ERG/200905

Energy wedges: A systematic way to address energy security and greenhouse gas emissions

Larry Hughes, PhD
Energy Research Group
Department of Electrical and Computer Engineering
Dalhousie University
Halifax, Nova Scotia, Canada

larry.hughes@dal.ca
http://lh.ece.dal.ca/enen

6 May 2009

A version of this paper will be presented at the Fifth Dubrovnik Conference on Sustainable Development of Energy, Water, and Environment Systems in Dubrovnik, Croatia, September 2009.

Energy wedges: A systematic way to address energy security and greenhouse gas emissions

Larry Hughes

Abstract

Energy security and the anthropogenic emissions of greenhouse gas are two of the most significant energy-related challenges facing the world in the twenty-first century. Policies and programs put in place today will have long-term and far-reaching economic, social, and environmental impacts. Despite the importance of energy to the world's well-being, many people, policymakers, and politicians have difficulty understanding these energy challenges.

The four 'R's is an approach to clarifying energy issues and making energy policy understandable. In this case they are applied to energy security and greenhouse gas emissions: review (understanding the problem), reduction (use less energy), replacement (replace existing supply with sources that are secure or low-carbon, or both), and restriction (limit new demand to sources that are secure or low-carbon, or both).

This paper introduces a graphical representation of the four 'R's known as energy wedges. Wedges allow the long-term effects of energy policy to be visualized and hence explained to—or by—those who are developing energy policies, enacting them, and being affected by them.

1 Introduction

It is generally agreed that the world is facing two significant energy-related challenges: energy security and the increased emissions of greenhouse gases. Despite this, the general public, many policymakers, and politicians have difficulty understanding energy issues in general and these problems in particular (Smith 2002, McKeown 2007). As a result, one finds energy policies that are often unclear, counterproductive, and motivated by short-term political expediency (Brown 2007, Bryce 2008). These energy challenges suggest that there is a need for efficient and effective energy policies that are understandable to the public, policymakers, and politicians.

A methodology, known as the four 'R's of energy security, allows for the development of energy policies targeted to specific energy services or tasks and can be used to explain the state of a jurisdiction's energy security and how it can be improved. The methodology consists of four 'R's: review (understanding the problem), reduce (using less energy), replace (shifting to secure sources), and restrict (limiting new demand to secure sources) (Hughes 2009). It can be applied to the energy services used by individuals and organizations and can also be employed as a method for developing a jurisdiction's energy policies and improving its energy security. Although originally intended for energy security, the four 'R's are equally applicable to other energy policy issues, such as greenhouse gas emission reduction, as will be demonstrated in this paper.

Energy policy is temporal in nature, spanning years or even decades. By classifying different energy policies into one of reduction, replacement, or restriction in terms of time, it is possible to see the effects of past energy policies or the anticipated outcomes of existing ones. As policies effectively start at a zero point and change consumption patterns over time, a wedge shape is created with a horizontal axis (time) and a vertical axis (demand).

Energy wedges have occurred throughout history; for example, as one fuel source replaces another. More recently, they have been proposed as a means of addressing greenhouse gas emissions (Pacala and Socolow 2004), illustrating the potential policy benefits of restricting all new energy supply and services to low- or non-carbon energy sources, thereby effectively stabilizing existing greenhouse gas emissions at a known level. This paper extends the generic energy wedge into three distinct ones that can be applied to both energy security and greenhouse gas emissions. The paper also demonstrates the versatility of energy wedges: as an educational tool, a policy instrument, and a way to consider different energy futures.

2 Energy Demand

Even the most casual examination of a graph representing energy demand will show demand changing over time. Depending upon the jurisdiction, this demand is met by a variety of primary energy sources. In most, but by no means all, cases, the demand for each energy source increases over time; an example of the changes in the demand for primary energy in the United States is shown in Figure 1.

