# Economic and Environmental Impacts of Increased US Exports of Natural Gas

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## ABSTRACT

*With the shale gas boom, the US is expected to have very large natural gas resources. In this respect, the key question is would it be better to rely completely on free market resource allocations which would lead to large exports of natural gas or to limit natural gas exports so that more could be used in the US. Even after accounting for the cost of liquefying the natural gas and shipping it to foreign markets, current price wedges leave room for considerable profit from exports. On the other side, there is potentially large domestic demand for natural gas in electricity generation, industrial applications, transportation, and for other uses. A hybrid modeling approach has been carried out using our version of the well-known MARKAL-Macro model to keep bottom-up model richness with macro effects to analyze these choices. The major conclusion of this research is that permitting natural gas exports causes a small reduction in GDP and also increases GHG emissions. We also evaluate the impacts of natural gas exports in the presence of a Clean Energy Standard for electricity. In this case, the GDP and sectoral impacts are similar, but the impacts on electricity and transport are substantially different.*

## 1 Introduction

The main objective of this paper is to examine the likely economic and environmental impacts of increased US exports of natural gas. With the shale gas boom, the US is expected to have very large natural gas resources, so the key question is would it be better to rely completely on free market resource allocations which would lead to large exports of natural gas or to limit natural gas exports so that more could be used in the US. Exports would be economically attractive because there is a very large price gap at present between US natural gas price (around $3.50/MCF) and prices in foreign markets, which can range up to $15/MCF. Even after accounting for the cost of liquefying the natural gas and shipping it to foreign markets, current price wedges leave room for considerable profit from exports. On the other side, there is potentially large domestic demand for natural gas in electricity generation, industrial applications, the transportation sector, and for other uses. There is no doubt that exporting a large amount of natural gas would increase the domestic natural gas price for all these potential uses. Higher natural gas prices would, in turn, mean higher electricity prices in addition to higher energy costs for all other sectors that use natural gas. These higher energy costs would also lead to contraction in energy intensive sectors relative to the reference case with small natural gas exports. On a global scale, more natural gas exports would benefit foreign companies and hurt domestic energy intensive industries. Foreign consumers also would benefit through lower energy costs, and US consumers would be hurt.

Thus, the question is which pathway provides the best economic and environmental outcome for the US. This is a very important energy policy question and one difficult to answer because of all the complex economics linkages among different economic sectors and also

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among the primary energy supply sectors. Our approach is to use a well-established bottom-up energy model named MARKAL (MARKet ALlocation). Bottom-up means that the model is built upon thousands of current and future prospective energy technologies and resources. These energy resources supply projected energy service demands for the various sectors of the economy. In addition to the standard MARKAL model, we also have adapted a version of the MARKAL-Macro model which permits us to include feedbacks between energy prices and economic activity. Thus the GDP effects of alternative energy policies are captured as well as technology and supply impacts. For these reasons, MARKAL-Macro is an ideal tool for this kind of analysis.

Our focus in this paper is on the impacts of different levels of natural gas exports on the economy and environment. We include 2.7 BCF/day of natural gas exports in the reference case because that level is already permitted, and the other simulated cases are additions of 6, 12, and 18 BCF/day of natural gas exports. These levels were chosen based on the EIA simulated levels (Energy Information Administration, January 2012) and to provide a wide range of natural gas export levels to determine how sensitive the various metrics are to the level. The export levels are compared with a reference case. Since the Renewable Fuels Standard (RFS) for biofuels and the CAFE standard for automobile and light duty vehicle fuel economy are now established US policy, we have included those policies in the reference case. However, the reality is, for this particular question, the results would not be very different between a reference case with and one without these policies. Our interest is in the difference or delta caused by three levels of increased natural gas exports compared with the reference case.

We do also examine one additional policy called the Clean Energy Standard (CES). This is the CES proposed by President Obama in his first term. The CES calls for doubling the percentage of clean electricity from 40 to 80 percent by 2035. Clean electricity includes coal with carbon capture and sequestration, nuclear, solar, hydropower, biomass, and wind. Natural gas based electricity is considered 50% clean in the CES. We develop a reference with CES case and then compare that with the three levels of natural gas exports as well.

The remainder of this paper is divided into four sections. First we provide a short literature review. Then we provide a more complete description of the MARKAL-Macro model used for the analysis. Third we provide the main results of the analysis comparing the three levels of natural gas exports with the reference and reference plus CES cases. Finally, we provide the conclusions we glean from this analysis.

## 2 Relevant literature

While there are many papers in the literature that have used MARKAL and some that have used a version of MARKAL-Macro, we will not review that literature. Other papers we have done provide that literature review. Here, the only directly relevant study is the recently completed NERA Economic Consulting study done for the US Department of Energy (DOE) (NERA Economic Consulting, 2012). They used their own proprietary energy-economy model named NewERA for the analysis. Their results suggest that the US achieves economic gains from natural gas exports and that the gains increase as the level of natural gas exports grows. Their result is the classical economic result that free trade provides net gains to the economy under most conditions. While economic theory does not suggest that free trade always produces economic gains for all parties under all conditions, the general argument is that under a wide range of conditions, free trade does provide net benefits with some winners and some losers. The NERA results do show higher natural gas prices due to exports with the magnitude of the increase depending on domestic and global supply and demand factors. The NERA study used input data and information from a companion study done by the Energy information Agency in DOE (Energy Information Administration, January 2012), which estimated the impacts of export levels on US natural gas prices.

The NERA analysis focused on export levels of 6 and 12 BCF per day, but there were many other scenarios and sensitivity analyses. In general, the welfare or net income increases estimated in the NERA scenarios were very small, generally ranging from 0.01 to 0.025 percent over the reference case. There were considerable losses in capital and wage income in sectors affected by the higher natural gas prices, and income gains to natural gas resource owners through export earnings and wealth transfers to resource owners. By 2030 the total net increase in GDP amounted to about $10 billion 2010$, which could be perceived as being quite small in a $15 trillion economy (Trading Economics, 2012). Wage income falls in agriculture, energy intensive sectors, and the electricity sector. The percentage declines in wages in these sectors were generally much greater than the percentage increases in net national income. Natural gas price increases did not exceed 20 percent in any of the simulations. The NewERA energy-economy model takes inputs from the EIA NEMS natural gas projections (Energy Information Administration, January 2012) and from a global natural gas model.

## 3 Modeling Methodology

### 3.1 US MARKAL – Macro model

MARket ALlocation (MARKAL) is a widely applied, dynamic, perfect-foresight, technology-rich linear programming, energy systems, optimization model. In its standard formulation, its objective function is the minimization of the discounted total system cost which is formed by summation of capital, fuel and operating costs for resource, process, infrastructure, conversion and end use technologies. The general framework enables the calibration of a model to local, national, regional or multiregional energy systems. Model applications include, but are not limited to, climate policy, impact assessment of new technologies, taxes, subsidies, and various regulations. Further details regarding the methodology can be found in Loulou et al. (2004).

