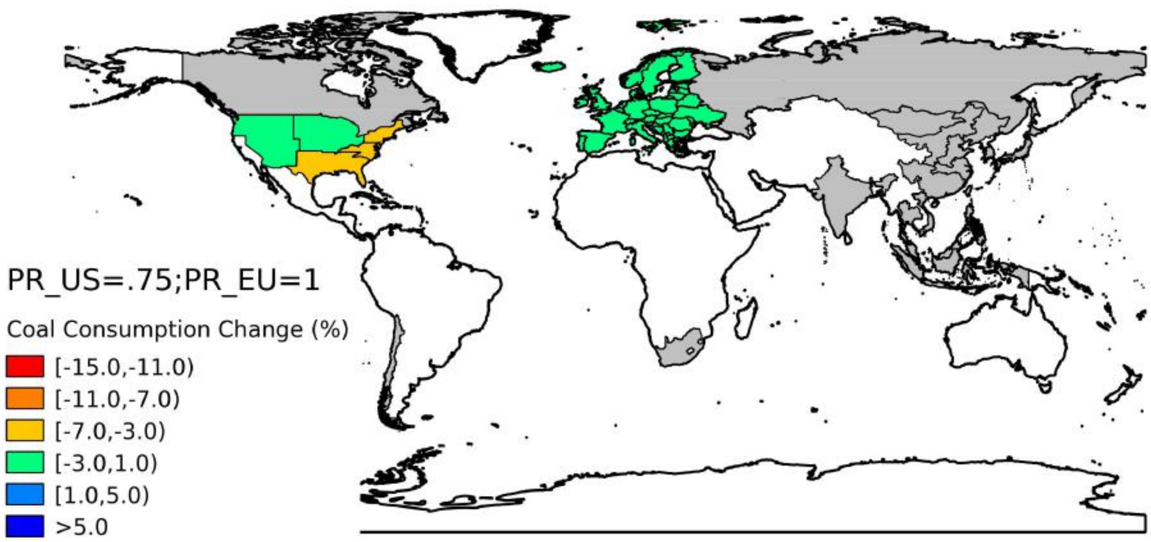

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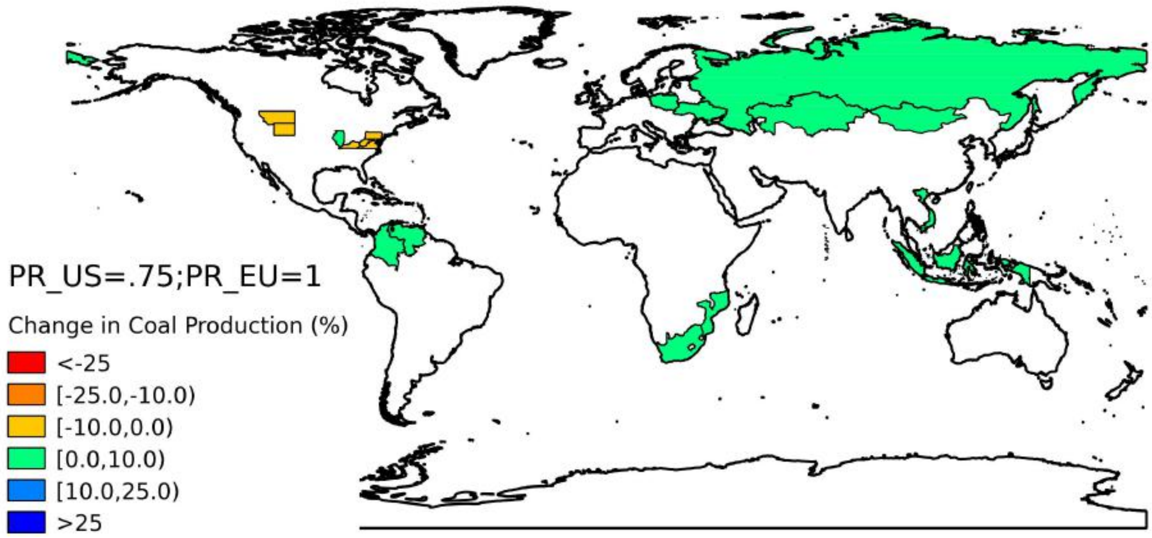

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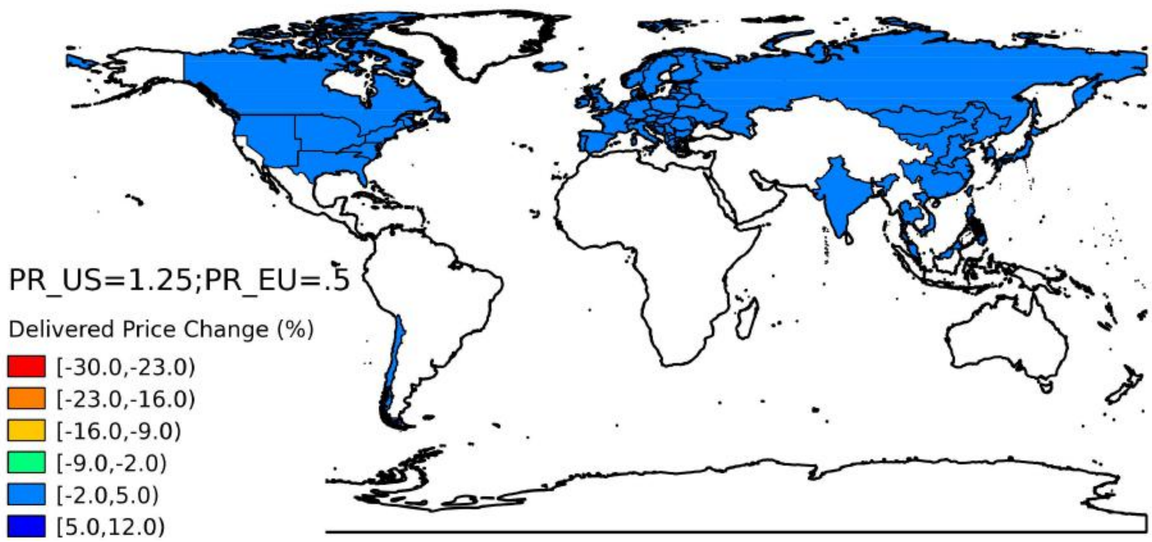

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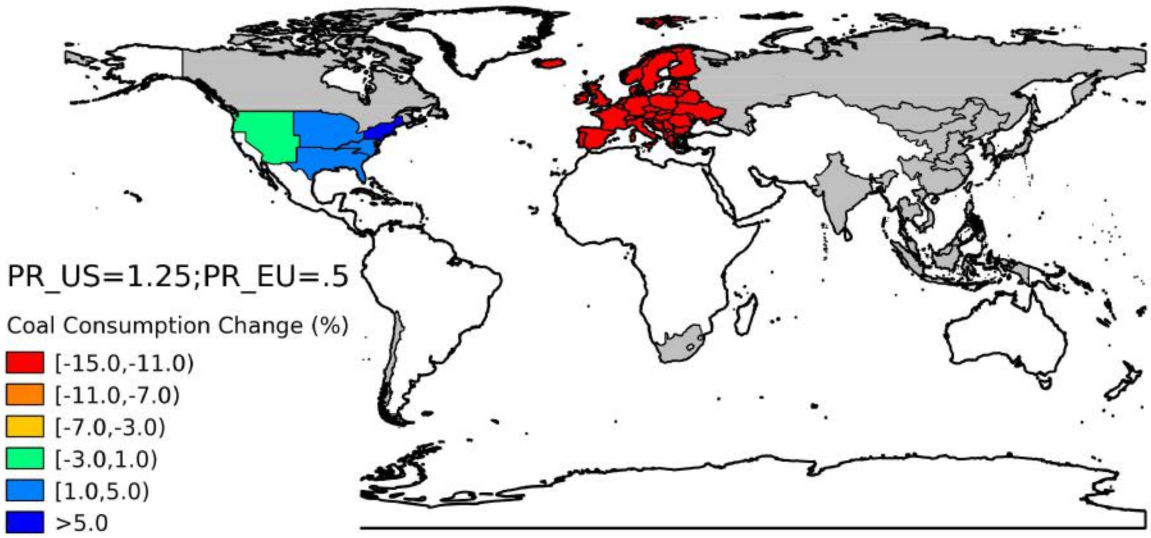