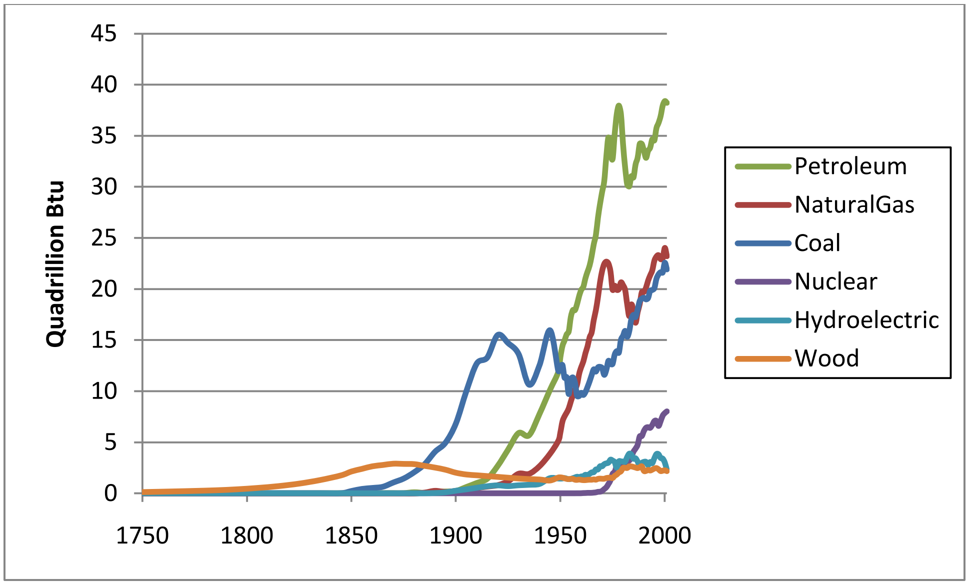

Figure 1. Primary energy sources in the United States (DOE/EIA 2002)

The demand for primary energy is not limited to the United States, as most other developed countries show similar trends. When a decline in demand does occur, it can be explained by a variety of factors, including:

- Political, typified by the first brief drop in demand for petroleum in the 1970s caused by the two “oil shocks”,
- Economic, the declines in petroleum and natural gas consumption in the United States in the 1980s,
- Technological, the shift away from petroleum for electrical generation and the rise of nuclear power, and
- Consumer preference, the decline of wood in the late 1800s due to the availability of other, more convenient, energy sources, notably coal and then petroleum.

Environmental concerns can also drive changes in the demand for different energy sources. In the case of the European Union, the demise of the Soviet Union and its satellite states led to a significant drop in energy demand, especially from coal. The expansion of the EU into Eastern Europe was followed by an uptake in natural gas rather than a return to coal. These changes in primary energy demand are shown in Figure 2.