The US EPA MARKAL is a standard MARKAL model where energy service demands are inelastic, exogenous, and model structure is linear. A database that represents a particular energy system must be developed to use with MARKAL. The U.S. EPA (2006) developed MARKAL databases that represent the US energy system at the national and regional levels. Both databases cover the period 2005 through 2055 in five-year increments and represent the sectors: resource supply, electricity production, residential, commercial, industrial and transportation sectors. The US EPA MARKAL model has been used for several national or international case studies (Hu and Hobbs, 2010; Sauthoff et al., 2010; Schafer and Jacoby, 2006). The original model has now been updated to 2010 data. In this study we use the national single region US EPA MARKAL model.

Characterizations of current and future energy demands, resource supplies, and technologies within the databases were developed primarily from the Energy Information Agency's 2010 Annual Energy Outlook report, extrapolated to 2055 using National Energy Modeling System (NEMS) outputs published by DOE (2010). Additional data sources include the AP-42 emission factors from US EPA (1995), and Argonne National Laboratory's Greenhouse Gas, Regulated Emissions, and Energy Use in Transportation (GREET) model

(Burnham et al., 2006). Further details regarding US EPA MARKAL can be found in Shay et. al. (2006).

### 3.2 Model Modifications

Significant data and model changes were introduced into MARKAL for this analysis. First, biomass supply was introduced using land rent outputs from the Global Trade Analysis Project (GTAP) model. Essentially, we captured the land rents as increasing amounts of biofuels were demanded in that model and used those for land supply curves for MARKAL. Second, the biochemical conversion technologies in MARKAL were updated to the latest and most reliable available. Third, biomass thermochemical conversion technologies were added to the model. All these changes are detailed in previous work (Sarica and Tyner, 2013 ). Fourth, new data on natural gas supply was introduced to reflect the increased supply of shale gas. Fifth, the transportation sector CNG use has been restructured. Each of these modifications is discussed in greater detail below.

The approach for the modeling of biomass production in the original US EPA MARKAL is similar to the approach used for modeling oil, natural gas, coal or hydraulic power production, where the production activity itself does not interfere with any other economic activity. No competition for another resource is present due to the production processes of coal, natural gas or uranium. You do not have to sacrifice production of oil to produce uranium or vice versa. In reality use of land for biomass production itself interferes with the ongoing biomass production for crops, vegetables or any other related economic activities. In that sense the current US EPA MARKAL model or any national or international MARKAL model does not reflect this reality.

The introduction of land to the supply chain of corn, corn stover, switchgrass and miscanthus required that a considerable amount of data be implemented in the MARKAL modeling framework. The land data came from the Global Trade Analysis Project (GTAP) database. The GTAP land data is stratified into agro-ecological zones (AEZ), so it permitted us to introduce the yield levels by region (Taheripour and Tyner, 2011; Tyner et al., 2011). Land data is incorporated as piecewise linear approximations to the GTAP output and more detail regarding this issue can be found in Sarica and Tyner (2013). With these changes we have depicted the total supply chain of the selected biomass products. Land rent is now a part of the cost of producing biomass. In addition, we have introduced the most up to date seeding, harvesting, transport and harvesting costs for the feedstocks mentioned earlier (Taheripour and Tyner, 2011).

Another set of changes is the update of natural gas resource supply curves in the US EPA MARKAL database based on the MIT Energy Initiative report (The MIT Energy Initiative, 2011).Natural gas is expected to be available at low cost for the US, due to shale gas and other technological improvements. Due to the expectation of improvements in gas extraction techniques, the high availability case is quite plausible as suggested by the MIT Energy Initiative Report (The MIT Energy Initiative, 2011). With this expectation we make the use of high availability case supply curve in the modified MARKAL database.

The last set of changes is the restructuring of the Compressed Natural Gas (CNG) use in the transportation sector. The distribution of CNG within the sector is restructured such that it can be tracked based on type of use such as Light Duty Vehicles (LDV), transit buses, school buses, garbage trucks and Heavy Duty Vehicles (HDV). And relevant policies can be modeled and adapted accordingly. Based on the fleet sizes and energy use distribution from Federal Transit Authority’s National Transit Database (2010), Institute of Education Sciences’ National Center for Education Statistics (2011), Waste and Recycling News magazine’s 2010 Hauling and

Disposal Rankings (2011) and 2002 Economic Census - Vehicle Inventory and Use Survey (Department of Commerce, 2004), database has been updated to reflect the economies of scale in those subsectors. Besides the cost of CNG stations is based on the study carried by Caley Johnson (2010), VICE model which shows the economies of scale effect on CNG station design.

Our US MARKAL-Macro model is based on the national US EPA MARKAL model with the modifications described in this section and earlier references. In the first stage of the calibration process, the MARKAL model is calibrated to the base year, 2005, to match the model outputs to the electricity outputs, primary energy use, installed technology capacity and sectoral outputs. After the first phase, MARKAL and MACRO modules went through an iterative calibration process which is used to match the projected energy service demands and projected GDP growth rates. Annual Energy Outlook (Department Of Energy, 2010) is the principal data resource in all calibration processes.

### 3.3 Macro Linkage

In this paper, a neoclassical growth model has been integrated to the technology rich representation of the US energy system. Despite the simplicity, MARKAL-Macro is one of the very few hard-linked top-down bottom-up hybrid modeling approaches (Messner and Schrattenholzer, 2000). Figure 1 graphically summarizes the integration process.

