Energy Security and Climate Change Protection: Complementarity or Tradeoff?

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Abstract: Energy security and climate change protection have risen to the forefront of energy policy—linked in time and a perception that both goals can be achieved through the same or similar policies. Although such complementarity can exist for individual technologies, policymakers face a tradeoff between these two policy objectives. The tradeoff arises when policymakers choose the mix of individual technologies with which to reduce greenhouse gas emissions and enhance energy security. Optimal policy is achieved when the cost of the additional use of each technology equals the value of the additional energy security and reduction in greenhouse gas emission that it provides. Such an approach may draw more heavily on conventional technologies that provide benefits in only one dimension than on more costly technologies that both increase energy security and reduce greenhouse gas emissions.

Keywords: Energy Security; Climate Change; Energy Policy

1. Introduction

Over recent years, energy security and climate change protection have risen to the forefront of energy policy—linked in time and by a perception of complementarity. In November 2007, the International Energy Agency (2007) released what is probably its most pessimistic World Energy Outlook to date. If countries don't change their energy use policies, the agency said that oil and natural gas imports, coal use and greenhouse gas emissions are set to grow inexorably through 2030—trends that threaten to undermine energy security and accelerate climate change. The U.S. Energy Information Administration (2007) outlines a similar perspective, with world energy consumption growing by 1.8 percent per year through 2030 and conventional oil production from the Organization of Petroleum Exporting Countries (OPEC) rising by 2.0 percent per year.

In addition, those who examine specific energy conservation or alternative fuel technologies, such as oil conservation or the substitution of biofuels for petroleum products, frequently observe a complementarity between the abatement of greenhouse gases and an increase in energy security (Farrell et al, 2006; Tyner, 2007). For example, by reducing reliance on fossil fuels that are also vulnerable to disruption (e.g., oil and natural gas from the Persian Gulf oil and natural gas from Russia), an individual technology can both reduce greenhouse gas emissions and enhance energy security.

Although such complementarity can exist for individual technologies, policymakers are confronted with a tradeoff between these two policy objectives.[1] The tradeoff arises when policymakers choose the mix of individual technologies with which to reduce greenhouse gas emissions and enhance energy security. Various technologies have different costs and contribute differently to the achievement of either or both objectives. As a result, cost differences could lead to an optimal policy that includes a suite of technologies that each contributes more to a single policy objective rather than to individual technologies that contribute to both objectives.

2. Enhancing Energy Security and Protecting Against Climate Change

The use of a specific alternative energy or energy conservation technology can improve energy security, protect against the accumulation of greenhouse gases, or provide a combination of these two policy goals. Suppose that these two policy objectives are well defined and their benefits can be easily measured. In either case, private markets are not likely to provide these social benefits without further government intervention because enhanced energy security and reduced greenhouse gas emissions confer external benefits that are not reflected in private market pricing. Policy could take the form of pricing these externalities, promoting the use of specific technologies or mandating energy use consistent with the policy objectives.

Figure 1 provides some examples of how different technology options compare in providing energy security or climate change protection. Under baseline conditions, the levels of energy security and greenhouse gas emissions are projected for a future year and plotted at the origin of Figure 1. Energy security can be improved from these baseline conditions by increasing along the vertical axis, and climate change protection can be improved by expanding along the horizontal axis. Security increases as the nation reduces the risks associated with being more vulnerable to an energy supply disruption, and climate protection increases as the nation reduces the risks associated with more anthropomorphic global climate change.[2]

Broadly speaking, an improvement in energy security is achieved by reducing the vulnerability of economic activity in a country to potential disruptions of energy supply. Energy security can be improved by replacing more vulnerable supplies with more stable sources.[3] Any particular disruption event will remove less supply and have a smaller price impact when the disrupted source comprises a smaller share of the total market prior to the disruption. Security can also be improved by ameliorating the economic impacts of any given energy price shock. A nation can reduce these economic impacts by making its economic infrastructure less dependent on the vulnerable fuel.

Climate change protection risks depend upon many factors that are only now becoming well understood. The Intergovernmental Panel on Climate Change (2007) assessment report is more certain about the role that fossil fuels play in global climate change than previous assessments, but there remains considerable uncertainty about the relative importance of both anthropomorphic and natural sources in total greenhouse gas concentration levels. Similarly, the precise relationship between greenhouse gas concentration and more detailed climatic change impacts is being actively researched. The principal climate change risks associated with the different technologies shown in the figure are related to the amount of greenhouse gases emitted from using each source rather than to any of the basic scientific uncertainties identified above.