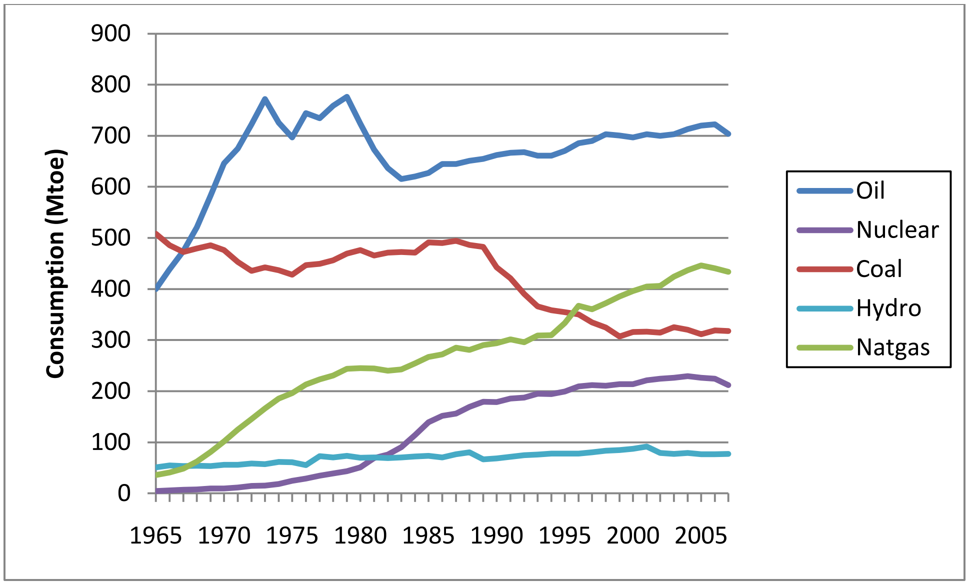

Figure 2. Primary energy demand in the European Union (BP 2008)

In recent times, one of the most significant arguments for changing energy demand in much of the developed world has been the increase in anthropogenic greenhouse gas emissions, notably carbon dioxide. For example, in 2001, the Intergovernmental Panel on Climate Change (IPCC) released its third assessment report, which presented a 50-year "business-as-usual" case where, by mid-century, greenhouse gas emissions doubled from seven to 14 gigatonnes of carbon (GtC) per year (IPCC 2001).

In an attempt to avoid these levels of emissions and to impose a degree of rigor to any emissions reduction strategies, Pacala and Socolow proposed holding world emissions constant at seven GtC/year by replacing the business-as-usual (represented as a triangle) with a set of seven "stabilization wedges" (Pacala and Socolow 2004). Each stabilization wedge would start at zero, grow linearly, and after 50 years would be reduced to the equivalent of one GtC/year; together, the seven wedges would eliminate a total of seven GtC/year by mid-century. The authors proposed fifteen stabilization wedges, including increased building efficiency, a shift to natural gas, nuclear, wind, solar (PV), and biomass, and carbon capture and storage.

3 Energy Wedges

Over time, all energy sources exhibit changes in consumption, growing or declining, depending on a variety of factors, including price and availability. Each of these changes can be attributed to factors that encouraged reduction in the consumption of energy from one or more sources, replacement of one energy source with one (or more) others, and restriction of new consumption to specific sources.

The effect on demand depends upon the type of wedge being applied. A reduction wedge represents actions that reduce demand for a given energy service. Replacement wedges are employed when an existing insecure or environmentally destructive energy source is replaced by one that is secure. A restriction wedge is for new demand and limits the supply to secure sources. All three wedges illustrate the annual interim steps required of a jurisdiction to meet some long-term target.

The three energy wedges can also be applied to environmentally-related energy issues such as greenhouse gas emissions. Ideally, the energy sources used for replacement and restriction wedges should be both secure and low-carbon; however, when security of supply is lost, political expediency can lead to the development of wedges that favour security over the environment.

The remainder of this section shows how these three 'R's can discussed in terms of energy wedges. (Review, the fourth 'R' is still required, as it is necessary to determine the state of a jurisdiction's energy supplies, the infrastructure required for producing, distributing, and possibly storing the energy, and the associated costs to the consumer.)

3.1 Reduction wedges

Policies that lead to a reduction in energy demand can have an impact on energy security, greenhouse gas emissions, or both. Energy reduction can be accomplished through both energy conservation and energy efficiency measures. In energy conservation, less energy is available for a particular energy service, often meaning that the same service is not performed to its previous levels, whereas improvements in energy efficiency allows the same level of service to be achieved with less energy. It should be noted that improving energy efficiency does not necessarily result in a reduction in energy consumption (Sorrell 2007).

An energy reduction wedge is one that, over time, brings down existing or potential demand. A reduction wedge is shown in Figure 3.