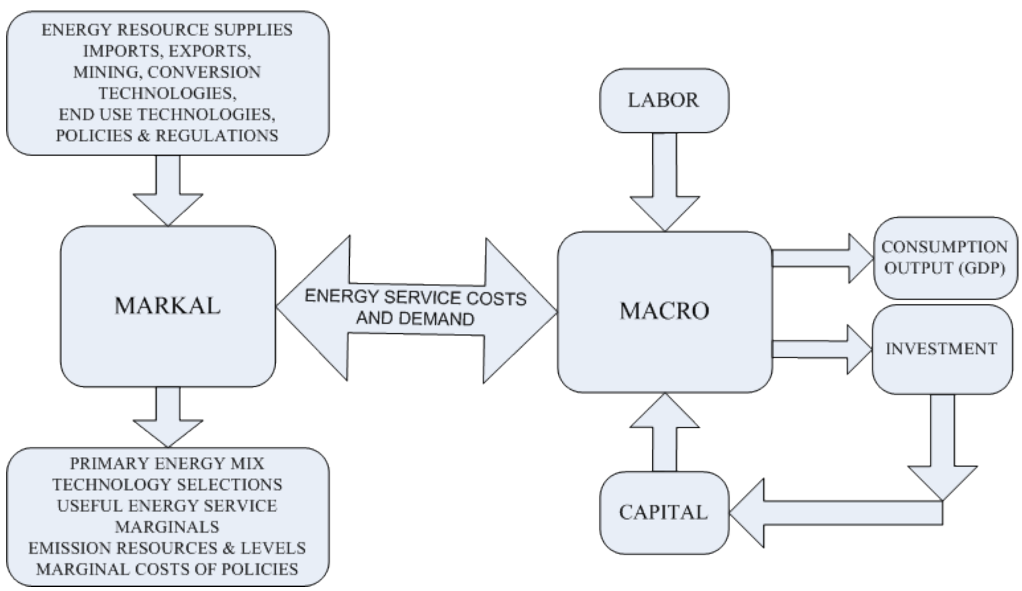


Figure 1 MARKAL-Macro Integration

The objective function of MARKAL-Macro, as can be seen in Equation 1, is the maximization of the discounted log of utility, which is basically derived as the log of consumption, accumulated over all modeling horizon periods (*t*), with an added terminal value. Where $C_t$ is consumption; *kpvs* is the value share of capital in the labor–capital aggregate; *kgdp* is the initial capital-to-GDP ratio; *depr* is the annual depreciation of the capital stock; and *grow* is the expected growth rate of the economy. The discount factor $udf_t$ is accumulated discount rate from year t to 0 and $udr_t$ is the year t's annual discount rate. *ny* is the number of years per period.

$$Utility = \sum_{t=1}^{T-1} (udf_t)(\log C_t) + \frac{(udf_T)(\log C_T)}{1-(1-udr_T)^{ny}}$$
$$udf_t = \prod_{t=0}^{t-1} (1-udr_t)^{ny} \qquad (1)$$
$$udr_t = \frac{kpvs}{kgdp} - depr - grow$$

The output of the economy ($Y_t$) is composed of consumption, investment and energy costs, as shown in Equation 2, in a single economic sector with perfect foresight. The financial link between MARKAL and Macro module is represented by $EC_t$.

$$Y_t = C_t + I_t + EC_t \qquad (2)$$

where $I_t$ is investment; and $EC_t$ is the total energy cost where a simplified breakdown is given in Equation 3. *k* stands for utilized technologies in this equation. The key point in Equation 3 is the revenue generated from export activities. Any export activity has a potential to reduce the energy system cost thus creating growth potential for other economic activities. Besides, for this to hold, the cost of extracting exported commodity and extra burden created by the disturbance in the energy system must be less than the revenue generated. A more detailed cost description can be found in Loulou *et al.* (2004).

$$\begin{aligned} EC_t = \sum_k \{ & Annualized\ Investment\ Costs(t,k) \\ & + Fixed\ Operating\ \&\ Maintaining\ Costs\ (t,k) \\ & + Variable\ Operating\ \&\ Maintaining\ Costs\ (t,k)\} \\ & + \ Mining\ Activity\ Costs(t) \\ & + Trade\ Related\ Costs(t) \\ & + Energy\ Import\ Costs(t) \\ & - Energy\ Export\ Costs(t) + Enviromental\ Tax\ (t) \end{aligned} \qquad (3)$$

Production roots from three substitutable inputs by a nested Constant Elasticity of Substitution (CES) function. As can be seen in Equation 4, under this formulation, capital and labor substitute directly for one another based on the value share of capital in the labor–capital aggregate (*kpvs*). Their aggregate is then substituted for a separable energy aggregate. Investment is used to build up the stock of (depreciating) capital, while labor is exogenous.

$$Y_t = \left[ akl\ (K_t)^{\rho\alpha}\ (L_t)^{\rho(1-\alpha)} + \sum_{dm} b_{dm}\ \left(D_{dm,t}\right)^{\rho} \right]^{1/\rho}$$
$$L_t = (1 + grow_{t-1})^{ny}\ L_{t-1}\ , where\ L_0 = 1 \qquad (4)$$
$$\alpha = kpvs, \rho = 1 - \frac{1}{ESUB}$$

where $akl$ is the production function constant, $b_{dm}$ are the coefficients on demands in the MACRO objective function; $K_t$ is the capital stock; $L_t$ is labor; $D_{dm,t}$ is the demand for energy services of type $dm$ in period $t$; and $ESUB$ is the elasticity of substitution between the energy and the capital–labor aggregate. Parameters $akl$ and $b_{dm}$ can be determined using base year statistics, via the following two-step procedure. First, the reference price of energy service $dm$ ($price(ref)_{dm,t}$) is equated to the partial derivative of $Y_t$ , as can be seen in Equation 4, with respect to $D_{dm}$, yielding:

$$\frac{\partial Y_t}{\partial D_{dm,t}} = \left(\frac{Y_t}{D_{dm,t}}\right)^{1-\rho} \quad b_{dm} = price(ref)_{dm,t} \tag{5}$$

thus allowing the computation of $b_{dm}$, for all dm. Next, the expression of the production function ($Y_t$) in base year is used to directly compute $akl$.

Due to the first order optimality condition for the partial derivative of production with respect to demand, the marginal change in output is equal to the cost of changing that demand. In practice this has two main conclusions. First, different demands will be altered based on the cost of changing that demand. So if it is very expensive to reduce a particular demand, then this will be reduced relatively less. Secondly, great care is needed to have smooth (and certainly not zero) shadow prices which can occur due to over-constrained runs. This ensures that the marginal output (demand) responses are realistic.

Capital stock ($K_t$) formation is endogenous and has its own dynamics as expressed in Equation 6. An additional equation ensures new capital is provided through investment, accounting for depreciated capital.

$$\begin{aligned} &K_{t+1} = (1 - depr)^{ny}\, K_t + (ny/2)\,[(1 - depr)^{ny}\, I_t + \; I_{t+1}] \\ &I_0 = (grow_0 - depr)\, K_0 \end{aligned} \tag{6}$$

Terminal condition, Equation 7, ensures sufficient investment for replacement and constant growth of capital at all-time intervals.

$$K_t(grow_t + depr) \; \leq \; I_t \tag{7}$$

Finally MARKAL supply activities are linked to Macro demand variables through two equations. The demand levels ($D_{dm,t}$) and cost of energy ($EC_t$) are the links between MARKAL and the Macro module.