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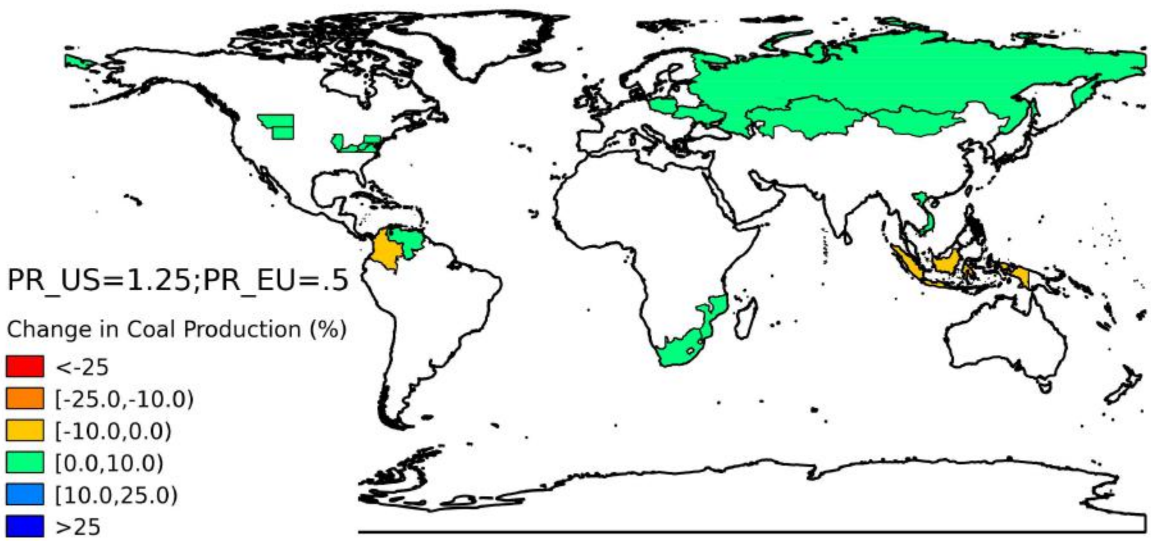

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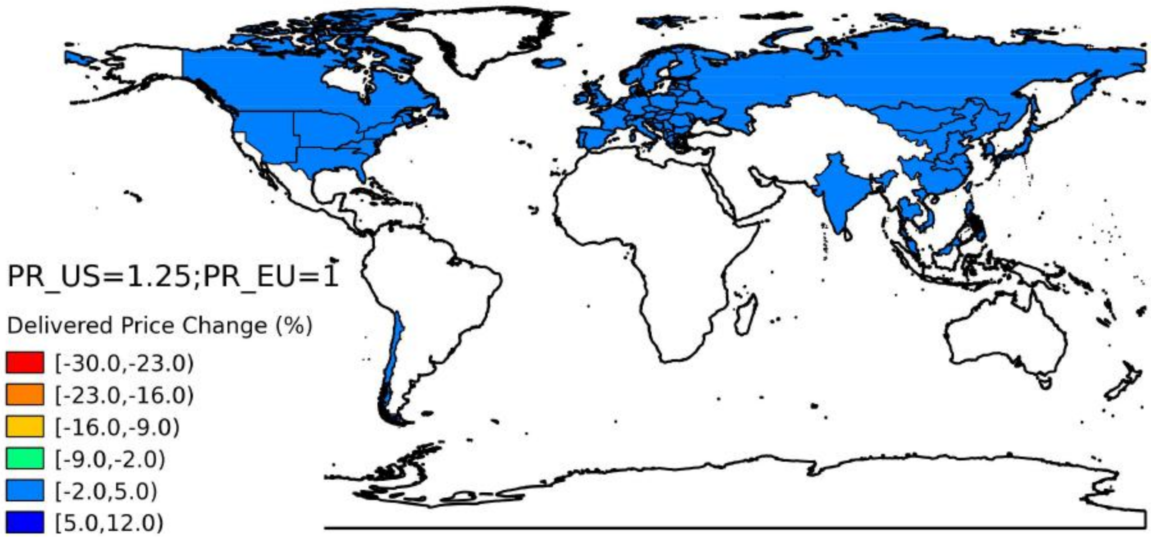

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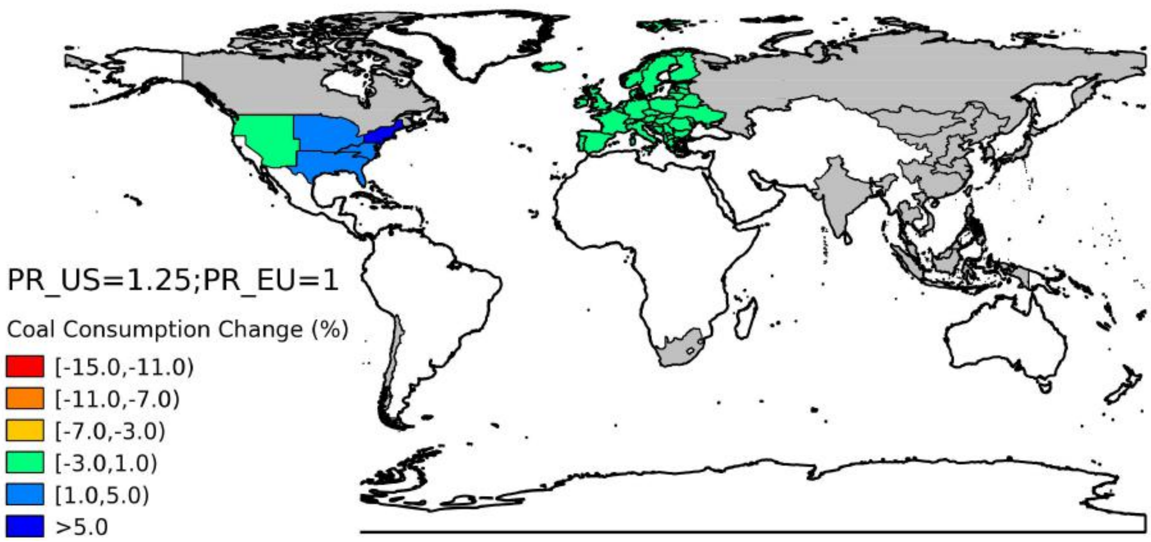

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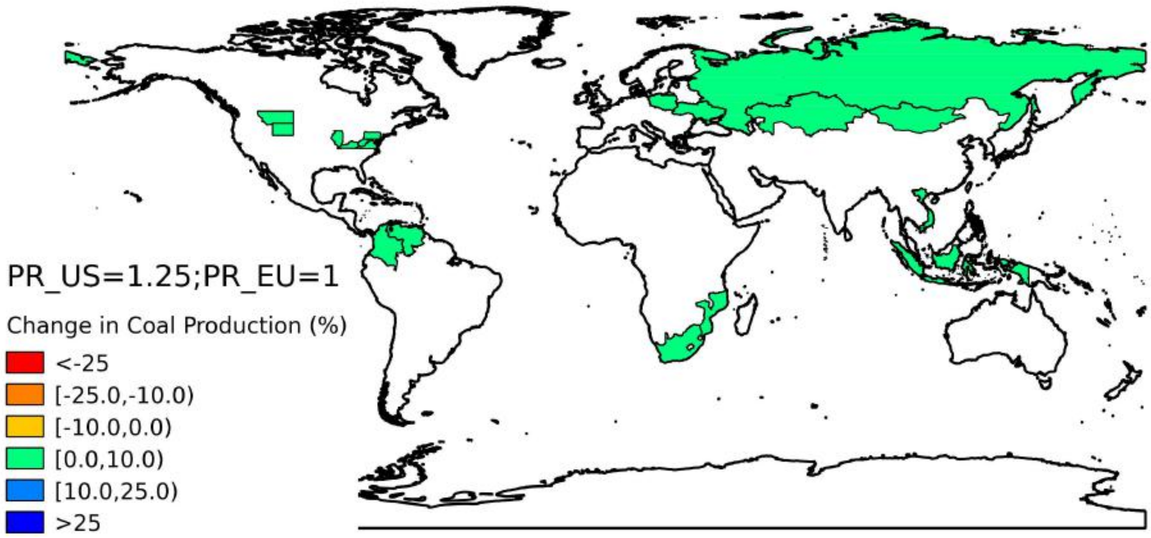