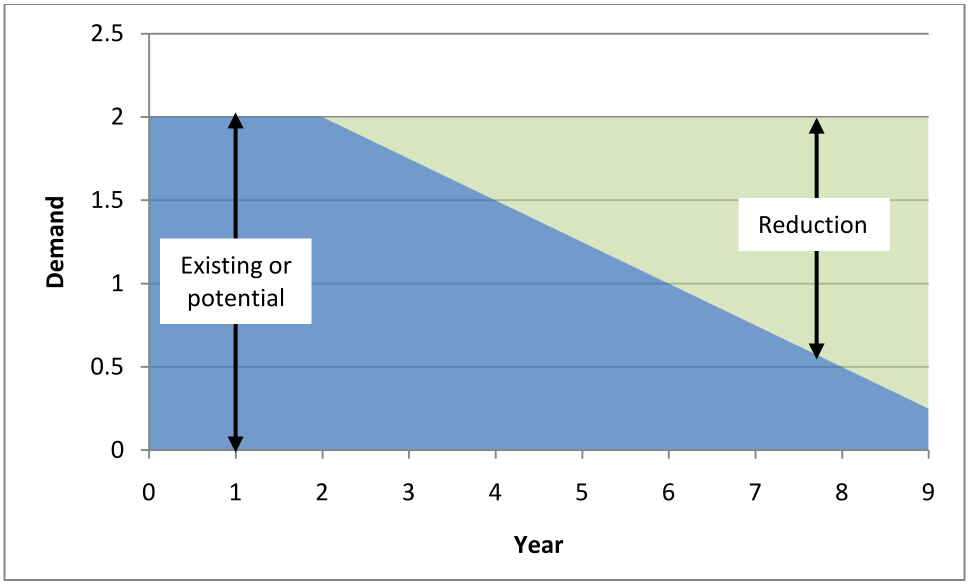

Figure 3. Existing (or potential) demand is decreased by the reduction wedge

Policies for reducing potential demand can be applied to most energy services. Examples include building codes that require a reduction in energy intensity or vehicle fuel-economy standards that expect less fuel demand per kilometre.

3.2 Replacement

The impact of reduction policies is limited by the fact that any anthropogenic system (whether it is household, industry, or country) requires a minimum level of energy to function. Therefore, in addition to reducing demand, policies intended to improve energy security and reduce greenhouse gas emissions also require the replacement of those energy supplies deemed insecure and carbon-intensive with ones that are secure with lower carbon intensity. Most, if not all, replacement policies are achieved by either diversifying energy supplies or changing infrastructure to allow alternative energy sources. Figure 4 shows how a replacement wedge supersedes existing demand over time.

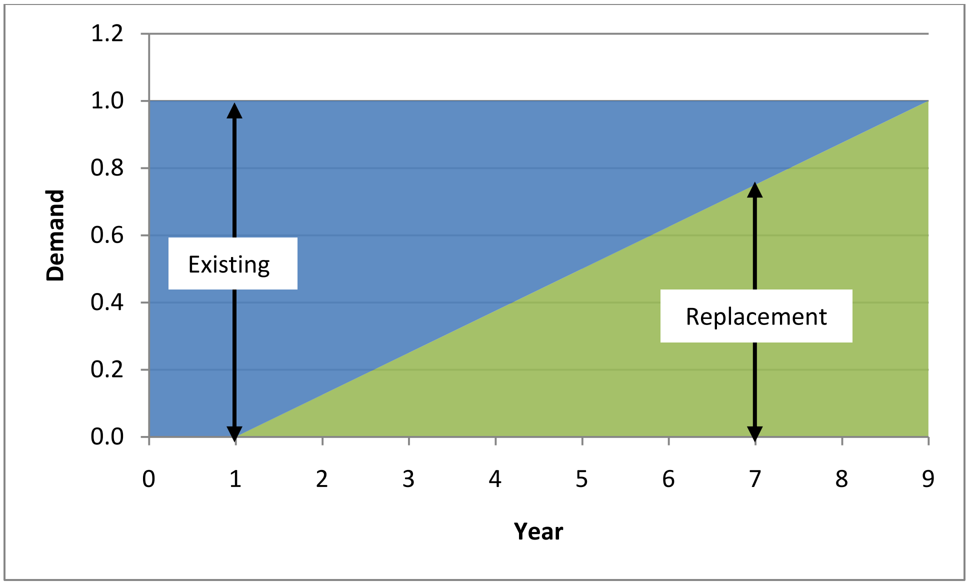

Figure 4. Existing demand is supplanted by the replacement wedge

In diversification, the same form of energy is used the meet the demands of the energy service, but the supplier changes. The oil embargos of the 1970s resulted in the United States diversifying its oil supplies by replacing much of its Middle Eastern oil imports with supplies from Canada, Venezuela, Mexico, and Nigeria (EIA 2008).