Let $X_{j,t}$ be an activity $j$ of MARKAL supplying energy service demand ($dm$) proportional to $supply_{j,dm,t}$ in time $t$. With the 'autonomous energy efficiency improvements factor (efficiency of converting physical energy to energy services) $aeeifac_{dm,t}$ MARKAL supply activities are linked to Macro demand variables. This process is also termed demand decoupling since it permits the model to decouple demands from the linear relationship with GDP e.g. primary metals industry is projected to squeeze down, while high duty vehicle energy service demand is projected to grow very close to GDP growth rates.

$$\sum_j supply_{j,dm,t}\, X_{j,t} = aeeifac_{dm,t}\, D_{dm,t} \tag{8}$$

To transfer the costs from MARKAL to Macro, the link in Equation 9 computes for each activity $j$ and period $t$ the cost, $cost_{j,t}$ ,per unit of activity $X_{j,t}$ (which is equivalent to Equation 3) and quadratic penalty terms are introduced to smooth the rate of market penetration of new technologies:

$$\sum_j cost_{j,t}\, X_{j,t} + c \sum_{tch} c_{tch}\, XCAP_{tch,t}^2 = EC_t \\ CAP_{tch,t+1} = expf\ CAP_{tch,t} + XCAP_{tch,t+1} \tag{9}$$

Where $CAP_{tch,t}$ is the capacity of technology *tch* during period *t*, and $XCAP_{tch,t}$ is the capacity installed beyond the capacity expansion factor *expf* that limits the projected capacity of technology *tch* in period *t* due to technological, economical and/or environmental factors.

Useful energy services from MARKAL are aggregated to form the energy input in the output (production) function of the Macro module. In the Macro module, there exists a competition between investment in energy and investment in the rest of the economy. Economic output is shaped based on this competition and this information is passed back to MARKAL. With this connection between MARKAL and Macro, MARKAL–Macro determines a baseline and resultant dynamic changes for energy services demand, carbon emissions, technology choices, and GDP. Even though aggregated energy demand responds to single price elasticity (*ESUB*), sub-sectoral energy service demands will react decoupled from aggregated energy demand dependent on the economic impacts of their reductions, in which demand marginals express the magnitude of those impacts.

In summary, MARKAL-Macro, with its described structure, is able to incorporate aggregated energy service demand feedback due to price changes in energy. Since the demand changes are autonomous, some energy service demands may be decoupled from economic growth. By integration of Macro portion; calculation of GDP, consumption and investment in an explicit manner is possible. Overall, detailed energy systems analysis is maintained, without loss compared to MARKAL.

## 3.4 Model Key Parameters

US MARKAL-Macro model uses 2000 real U.S. dollars as the financial metric throughout the modeling horizon. GDP growth estimates are 3%, 2.5% and 2.4% for 2010 – 2020, 2020-2030, 2030-2045 periods respectively in line with AEO 2010. Energy service demand changes through the modeling horizon are displayed in Table 1. Annual growth rate estimate for the period 2030-2045 is set to be long term historical average growth rate for the US.

Parameters regarding the Macro portion of the US MARKAL-Macro model are chosen to best represent the US economy. The aggregated elasticity of substitution between the energy aggregate and labor-capital aggregate (*ESUB*) is assumed to be 0.4, in line with the ETSAP estimate range, 0.2-0.5 (Loulou et al., 2004). The initial capital to GDP ratio, *kgdp, is* 2.4, and the optimal value share of capital in the value added nest, *kpvs*, is 24% are based on historical economic data for the US. Model wide discount rate of 5% real is used for all non-demand related sectors. For end use related technologies, hurdle rates (technology specific discount rates) are applied differentially to simulate the consumer’s reluctance to purchase newer technologies.

Table 1 Annual growth rates of demand (%)(Source AEO (2010)).

| Energy service demands | Average Growth | | |
|---|---|---|---|
| | 2010 - 2020 | 2020-2030 | 2030-2045 |
| *Commercial* | | | |
| *Cooking* | 1.16% | 1.30% | 1.23% |
| *Lighting* | 1.36% | 1.27% | 1.24% |
| *Misc - DSL* | -0.66% | -0.20% | -0.98% |
| *Misc - ELC* | 2.46% | 2.22% | 2.28% |
| *Misc - LPG* | 0.34% | 0.40% | 0.54% |
| *Misc - NG* | 0.53% | 1.42% | 0.98% |
| *Misc - RFL* | -0.58% | 0.13% | 0.74% |
| *Office Equipment* | 1.80% | 1.34% | 1.80% |
| *Refrigeration* | 1.36% | 1.27% | 1.24% |
| *Cooling* | 2.11% | 1.74% | 1.48% |
| *Heating* | 1.06% | 1.01% | 1.03% |
| *Ventilation* | 1.36% | 1.27% | 1.24% |
| *Water Heating* | 1.36% | 1.27% | 1.24% |
| *Industry* | | | |
| *Chemical* | 0.26% | -0.97% | -0.38% |
| *Food* | 1.92% | 1.61% | 1.67% |
| *Primary Metals* | 2.80% | -1.90% | -0.61% |
| *Non-metallic* | 2.19% | 0.49% | 0.59% |
| *Paper* | 1.33% | 0.48% | 0.61% |
| *Transport Vehicles* | 0.28% | 2.82% | 1.93% |
| *Aggregate Non-Manufacturing* | -0.09% | -0.51% | -0.22% |
| *Other Sector* | 2.99% | 1.31% | 1.65% |
| *Residential* | | | |
| *Freezing* | 1.40% | 0.99% | 1.14% |
| *Lighting* | 1.93% | 1.42% | 1.03% |
| *Refrigeration* | 1.29% | 1.61% | 1.30% |
| *Cooling* | 1.70% | 0.58% | 0.50% |
| *Heating* | 1.04% | 1.00% | 0.80% |
| *Water Heating* | 0.83% | 1.14% | 0.74% |
| *Other Appliances - Electricity* | 1.62% | 0.27% | -0.10% |
| *Other Appliances - Natural Gas* | 0.47% | -0.19% | -0.56% |
| *Transportation* | | | |
| *Air* | 1.61% | 0.98% | 1.35% |
| *Bus* | 1.16% | 1.09% | 1.12% |
| *Truck* | 1.93% | 1.42% | 1.34% |
| *High Duty Vehicle* | 2.33% | 1.82% | 1.75% |
| *Light Duty Vehicle* | 1.83% | 1.83% | 0.69% |
| *Offroad Diesel* | 0.16% | 0.16% | 0.16% |
| *Offroad Gasoline* | 0.18% | 0.18% | 0.18% |
| *Rail - Freight* | 1.34% | 0.74% | 0.63% |
| *Rail Passenger* | 1.52% | 1.15% | 1.24% |
| *Shipping* | 1.00% | 0.75% | 0.67% |

## 4 Results

We will report results on GDP, primary resource mix, electricity sector price and generation source changes, transport sector impacts, impacts on selected other sectors, and impacts on domestic GHG emissions. In each case, we will compare the reference case with the three levels of natural gas exports.