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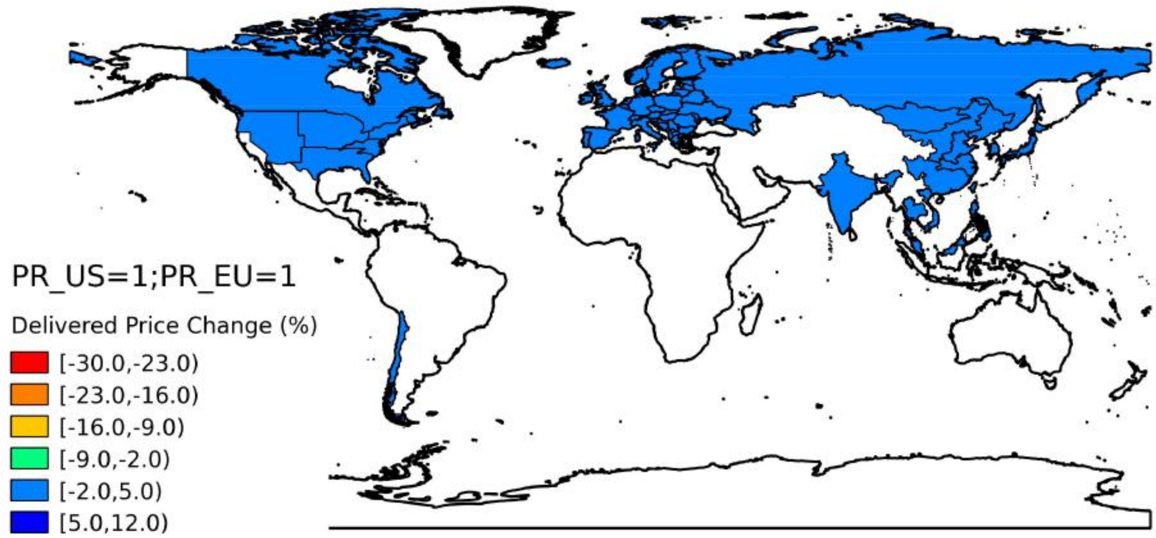

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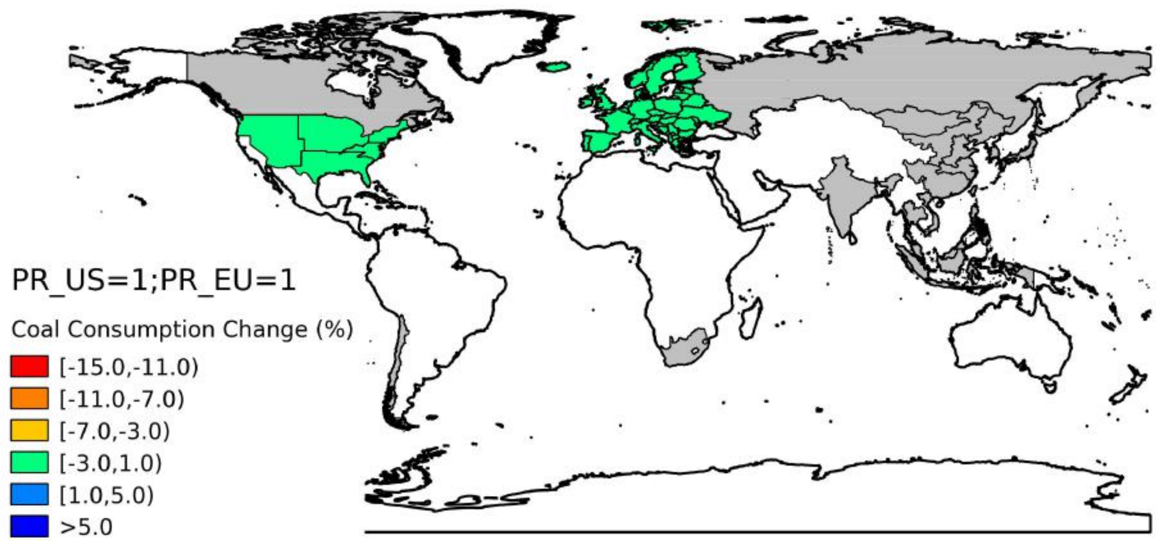

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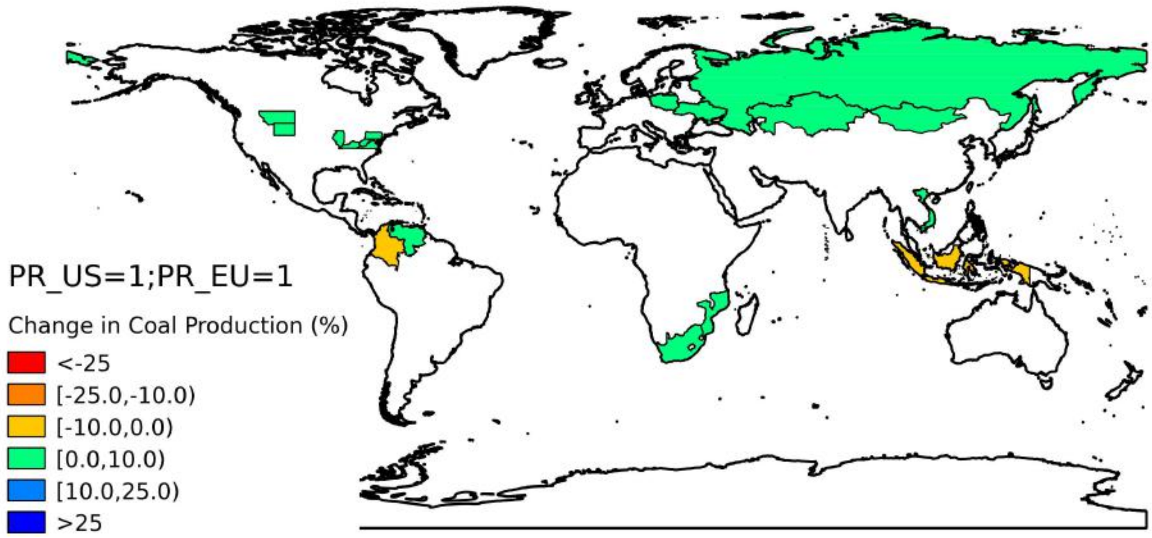

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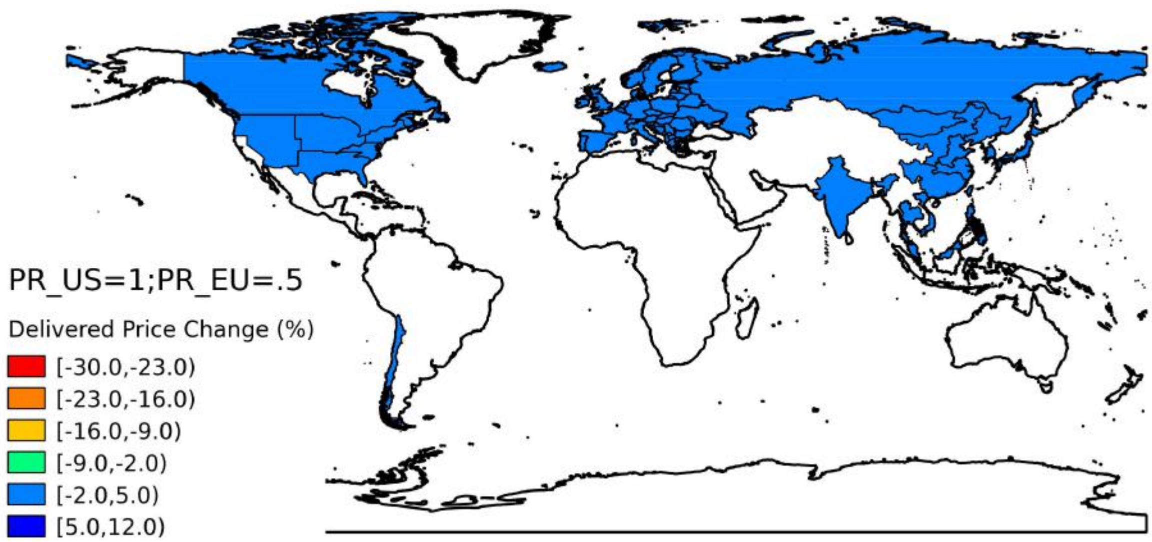