Some options operate primarily in the energy security dimension. The figure shows the Strategic Petroleum Reserve (SPR) with an arrow directed primarily in the vertical dimension. A larger SPR with a more effective trigger mechanism for releasing oil during a disruption might conceivably improve energy security, but its negligible impact on energy consumption would not abate greenhouse gas emissions. Similar principles apply to expanding domestic oil supplies, including the development of the Arctic National Wildlife Refuge (ANWR) in Alaska.

Other options shown in the figure provide stronger climate protection benefits. Ethanol or soybean diesel might improve security by replacing more vulnerable oil sources while at the same time emitting fewer greenhouse gas emissions than gasoline. The figure differentiates between corn-based ethanol, soybean diesel and cellulosic ethanol, with the latter option showing more horizontal direction because its use abates more greenhouse gases per unit of energy. Corporate automobile fuel efficiency (CAFE) rules for new vehicles might improve security by reducing the dependence on oil supplies as well as improve climate protection by decreasing gasoline use.

Finally, we show the use of nuclear power and renewable portfolio standards (RPS) to promote the use of solar and wind energy for generating electricity as the most horizontal ray in the figure. Increased use of these technologies would reduce greenhouse gas emissions from coal- and natural gas-fired power plants, and could reduce the electricity sector's dependence on vulnerable natural gas imports to some extent. The overall effects of enhanced energy security in electric power generation are likely to be substantially less than for transport fuels until electric and plug-in hybrid vehicles penetrate the transportation sector. Other similar options, not shown in the figure, would be any one of several electricity-efficient technologies, such as compact fluorescent light bulbs (CFL) replacing traditional incandescent bulbs.

The examples in Figure 1 are illustrative and do not exhaust the many different technology options. Other possibilities include pursuing technologies to the left of the vertical axis in Figure 1 that improve energy security at the expense of reduced climate protection. Such technologies include developing coal-to-liquids, oil sands and oil shale. All these technologies diversify the sources of transport fuels but are currently expected to increase greenhouse gas emissions unless they are supplemented by some form of carbon sequestration.

In the same vein, but with a smaller consequence for energy security, might be policies that relaxed mercury and other environmental restrictions on coal use in electric power plants or that otherwise encouraged more coal use without carbon sequestration. Coal supplies might be more secure than Persian Gulf or Russian natural gas, but greenhouse gas emissions would be higher. The opposite case could arise from expanded use of imported natural gas to displace coal in electric power generation.

The growing use of imported liquefied natural gas (LNG) presents contrasting cases by itself. For Western Europe, LNG will likely originate from North Africa and the Persian Gulf. Such imports may enhance energy security because they are seen as more stable than natural gas piped from Russia, which is currently the source for most imported natural gas in Western Europe. In contrast, LNG imports may be seen as less reliable than domestic natural gas and detracting from energy security in North America.

3. Energy Security and Climate Change Policy

The tradeoff between energy security and environmental protection is more apparent when the choice between policy options requires one benefit to be substituted for another. What is less obvious is that reliance on a single technology option that simultaneously improves security and protection also can involve a tradeoff. The opportunity cost of pursuing this single option comes from not pursuing a different strategy of mixed options to achieve the same level of benefits. Optimal policy involves sorting through the available technologies to pick the most cost-effective means of pursuing what can be conflicting goals for energy policy—energy security and environmental protection. We consider both optimal policy and the tradeoff between energy security and climate protection at a given cost.

3.1 Optimal Policy

Consider *n* energy conservation and alternative fuel technologies (x_1 through x_n) with each technology enhancing energy security and abating greenhouse gas emissions. As was shown in Figure 1, the individual technologies offer gains in these two objectives at differing ratios. The total provision of energy security, S, is the summation of the individual security enhancement, s_i, associated with the increased use of each energy conservation or alternative-fuel technology, x_i, as follows:

$$S = \sum_{i=1}^{n} s_i(x_i) \qquad \textbf{(1)}$$

where the use of each technology is assumed to be separable for purposes of analysis. Likewise, the total abatement of greenhouse gas emissions, Q, is the summation of the individual abatement, q_i, associated with each technology, x_i, as follows:

$$Q = \sum_{i=1}^{n} q_i(x_i) \quad \textbf{(2)}$$

Similarly, total program costs, C, are the summation of the individual total cost, c_i, associated with each technology, x_i, as follows:

$$C = \sum_{i=1}^{n} c_i(x_i) \quad \textbf{(3)}$$

where total cost increases at an increasing rate with the greater use of each individual technology ($\partial c_i^2/\partial^2 x_i > 0$).[4]