## 4.1 GDP impacts

Our analysis shows that increasing natural gas exports actually results in a slight decline in GDP. Essentially the gains from exports are less than the losses in electricity and energy intensive sectors in the economy. Figure 1 shows the changes in GDP over time. The GDP losses are around 0.04%, 0.11%, and 0.17% for the 6, 12, and 18 BCF/day cases respectively for the year 2035. We recognize that this result runs counter to the standard expectation that more open trade results in a net gain for society. However, modern trade theory has many instances of welfare losses to countries and regions from more open trade. Any combination of terms of trade or allocative effects can lead to reduced welfare from more open trade. In any event, the reduction in GDP is relatively small, but it is negative. When we examine the sectoral results below, the sources of the losses will become clearer.

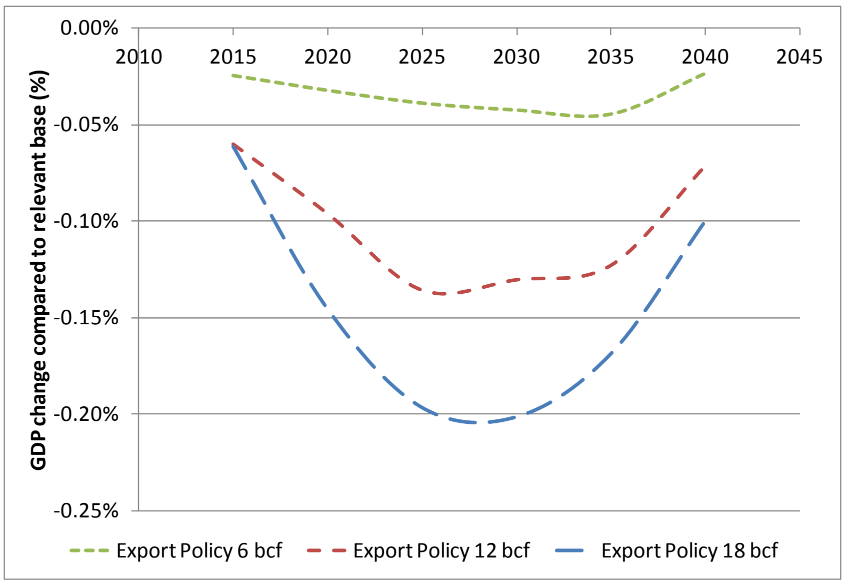


Figure 2 The changes in GDP over time in relevant scenarios compared to reference.

## 4.2 Energy resource mix

The change in energy resource mix with the different levels of natural gas exports for the year 2035 is shown in Table 2. The relative changes are similar for other years, so we pick 2035 to illustrate the differences among the export levels. The general trends are as follows: 1) the domestic energy share for natural gas falls from 25 to 22 percent) as exports of natural gas increase; 2) domestic use of coal increases from 21 to 23 percent as natural gas exports increase; 3) the fraction of oil in total consumption increases from 36 to 37 percent; 4) there are small increases in nuclear and renewables (hydro, solar, wind, and biomass). The directions of all these changes correspond to prior expectations.

Of course, the changes in primary energy mix are driven primarily by the changes in natural gas prices brought on by the increased demand for natural gas for export. Figure 3 shows the percentage changes in natural gas prices over time for the three export cases compared with the reference case. In 2035, natural gas price is 16%, 41%, and 47% higher for the 6 BCF, 12 TCF, and 18 BCF cases. These results are higher than the EIA and NERA analysis, and this difference likely is a major driver of the differences in results.

Table 2 Energy Resource Mix for 2035 for the Different Export Cases

| Energy source | reference | 6 BCF/day | 12 BCF/day | 18 BCF/day |
|---|---|---|---|---|
| Coal | 20.7% | 21.6% | 22.3% | 22.6% |
| Natural gas | 25.2% | 23.8% | 22.5% | 22.0% |
| Oil | 36.1% | 36.4% | 36.8% | 37.0% |
| Nuclear | 8.3% | 8.4% | 8.5% | 8.5% |
| Renewables | 9.3% | 9.4% | 9.5% | 9.6% |
| Elec. import | 0.3% | 0.3% | 0.3% | 0.3% |

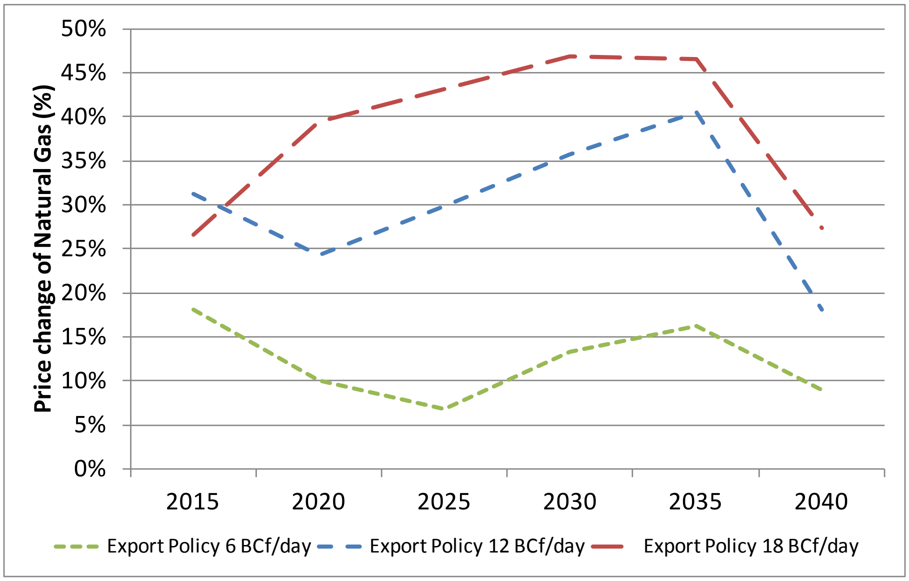


Figure 3 Price change wellhead Natural Gas price with respect to the reference as percentage.

The patterns of primary energy use over time are illustrated in Figure 4, which shows the time profile of primary energy use for the reference and 12 BCF/year cases. The patterns evident in Table 2 are clear in Figure 4, but also one can see that the total primary energy consumption is lower in the export case because of the negative impact on GDP.

## 4.3 Electricity sector impacts

The impacts on the electricity sector come in higher electricity prices and higher GHG emissions. In 2035, electricity price is up compared with the reference case by 1.1%, 4.3%, and 7.2% for the 6 BCF, 12 BCF, and 18 BCF cases respectively. Of course, these higher electricity prices are passed through the entire economy through industrial, commercial, and residential sectors.