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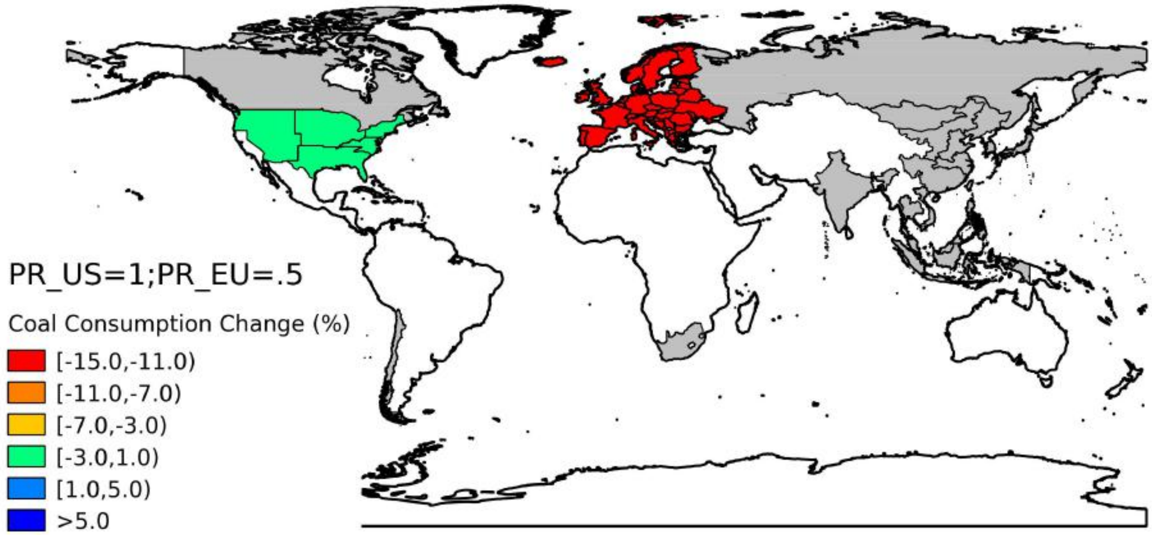

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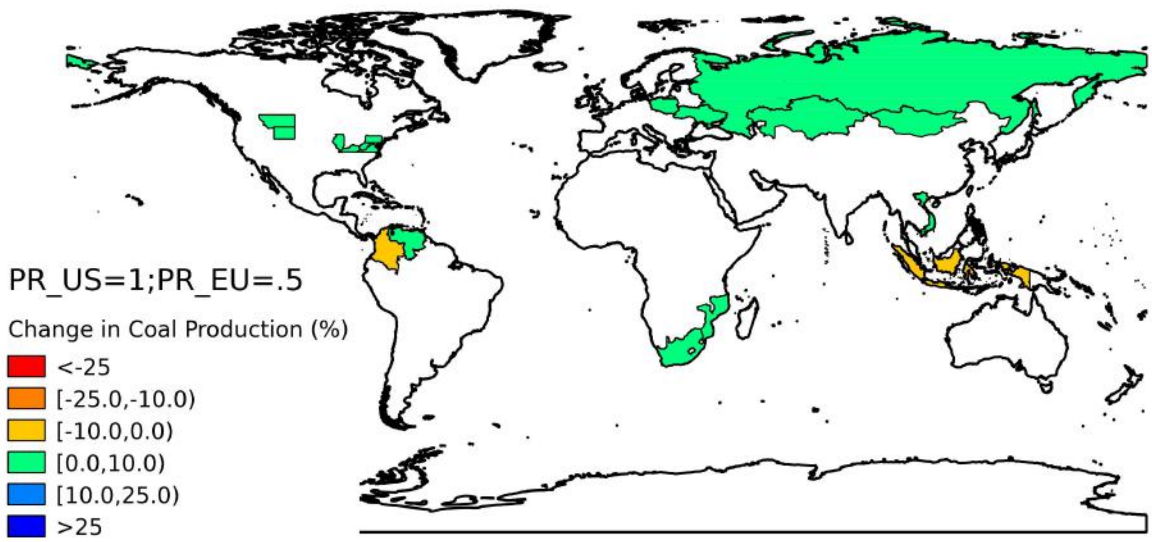

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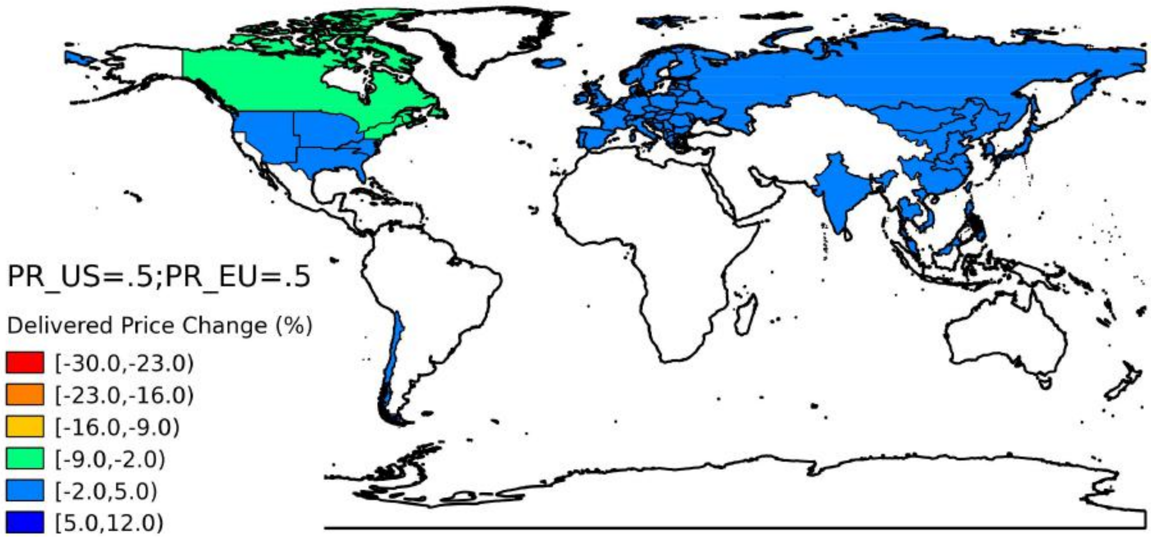

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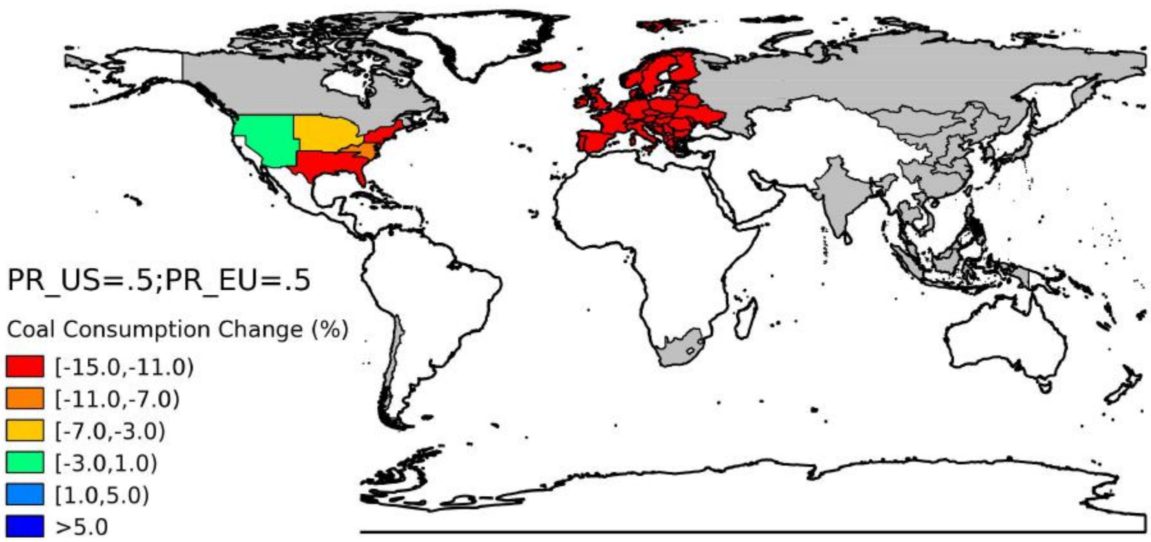