Minimizing cost, C, for achieving a given level of energy security, S, and a given abatement of greenhouse gas emissions, Q, along with some rearranging of terms, yields a general expression for the optimal deployment of technology to both increase energy security and reduce greenhouse gas emissions

$$\partial C / \partial x_i = \lambda_S \cdot \partial s_i / \partial x_i + \lambda_Q \cdot \partial q_i / \partial x_i \qquad \text{for each } i = 1, 2, \ldots, n \quad \textbf{(4)}$$

where λ_S is the incremental value of increasing energy security, and λ_Q is the incremental value of reducing greenhouse gas emissions.[5] Likely, the appropriate values of λ_S and λ_Q are determined through a political process, possibly with the help of economic-environmental studies or models.

As shown by equation 4, the optimal mix of policy is achieved when each technology is used to the point where the marginal cost of the technology equals the value of the additional energy security and reduction in greenhouse gas emission that it provides. Consistent with the optimality condition, the policy with the lowest overall costs may rely more heavily on conventional technologies (such as the strategic petroleum reserve and nuclear power) that provide benefits in only one dimension, than on more costly technologies (such as cellulosic ethanol) that both increase energy security and provide a reduction in greenhouse gas emissions.

The optimality condition also helps us understand how sound policy can be built from two technologies that each seem to work against one of the objectives. The increased use of coal-to-liquids to displace imported oil might increase energy security while reducing climate protection more modestly; there is a large positive $\partial s_i/\partial x_i$ and a small negative $\partial q_i/\partial x_i$. In contrast, the use of imported LNG to displace domestic coal might modestly reduce energy security while boosting climate protection; there is a small negative $\partial s_i/\partial x_i$ and a large positive $\partial q_i/\partial x_i$. Combining the two policies may be akin to displacing imported oil with imported LNG, depending on the tradeoffs between the two policies and the relative costs of the various technologies. Both energy security and climate protection might be enhanced by a strategy that is cost effective, even though each of the technologies employed works against one of the two objectives.

3.2 The Policy Tradeoff

Even when cost-effective technologies offer complementarity between enhanced energy security and reduced greenhouse gas emissions, policymakers face a tradeoff in setting policy. The tradeoff arises in selecting the mix of technologies to pursue for purposes of policy. The opportunity cost of using any given technology is the use of another technology.

Assuming each energy-conserving and alternative-fuel technology has different attributes in improving energy security and abating greenhouse gas emissions, the optimality condition yields a solution surface with the combinations of increased energy security and reduced greenhouse gas emissions that are consistent with a given cost (Figure 2).[6] Differing values of λ_S and λ_Q determine the positions along a given cost surface. Higher values of λ_S and lower values of λ_Q yield more energy security and less abatement of greenhouse gases. Similarly, lower values of λ_S and higher values of λ_Q yield less energy security and more abatement of greenhouse gases.

If policymakers assign a zero value to reducing greenhouse gas emissions—and all the technologies considered offer some gains in energy security—rearranging terms yields a familiar result:

$$\partial C / \partial s_i = \lambda_S \qquad \text{for each } i = 1, 2, \ldots, n \qquad \textbf{(5)}$$

To maximize energy security for any given cost, each technology should be used to the point where the marginal cost of additional energy security is equal across technologies. In Figure 2, the locus of such points is shown by the ray labeled *max S*. Along the ray, the degree to which each technology is implemented depends strictly on its usefulness in improving energy security rather than its usefulness in reducing greenhouse gas emissions. For the cost surface shown in Figure 2, S* is the policy that yields the greatest increase in energy security.

Because energy-conserving and alternative-fuel technologies have different attributes in improving energy security and abating greenhouse gas emissions, maximizing the energy security at any given cost will yield a smaller reduction in greenhouse gas emissions than would policies directed to achieve the abatement of greenhouse gas emissions. Those technologies offering the largest gains in energy security at the lowest costs will be the most heavily implemented.

Similarly, if policymakers assign a zero value to enhancing energy security and all the technologies considered offer some abatement of greenhouse gases, rearranging terms yields a familiar result:

$$\partial C / \partial q_i = \lambda_Q \qquad \text{for each } i = 1, 2, \ldots, n \qquad \textbf{(6)}$$

To maximize the abatement of greenhouse gases for any given cost, each technology should be used to the point where the marginal cost of the additional abatement of greenhouse gas emissions is equal across technologies. In Figure 2, the locus of such points is shown by the ray labeled *max Q*. For the cost surface shown in Figure 2, Q* is the policy that yields the greatest abatement of greenhouse gases.