Alternative energy sources are ones that differ from the existing one but perform the same or similar task, often using different infrastructure. One such example is the worldwide switch from oil to coal and nuclear for electrical generation in the late 1970s due to rising oil costs, driven in part by the first oil shock in 1970s (Gue 2008). The move from coal to natural gas and nuclear in the UK for electrical generation is another; due largely to the coal miners' strike in the UK which threatened supply in the early 1980s (Parker and Surrey 1995).

3.3 Restriction

Jurisdictions undergoing industrialization, economic growth, or increasing affluence will often experience an increased demand for new supplies of energy. Ideally, any of these should be restricted to energy sources that improve energy security and reduce greenhouse gas emissions. Restriction differs from replacement in that it targets new, rather than existing, demand.

Restriction policies may be easier in theory than in practice as the jurisdiction may not have access to the necessary energy sources or infrastructure to meet the new demand from secure or low-carbon sources, meaning that a portion of the energy may not come from sources that address security or emissions issues.

As with reduction and replacement, restriction wedges increase in size over time.

Figure 5 shows a restriction wedge atop existing demand.

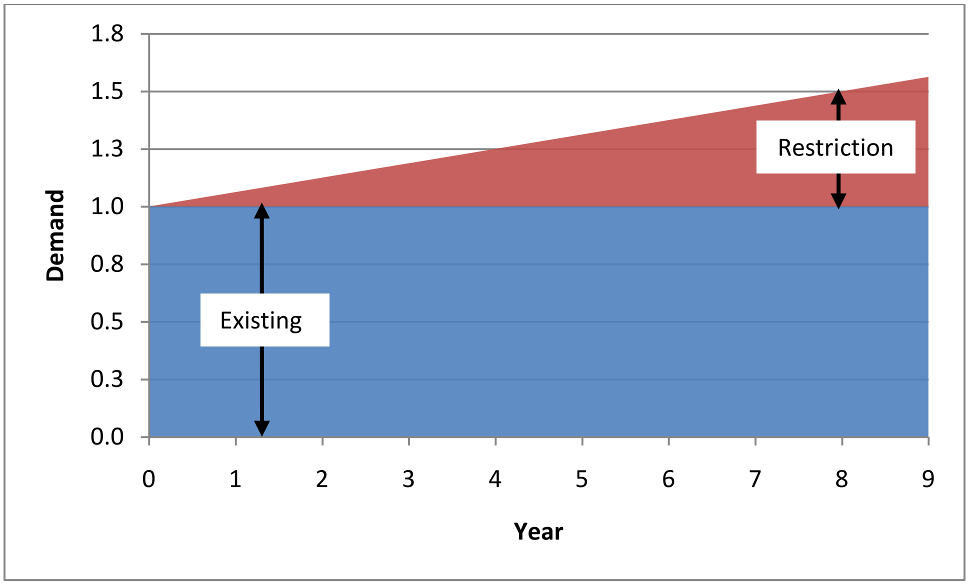

Figure 5. New demand is met by a restriction wedge

An example of an energy restriction policy is the German government's Renewable Energies Heating Law, which requires homeowners to use renewable energy sources to meet 14 percent of their household's heating and domestic hot-water demand (Burgermeister 2007). This can be represented as a restriction wedge that raises the use of renewables as the housing stock increases.

Several jurisdictions are attempting to introduce energy wedges that restrict the type of fuel used for transportation. In the United States, the focus is on promoting ethanol for transportation, where there have been several attempts to mandate the manufacture of flex-fuel vehicles that can operate on fuel blends of up to 85 percent ethanol. This is a restriction wedge intended to demand the use of ethanol in new vehicles.