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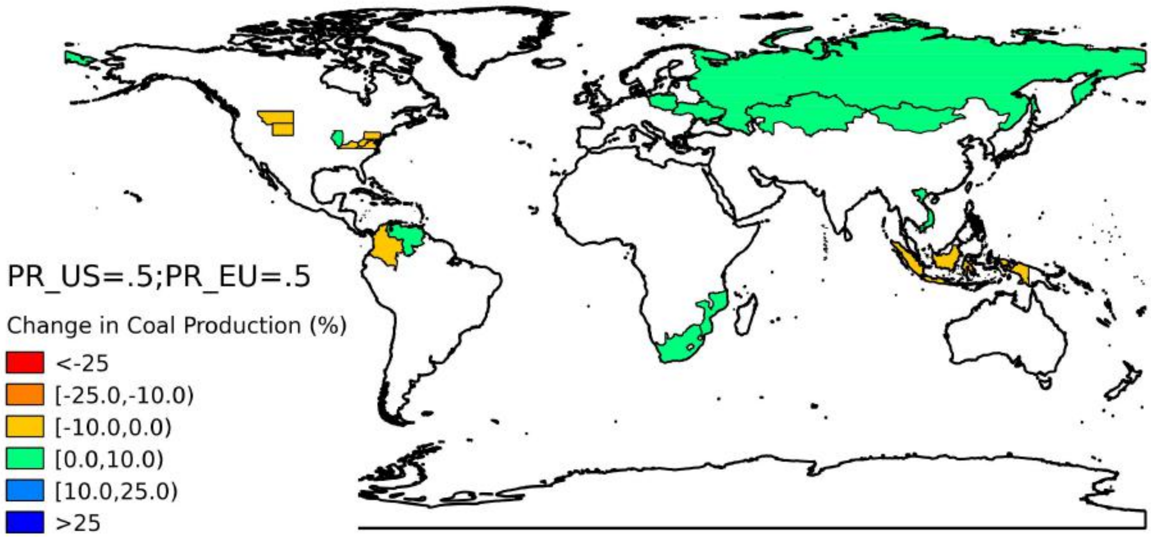

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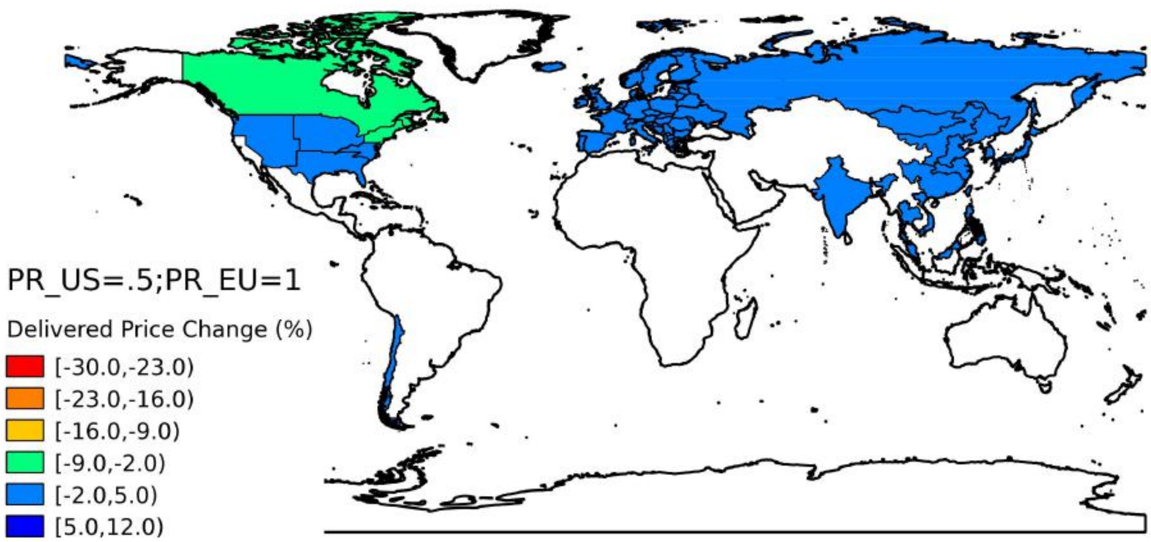

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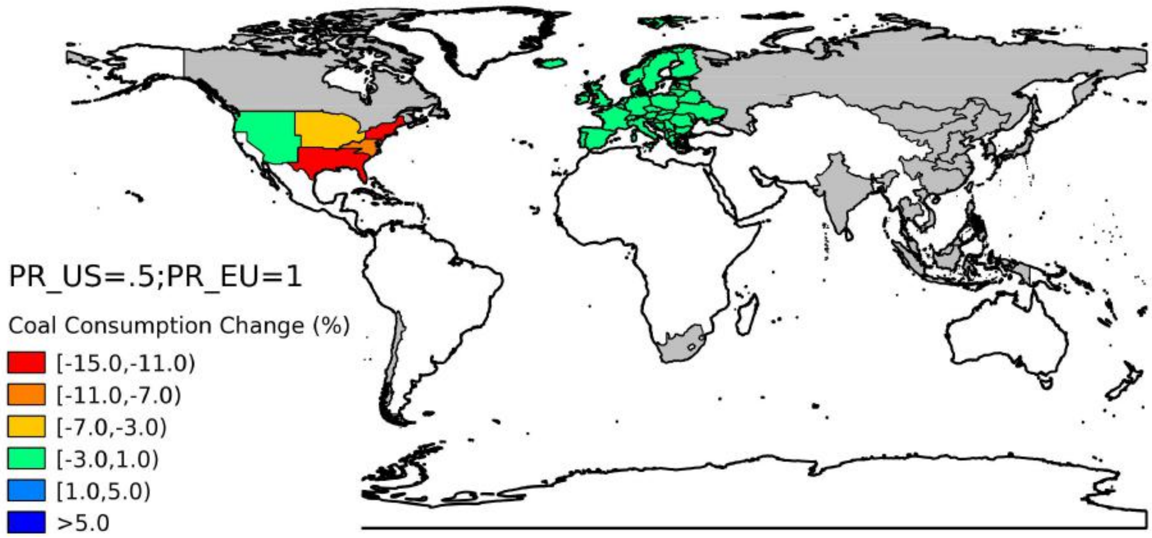