Electricity GHG emissions in the early years of the simulation horizon are around 2% higher for the 6 BCF case, and 7-12% higher for the 12 and 18 BCF cases. However, by the end of the simulation period, the differences are all in the 1-4% range. This decline in emission difference is due to the emergence of less expensive renewable energy technology after 2020 and to some increase in nuclear. The increase in coal use shown in Table 2 exists, but the higher coal emissions relative to natural gas in later years are partially offset by lower emissions from nuclear and renewables. Coal use for electricity generation for the four cases is shown in Figure

5. In the early years, higher natural gas exports results in substantially higher coal use for electricity generation.

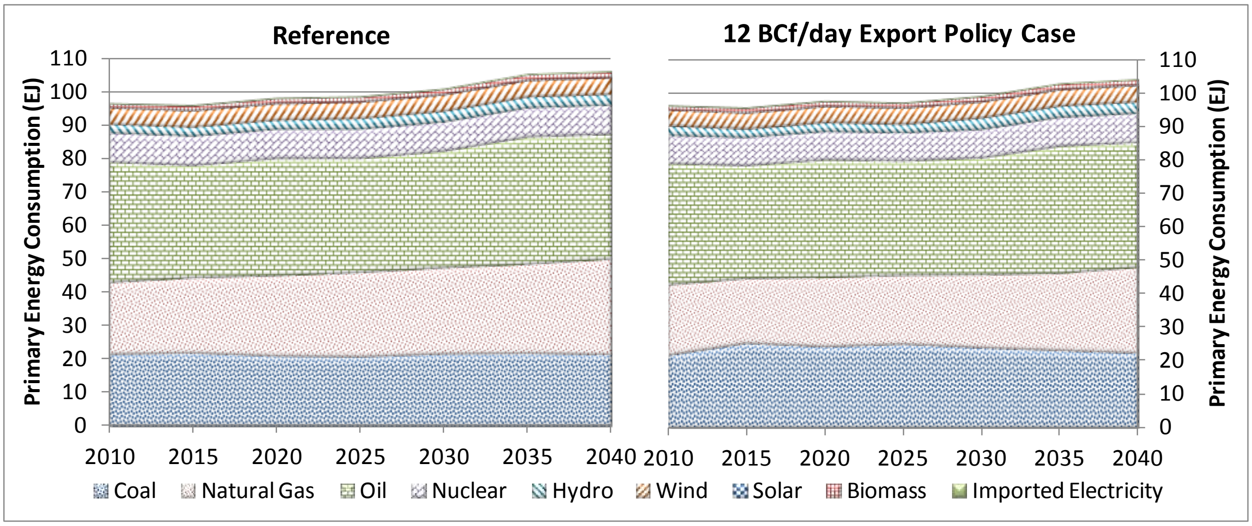


Figure 4 Primary energy mix for the 12 BCf/day export policy case and the reference scenario.

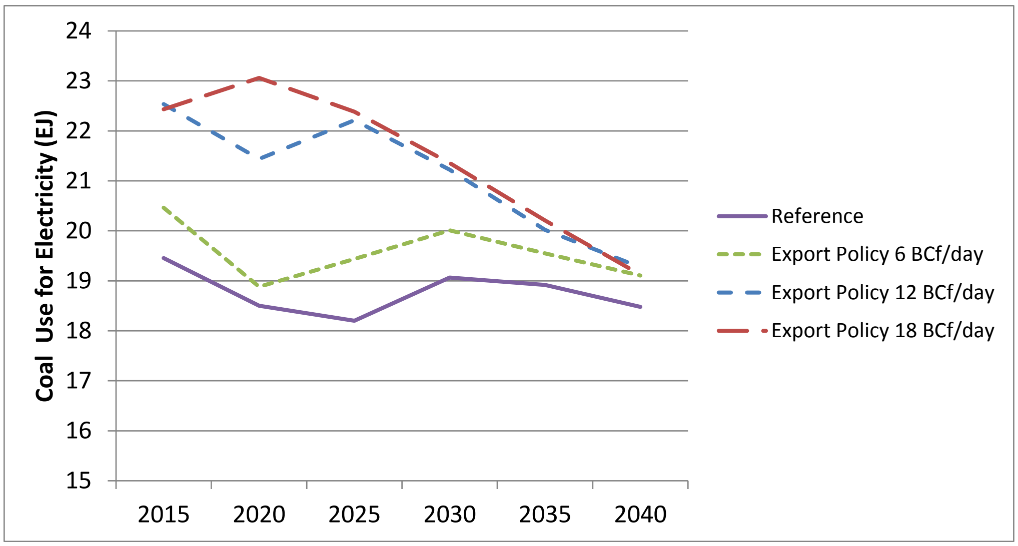


Figure 5 Coal use for electricity generation.

## 4.4 Transport sector

Figure 6 shows the CNG use in transportation over time for the reference and three export cases. In 2035, CNG use in transportation for the reference case is 1.3 bil. gal. gasoline equivalent, but it drops to 0.2-0.3 in the three export cases. Figure 7 shows what happens over time to fleet use of natural gas in the reference and 12 BCF cases. CNG use in heavy duty vehicles disappears in the 12 BCF case, and CNG use in most of the vehicle categories drops considerably. The bottom line is that while CNG use in transport is not large even in the reference case, it plummets in the export cases.

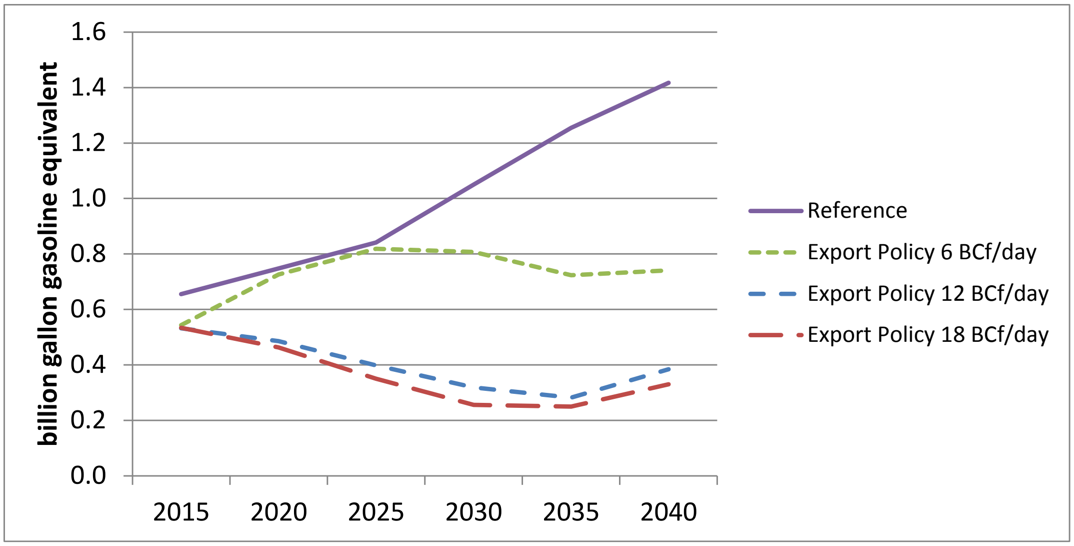


Figure 6 The CNG use in transportation over time for the reference and three export cases.