The European Union has directives that require the bioenergy content in transportation fuels (i.e., petrol and diesel) to increase from 2 percent in 2005 to 5.75 percent in 2010 (EU 2003). This can be considered either a replacement or restriction wedge: if transportation energy demand remains constant or falls, the bioenergy can be considered as a replacement, whereas an increase in demand, met all or in part by bioenergy, would be a restriction.

4 Example

In the Canadian province of Nova Scotia, space and water heating demand in the residential and commercial sectors are met from three principal sources: oil products, electricity, and wood. Nearly all oil products are imported (from the North Sea and various OPEC countries), while most of the province's electricity is generated from imported coal and petroleum coke (from Columbia and Venezuela), meaning that the energy sources for space and water heating are not particularly secure and are greenhouse gas intensive (Hughes 2007).

Nova Scotia has limited supplies of domestic energy and virtually no access to the rest of Canada for energy supplies. With these limitations in mind,

Figure 6 shows a hypothetical case in which the three energy wedges are applied to projected space and water heating demand for Nova Scotia's residential and commercial sectors between 2000 and 2020.

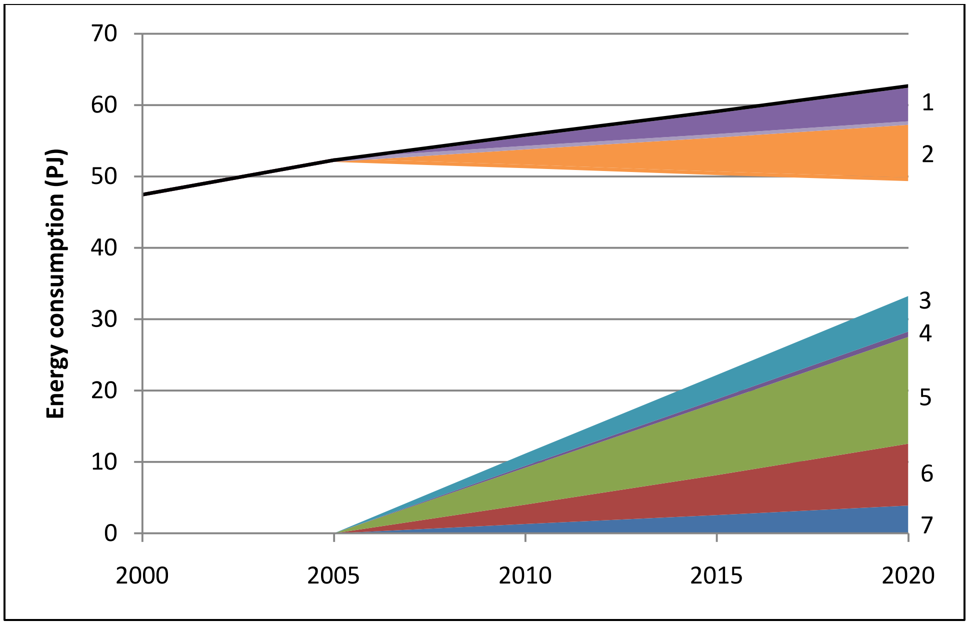

Figure 6. Wedges applied to Nova Scotia's space heating demand (Hughes 2007)

In the above figure, the topmost line is the actual (2000 to 2005) and business-as-usual projection (2005 to 2020) for consumption of space and water heating in Nova Scotia's residential and commercial sectors (NRCan 2006). Demand for space and water heating is expected to grow from 47.7 PJ and 62.9 PJ between 2000 and 2020, driven in large part by more people choosing to live alone and by a trend toward increased energy consumption in the residential sector. The energy wedges below this line are examples of reduction, replacement, and restriction wedges using a variety of secure and low-carbon energy sources.