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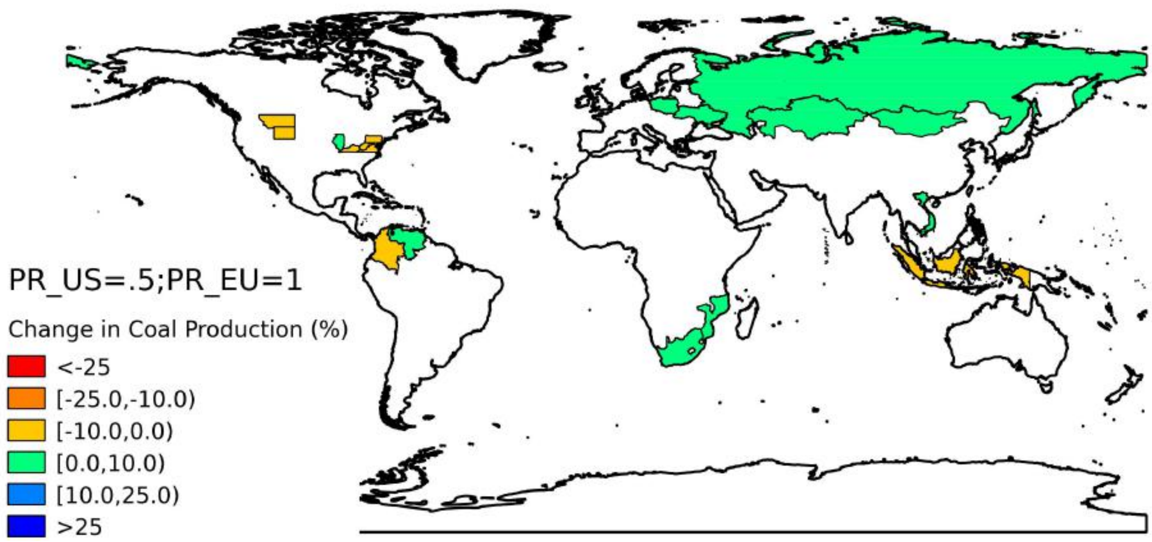

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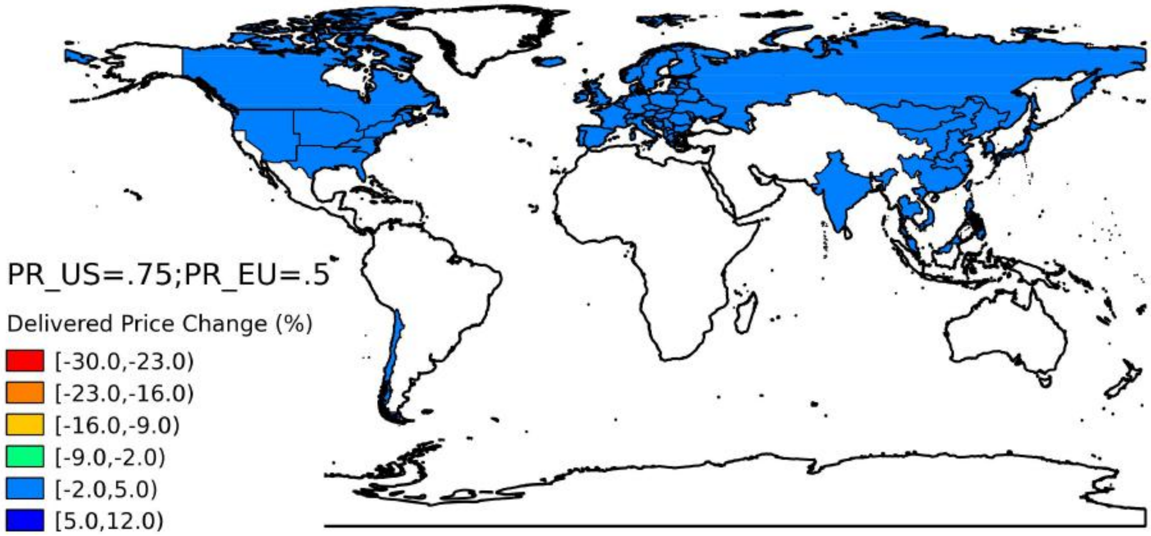

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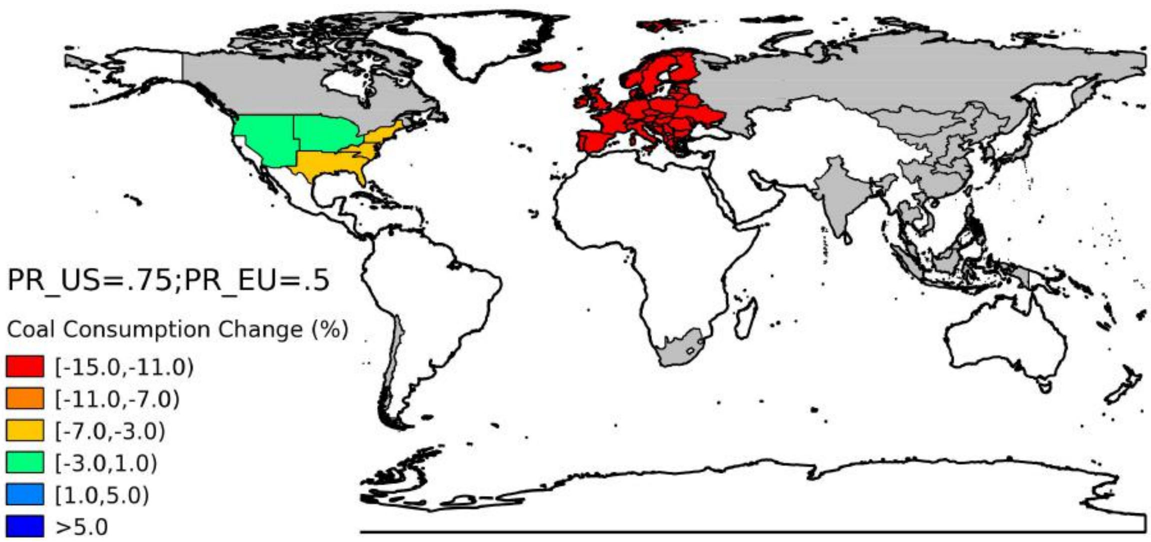

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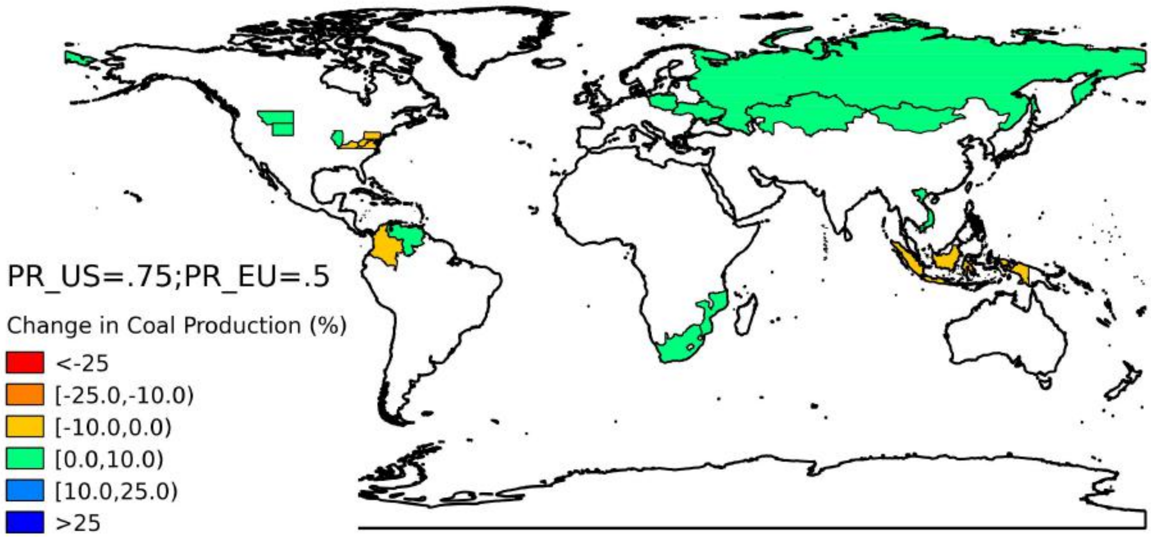