Because energy-conserving and alternative-fuel technologies have different attributes in improving energy security and abating greenhouse gas emissions, maximizing the abatement of greenhouse gas emissions at any given cost will yield a smaller gain in energy security than would policies aimed to achieve gains in energy security. Those technologies offering the largest reductions in greenhouse gases at the lowest costs will be the most heavily implemented.

Thus, we find for a given cost that there is a tradeoff between energy security and abating greenhouse gases—even if all the available technologies offer complementarity between enhanced energy security and reduced greenhouse gas emissions. This tradeoff arises in choosing the mix of technologies through which to pursue both goals. At any given cost, the increased use of any one technology must result in the reduced use of another technology.

4. Concluding Remarks

Policy discussions can sometimes emphasize that a single technology, such as ethanol or gasoline conservation, can provide both energy security and climate protection. This two-for-one appeal is attractive, but it can distract policy from the pursuit of a combination of options that could provide the same energy security and climate protection benefits at a lower cost. For example, a much improved SPR with a workable trigger mechanism might be grouped with an aggressive nuclear or RPS program. Alternatively, any set of options could be grouped together to form a viable policy strategy. Which options should be adopted and by how much will depend upon their relative costs. The danger of focusing upon only those options that simultaneously protect against both risks is that some deserving low-cost alternatives may be left unused and sitting on the shelf.

Moreover, the fact that some technologies offer complementarity between energy security and climate protection may obscure the fact that policymakers face a tradeoff when pursuing both policy goals. That tradeoff arises when policymakers select the mix of technologies to pursue both goals. Optimal policy can be achieved by pricing both energy security and greenhouse gas abatement and pursuing each technology to the point where its additional cost is equal to the marginal benefits achieved in both dimensions.

The pursuit of optimal policy could result in the adoption of a suite of technologies in which each contributes more to a single policy objective than to the heavy reliance on a few technologies, each of which contributes to both objectives. Such a suite might even include technologies that greatly further one objective while working slightly against another.

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Figure 1
Technologies for Abating Greenhouse Gases and Improving Energy Security