Wedges 1 and 2 are reduction wedges:

1. The reduction wedge for new buildings. A 50 percent decrease in heating demand (compared with existing buildings) resulting in an overall reduction of 5.2 PJ from the business-as-usual case. This is achieved primarily through the introduction of new building standards.

2. The reduction wedge for existing buildings. A 7.9 PJ reduction is achieved through lowering heating demand in existing buildings by one percent per year; by 2020, this is 15 percent less than in 2005. In this case, standards for existing buildings are improved and owners are encouraged to meet the new standards.

Wedges 3 through 6 are replacement space and water heating wedges for existing buildings:

3. A biomass reduction wedge, with biomass meeting 10 percent of heating demand by 2020 (5 PJ). Demand for biomass increases by about 0.33 PJ per year. The available biomass is assumed to come from waste biomass and improved silviculture practices (Dhaliwal and Joseph 2007).
4. The smallest reduction wedge, for cogeneration from thermal power stations, assumes limited uptake of cogeneration because of costs, limited interest on the part of electricity suppliers, and the location of existing thermal power stations in Nova Scotia. Cogeneration (i.e., district heating) would meet 1.5 percent or 0.7 PJ of heating demand by 2020.
5. A reduction wedge meeting 30 percent (15 PJ) of demand by 2020 using storage heaters charged from electricity generated by the wind. This wedge requires the addition of about 130 MW of wind capacity per year (1,900 MW over the 15 years).
6. A reduction wedge using active solar heating in existing buildings. This assumes a one percent increase in the uptake of solar energy per year, meeting 15 percent of heating demand (7.5 PJ) by 2020. This wedge is limited by building location.

Wedge 7 is a restriction wedge. In it, new buildings are to meet 75 percent of their demand (3.9 PJ) from solar sources by 2020.

In this example, had these wedges been introduced in 2005, by 2020, the reduction wedges would mean the demand for energy for space and water heating would have been reduced by 13.1 PJ. Energy replacement and restriction would meet 33.4 PJ and 3.9 PJ of demand, respectively, meaning that 16.6 PJ must be obtained from other sources.

5 Discussion

An energy wedge offers a means of explaining the temporal effects of an energy policy. It can show the expected long-term benefits and can act as a guide to whether the implementation of a policy is meeting the expected goals. Similarly, a wedge can be expressed in terms of, for example, carbon emissions, thereby allowing the jurisdiction to determine the state of its greenhouse gas emissions.

Multiple wedge-scenarios can be developed to illustrate the differences between possible policies. This can prove useful when comparing approaches to improving energy security or reducing greenhouse gases. It can also show the potential conflicts between security and emissions.

Wedges need not start at the same time because of, for example, lack of capital. In some cases, a wedge may take a period of time to become established, for example, as industry retools or production lines are changed (Hirsch, Bezdek and Wendling 2005).

In the above example, energy wedges were shown as increasing linearly over time. This need not—and probably would not—be the case in most instances. They could be choppy or non-linear, depending upon, for example, the application, energy supply availability, the state of the infrastructure, and access to capital.

Finally, energy wedges can show the difference between policies that reduce energy consumption and those that replace one form of energy with another. This concept is often misunderstood, as replacement energy sources (such as solar panels) are sometimes presented as means of reducing energy consumption (Pérez-Lombard, et al. 2008).

6 Concluding Remarks

This paper has introduced a methodology, referred to as energy wedges, for visualizing the temporal changes on energy demand caused by existing and potential energy policy and programs. An energy wedge has a horizontal axis (time) and a vertical axis (demand). The effect on demand depends upon which of the three types of energy wedge is being applied. A reduction wedge represents actions that reduce demand for a given energy service. Replacement wedges are employed when an existing insecure or environmentally destructive energy source is replaced by a source (or sources) that are secure and preferably low-carbon. A restriction wedge is for new demand and limits the supply to secure and low-carbon sources.

Since energy wedges allow “what-if” scenarios to be created, they have a variety of applications, including public education and policy development. The paper showed how wedges can be used to illustrate the interim steps required of a jurisdiction or organization to meet a long-term energy target. The paper also used wedges to illustrate the impact of the introduction of new energy supplies and technologies on energy demand.