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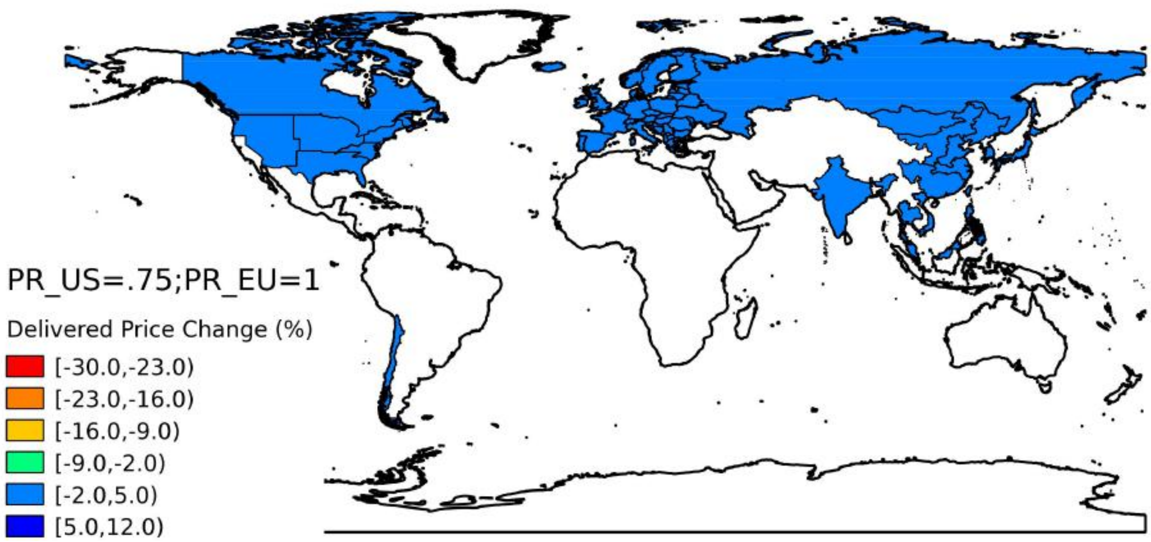

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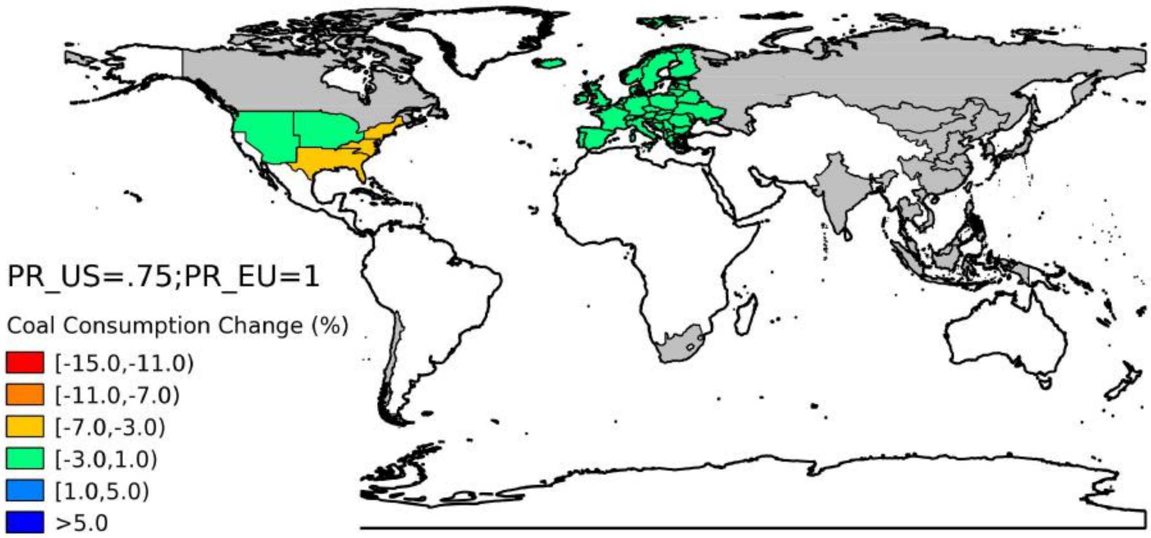

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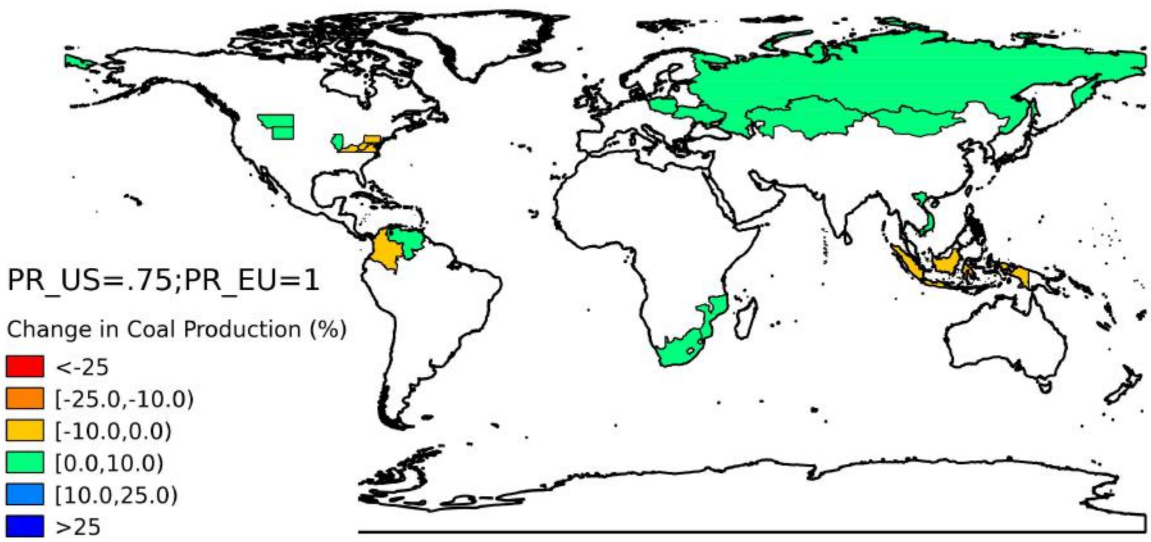

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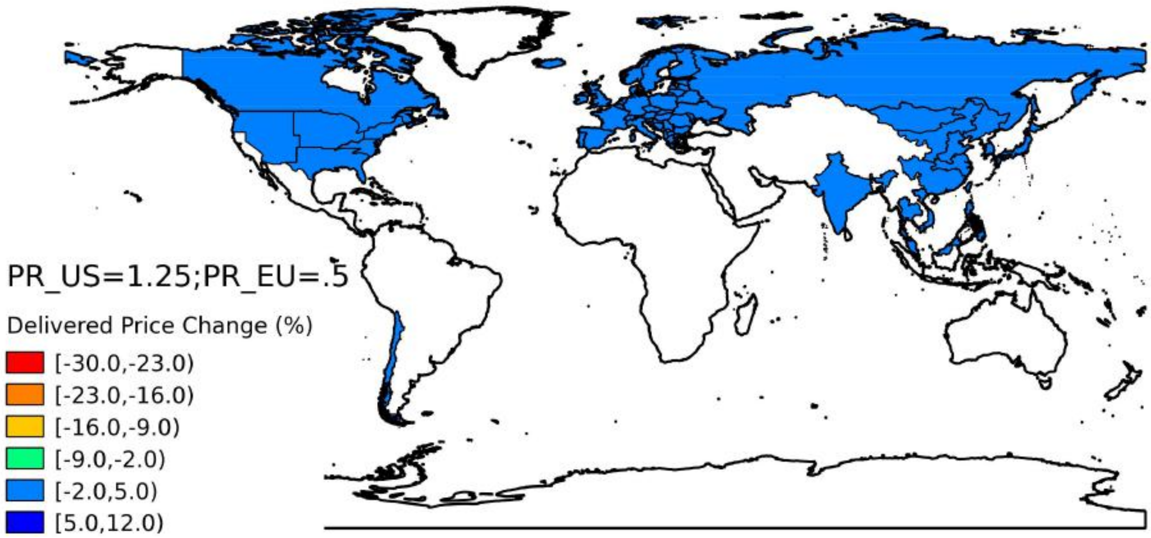