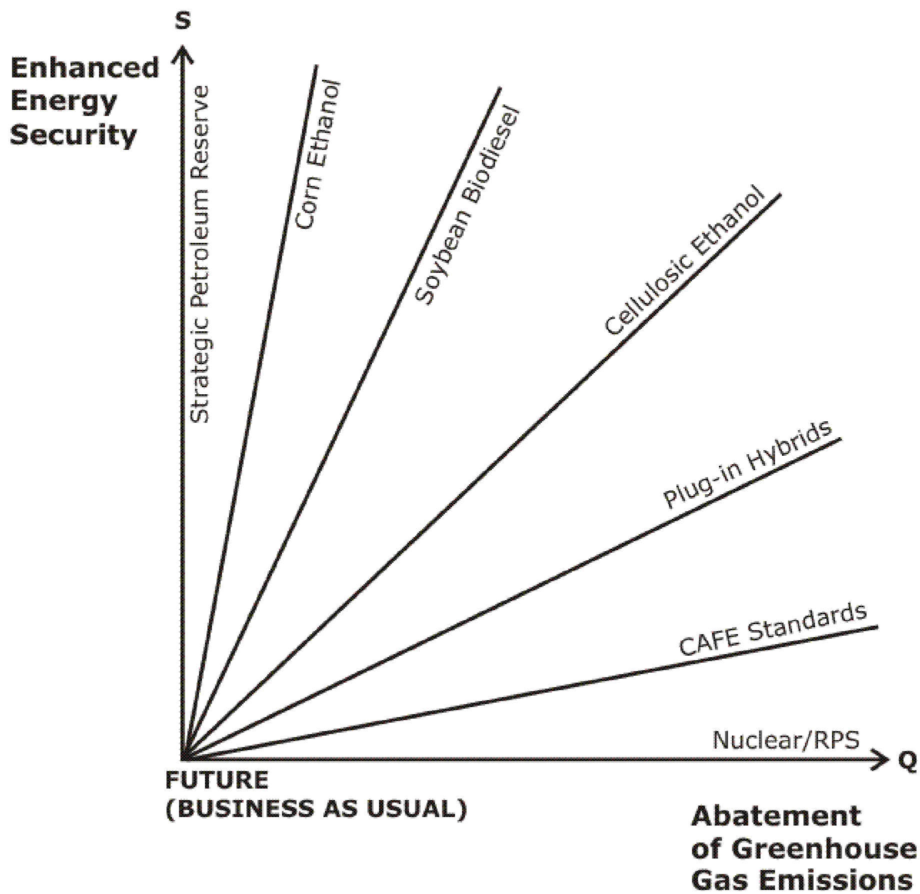
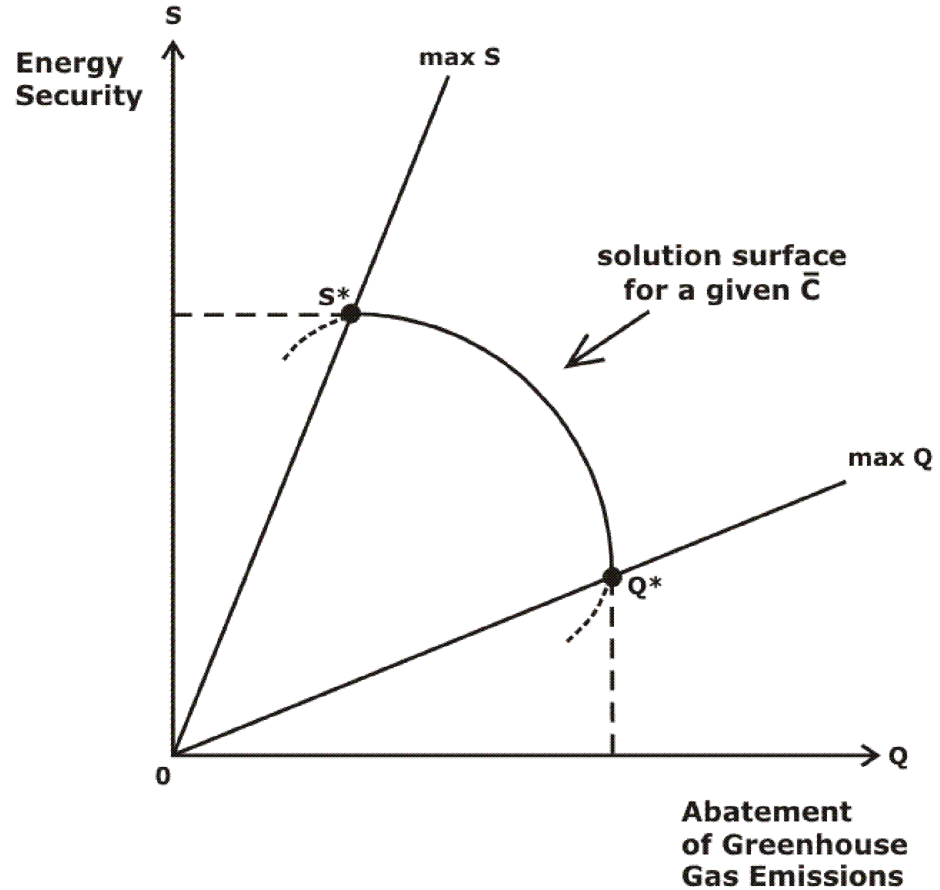


Figure 2
Tradeoff between Abating Greenhouse Gases and Improving Energy Security



Notes:

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[1] The possibility of tradeoffs and synergies between security and climate protection have also been discussed by Brown and Huntington (2004) and Turton and Barreto (2006). In contrast to these earlier papers, we focus on discussing general principles for designing policy strategies rather than specific scenario results.

[2] For simplicity, Figure 1 shows a linear relationship between energy security and climate protection for each technology option. One can imagine non-linearities in these relationships as the use of each technology increases from the origin. Similarly, the figure does not show cost contours. The cost contours connecting the disparate technologies represented in the figure are likely to be irregular rather than well behaved.

[3] Vulnerable sources do not need to be imports, and stable sources do not need to be domestic supplies.

[4] The exercise allows for the initial total costs of any technology to be negative. The increased use of any technology must eventually result in the positive marginal costs ($\partial c_i/\partial x_i > 0$) that are necessary for the model's solution.

[5] To minimize cost subject to given values of energy security and greenhouse gas abatement, the first derivatives of the expression $C - \lambda_S \sum s_i(x_i) - \lambda_Q \sum q_i(x_i)$ are set equal to zero, where λ_S and λ_Q are Lagrangian multipliers. The interpretation of λ_S and λ_Q as the respective shadow values of increased security and reduced greenhouse gas emissions are the properties of the dual.

[6] Solution of the optimization problem allows us to draw well-behaved cost contours, as is shown in Figure 2.