By allowing the effects of energy policy to be visualized, energy wedges can highlight the shortcomings of policies that fail to address energy security or greenhouse gas emissions, or both. In fact, wedges can also show the detrimental impact of conflicting energy policies, which, for example, can pit improving energy security against reducing greenhouse gas emissions.

As part of our continuing research into energy security, we are developing software tools that allow the examination of different energy scenarios by generating reduction, replacement, and restriction wedges to determine the costs and benefits of existing and potential energy policies and programs.

Acknowledgements

The author would like to thank Alain Joseph, Jim Parsons, Anirudh Muralidhar, and other members of the Energy Research Group for their feedback on this work.

References

BP. *BP Statistical Review of World Energy.* London: BP plc, 2008.

Brown, Marilyn A. "Energy Myth One--Today's energy crisis is 'hype'." In *Energy and American Society--Thirteen Myths*, by B K Sovacool and M A Brown, 23-50. Springer, 2007.

Bryce, Robert. *Gusher of Lies: The Dangerous Delusions of "Energy Independence".* Philadelphia: PublicAffairs, 2008.

Burgermeister, Jane. "Germany to Require Renewables for New Homes in 2009." *Renewable Energy World.com.* December 10, 2007. http://www.renewableenergyworld.com/rea/news/article/2007/12/germany-to-require-renewables-for-new-homes-in-2009-50746 (accessed April 14, 2009).

Dhaliwal, Mandeep, and Alain Joseph. "Wood Biomass Availability for Bioenergy Applications in Atlantic Canada." Environment Canada, Halifax, 2007.

DOE/EIA. *Annual Energy Review 2001.* DOE/EIA-0384(2001), Washington: Energy Information Administration, Office of Energy Markets and End Use, U.S. Department of Energy, 2002.

EIA. "How dependent are we on foreign oil?" *Energy Information Agency.* August 22, 2008. http://tonto.eia.doe.gov/energy_in_brief/foreign_oil_dependence.cfm (accessed December 11, 2008).

EU. "Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport." 2003, L 123/42-L 123/46.

Gue, Elliot. "Defining Demand Destruction." *The Energy Letter.* August 1, 2008. http://www.kciinvesting.com/articles/9196/1/Defining-Demand-Destruction/Page1.html (accessed December 10, 2008).

Hirsch, Robert, Roger Bezdek, and Robert Wendling. *Peaking of world oil production: Impacts, mitigation, and risk management.* Washington: Management Information Services, Inc., 2005.

Hughes, Larry. *Energy Security in Nova Scotia.* Ottawa: Canadian Centre for Policy Alternatives, 2007.

Hughes, Larry. "The four 'R's of energy security." *Energy Policy*, doi:10.1016/j.enpol.2009.02.038 (2009).

IPCC. "Decision-making Frameworks." Chap. 10 in *A Report of Working Group III of the Intergovernmental Panel on Climate Change*, by Ferenc,L Toth and Mark Mwandosya, 603-688. Geneva: IPCC Secretariat, 2001.

McKeown, Rosalyn. "Energy Myth Two--The public is well informed about energy." In *Energy and American Society--Thirteen Myths*, by B K Sovacool and M A Brown, 51-74. Springer, 2007.

NRCan. *Canada's Energy Outlook: The Reference Case 2006.* Ottawa: Natural Resources Canada, 2006.

Pacala, S, and R Socolow. "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies." *Science*, August 13, 2004: 968-972.

Parker, Mike, and John Surrey. "Contrasting British policies for coal and nuclear power, 1979–1992." 1995, 821-850 .

Pérez-Lombard, Luis, Jose Ortiz, Rocio González, and Ismael Maestre. "A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes." 2008.

Smith, Eric. *Energy, the environment, and public opinion.* Rowman and Littlefield, 2002.

Sorrell, Steve. *The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency.* UK Energy Research Centre, 2007.