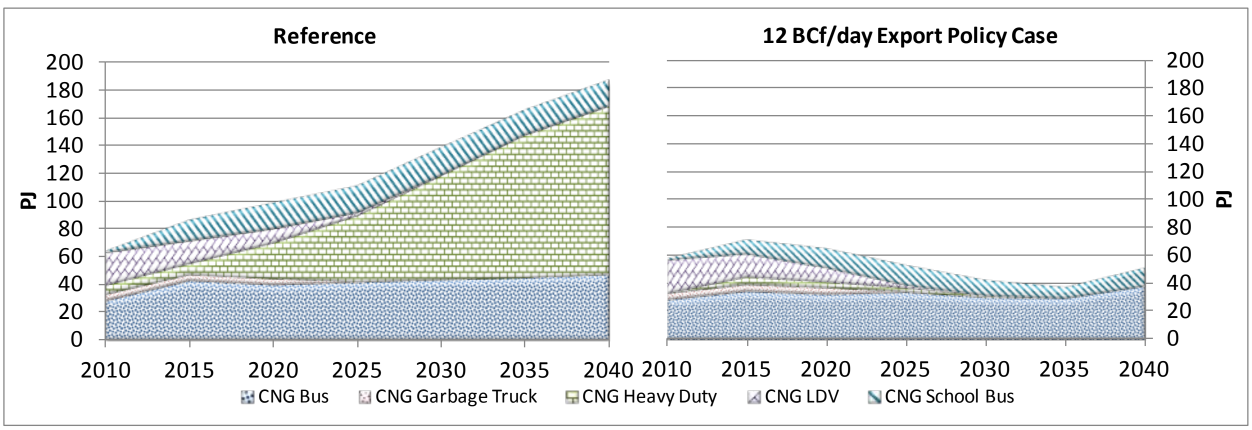


Figure 7 The CNG use breakdown in the Transportation Sector for the 12 BCf/day export policy case and the reference scenario.

## 4.5 Other sectors

Examination of impacts on certain sectors of the economy, particularly energy intensive sectors provides insight on why our analysis shows declines in GDP from the natural gas exports and associated higher natural gas prices. Table 3 provides the decline in total energy use in four important sectors of the economy for 2035. In every case, total energy use and therefore total sector output declines. The declines are less pronounced for the paper sector, which uses some renewable energy from wood.

## 4.6 Results with CES included in reference case

The Clean Energy Standard, as described above, substantially reduces GHG emissions in the electricity sector. Essentially, the sector goes from being 40% to becoming 80% clean by 2035. In all our results natural gas (considered 50% clean) plays a large role in meeting the CES. We do not know if the CES will be enacted or not, but increased attention on global warming suggests it is a real possibility and something that must be considered in evaluating future energy policy options.

Table 3 Declines in Total Energy Use for Four Important Sectors

| Sector | Percentage Energy Use Decline Relative to Reference Case in 2035 |
|---|---|
| Primary metals | |
| 6 BCF/day | -1.4 |
| 12 BCF/day | -3.0 |
| 18 BCF/day | -4.0 |
| Non-metalic | |
| 6 BCF/day | -2.2 |
| 12 BCF/day | -3.1 |
| 18 BCF/day | -3.5 |
| Paper | |
| 6 BCF/day | -0.8 |
| 12 BCF/day | -2.0 |
| 18 BCF/day | -2.8 |
| Chemical | |
| 6 BCF/day | -1.8 |
| 12 BCF/day | -2.4 |
| 18 BCF/day | -3.8 |

The biggest impact of the CES is substantially higher natural gas prices, as natural gas achieves significant penetration in the electric power sector. Thus, it is useful, first, to compare natural gas prices with and without the CES before moving to evaluating impacts of different levels of natural gas exports. Figure 8 shows the absolute price levels over time for the previous reference case and the reference with CES added. In every period, natural gas price is substantially higher under the CES than the standard reference. For example, in 2030, the reference price is $7.02, and the reference with CES is $10.60. Thus, the added demand for natural gas for electricity leads to much higher natural gas price even before considering exports.

Of course if we add exports, the price increases are even higher as illustrated in Figure 8, which shows the percentage increase in natural gas price with 12 BCF/day of exports for both the CES and standard reference cases, both compared with the standard reference. The bottom line is that the CES leads to relatively high natural gas price increases, which are accentuated by natural gas exports.

The GDP impacts of this policy case are pretty comparable with the cases described above. For example, the GDP reductions that were -0.10 to -0.15% for the standard reference are in the same range for the reference with CES. The sectoral impacts also were similar to the standard reference described above.