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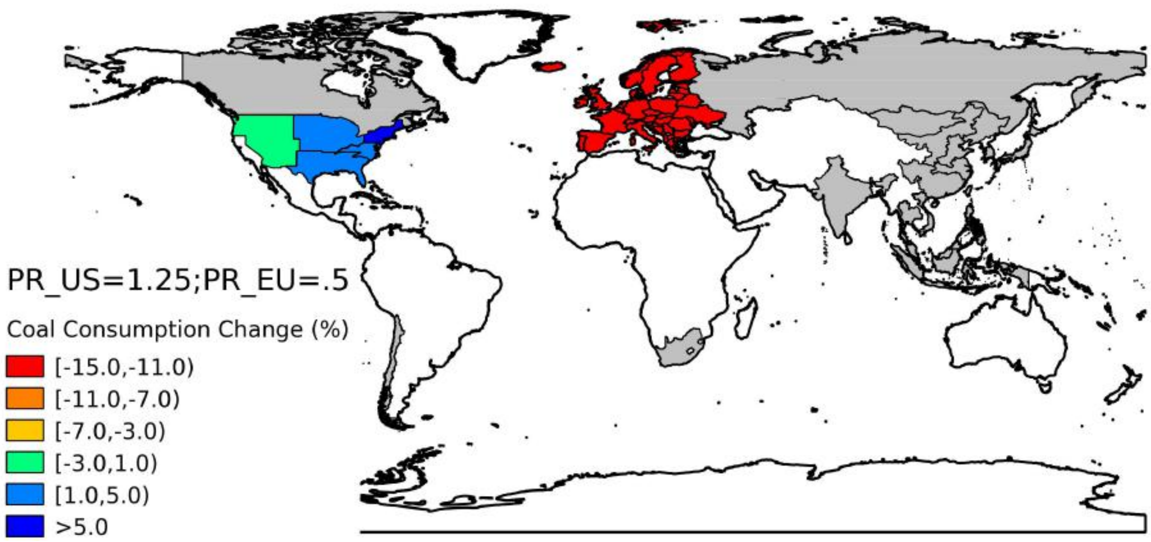

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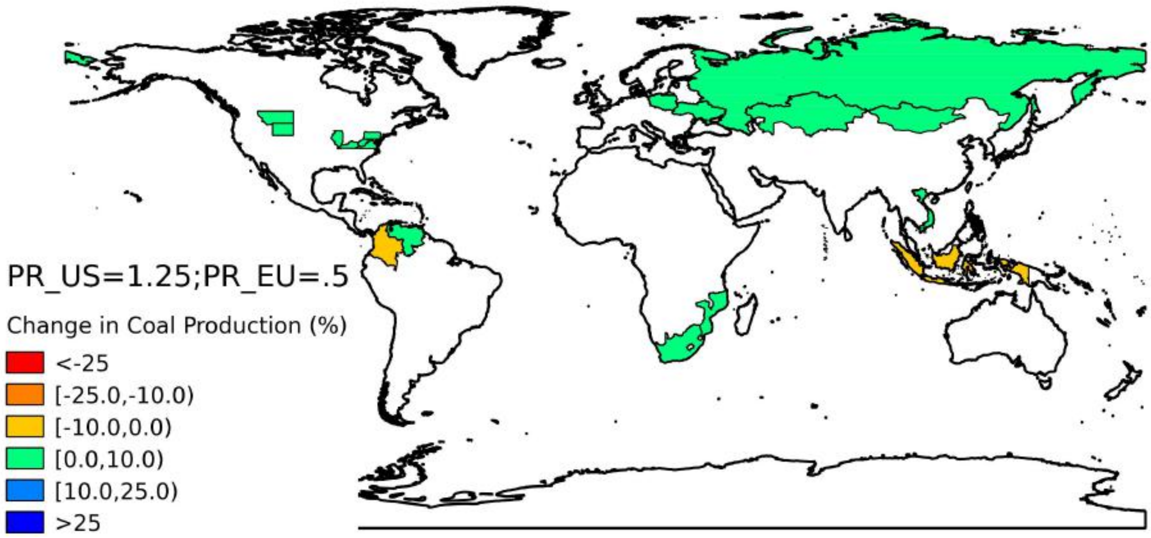

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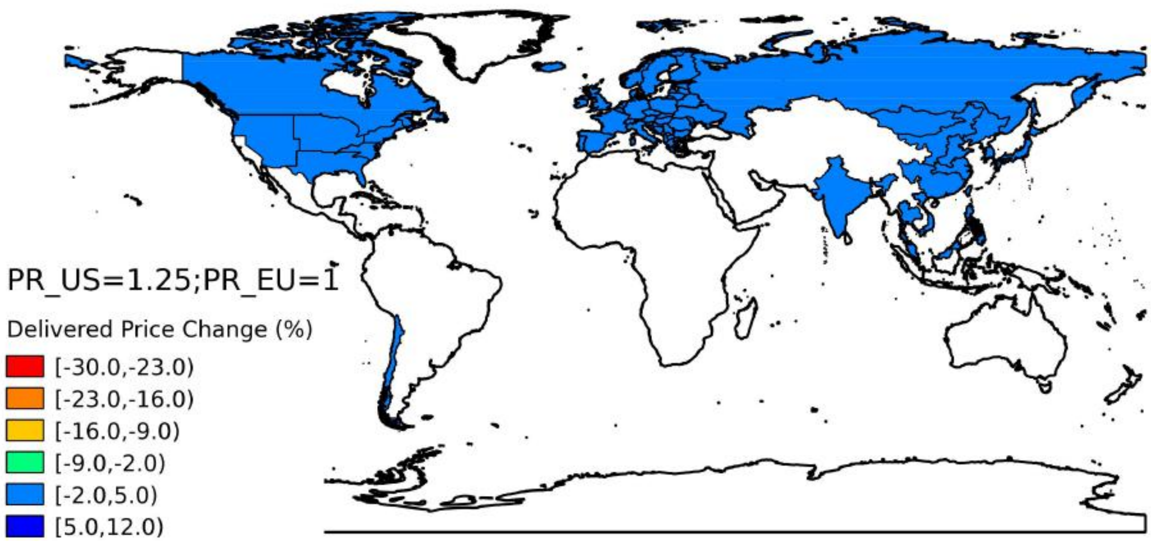

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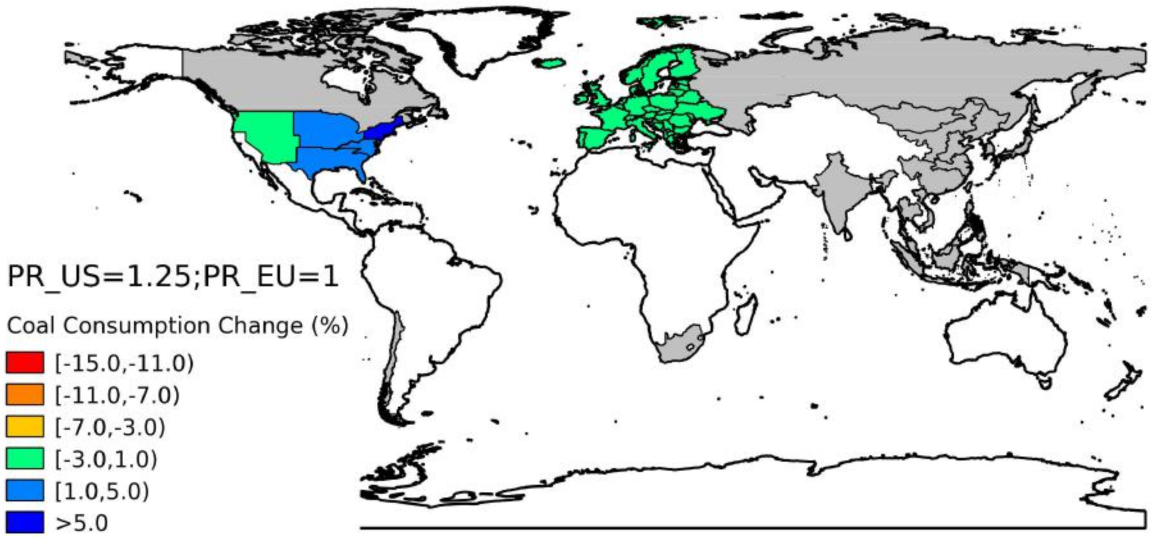

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