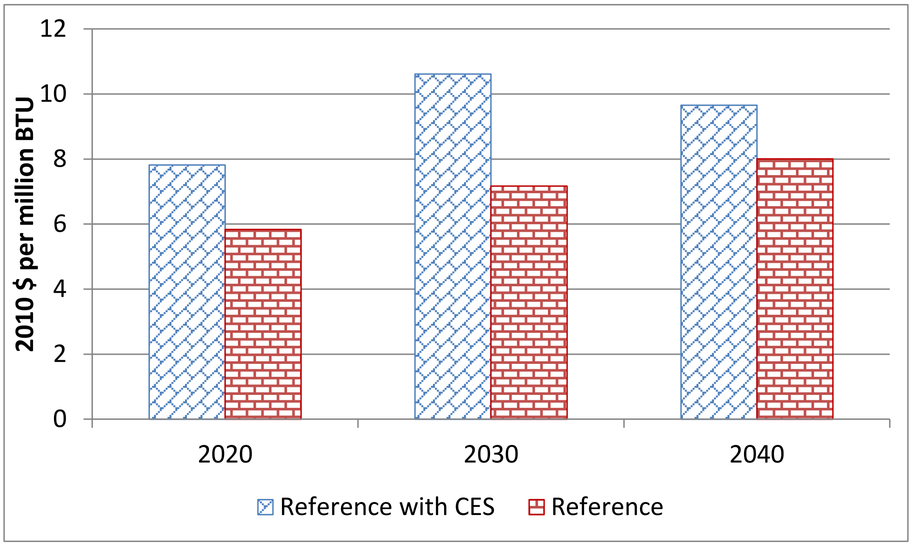


Figure 8 Wellhead Natural Gas prices

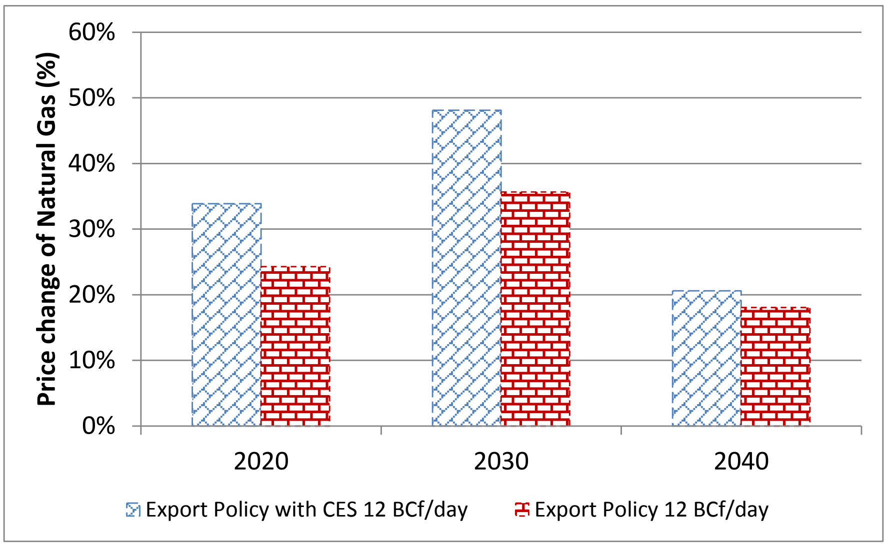


Figure 9 Natural Gas price change comparison for 12 BCf/day policy.

The primary energy source mix is quite different for the standard reference and reference with CES as would be expected. In the standard reference, coal use was relatively flat over the time horizon, and it increased with increasing natural gas exports. With the reference plus CES, coal use drops drastically (Figure 10) as would be expected since the CES cannot be met with so much coal power in the mix. Compare this primary resource mix with that shown in Figure 4 for the reference case.

Finally, we examine the impacts on the use of CNG in the transport sector. The CES virtually eliminates the use of CNG or LNG in the heavy duty truck sub-sector as shown in Figure 11. Compare this fleet mix (left panel of Figure 11 with the left panel of Figure 7. The right panel of Figure 11 shows the transportation fleets using CNG for the 12 BCF/day export level. It is clear that the combination of CES plus exports causes a huge reduction in CNG use in transportation in the US.

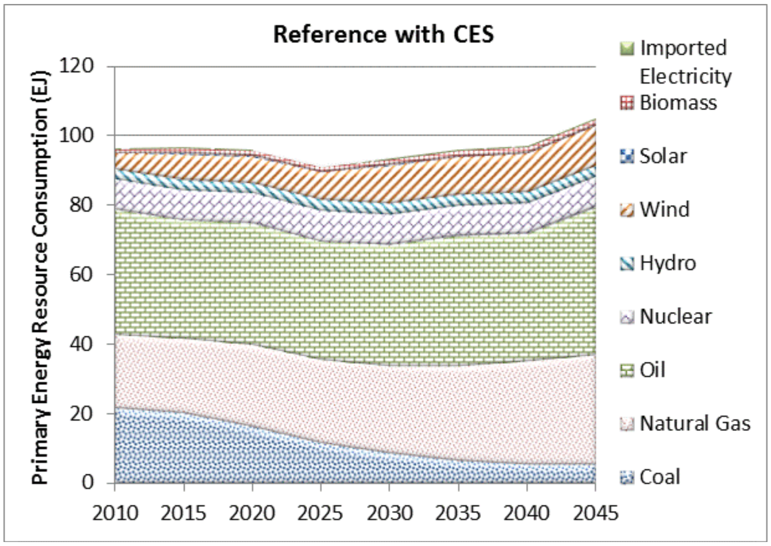


Figure 10 Primary energy mix for the Reference with CES policy.

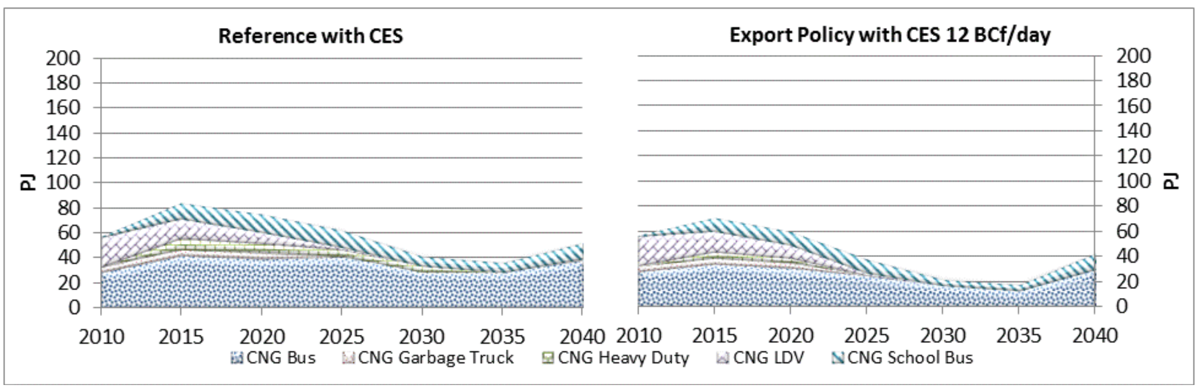


Figure 11 CNG use breakdown under selected policies.

## 5 Conclusions

The major conclusion of this research is that permitting natural gas exports causes a small reduction in US GDP and also increases GHG emissions and other environmental emissions such as particulates. There is loss of labor and capital income in all energy intensive sectors, and electricity prices increase. The major difference between our results and the other major study (NERA) are that we get considerably higher natural gas price impacts, and we do not get export revenue as large. The higher natural gas prices cause pervasive losses throughout the commercial, industrial, and residential sectors.

We also evaluate the impacts of natural gas exports in the presence of a Clean Energy Standard for electricity. In this case, the GDP and sectoral impacts are similar, but the impacts on electricity and transport are substantially different. The CES induces considerably higher natural gas prices because of the added demand for natural gas for power generation. Natural gas exports on top of CES cause prices to go even higher. In transport, the CES eliminates use of CNG or LNG for heavy duty trucks, and natural gas exports reduce CNG fleets substantially more in addition.

Beyond the analysis conducted here, it is important to note that neither the model used in this analysis nor the NERA model are global in scope. Thus, neither includes the trade impacts of US natural gas exports. However, we can describe those impacts qualitatively. Increased US natural gas exports will reduce energy costs for industry and consumers in foreign countries and increase those costs for the US. Thus, US industry will be rendered less competitive compared with foreign industry. This loss of export revenue would be in addition to the GDP loss estimated in this analysis. Moreover, US consumers lose due to higher energy prices, and foreign consumers gain.

Given all the results of this analysis, it is clear that policy makers need to be very careful in approving US natural gas exports. While we are normally disciples of the free trade orthodoxy, one must examine the evidence in each case. We have done that, and the analysis shows that this case is different. Using the natural gas in the US is more advantageous than exports, both economically and environmentally.

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