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A graphical technique for explaining the relationship between energy security and greenhouse gas emissions

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Abstract

The need for energy security and the impact of anthropogenic climate change are expected to be two of the major challenges facing humanity in the twenty-first century. Despite their common root cause—humanity's seemingly unquenchable demand for energy—the solutions to improving energy security and reducing greenhouse gas emissions are not necessarily compatible, since solving one may further exacerbate the other. The apparent lack of understanding and confusion over these two issues on the part of the general public, politicians, and policymakers suggests that there is a need to explain both the commonality and the differences between energy security and greenhouse gas emissions.

This paper presents a graphical technique for explaining this relationship, based upon jurisdiction-specific data on energy supply, infrastructure, affordability, greenhouse gas emission factors, and consumption. The jurisdiction's energy sources are ranked using AHP (Analytic Hierarchy Process). The resulting security-emissions graphs allow the viewer to understand the state of a jurisdiction's energy security, the level of greenhouse gas emissions, and the effort needed to improve energy security and reduce emissions.

Keywords: Analytic Hierarchy Process, Energy Security, Climate Change

1 Introduction

It is generally accepted that the world's population is facing two separate but interrelated energy challenges. One of these is the build-up of atmospheric greenhouse gases—predominantly carbon dioxide—caused in part by the anthropogenic combustion of fossil energy sources, notably coal, oil, and natural gas (IPCC, 2001). The other, energy security, or simply security of supply, is being driven by price increases and production challenges of these and other energy sources (Yergin, 2006).

Solutions to these challenges can be classified into one of two common approaches (Hughes, 2007). The first, energy reduction, consists of policies that lead to a measureable reduction in the consumption of energy for a given activity. Energy reduction policies, from improved building codes to limiting highway speeds, can help address energy security and greenhouse gas issues. The second, energy replacement, are those policies intended to encourage replacing one energy source with another.

However, unlike energy reduction, some strategies for replacing one energy source with another are not necessarily applicable to both reducing greenhouse gases and improving energy security. For example, a jurisdiction could cut its greenhouse gas emissions by phasing out its use of coal for electrical generation, but the economic and social effects could be devastating without finding a secure energy source that could replace the electricity generated from coal. Similarly, improving a jurisdiction's energy security through increased consumption of secure sources of fossil energy can exacerbate the anthropogenic emissions of greenhouse gases.

With the 2010-12 Kyoto deadline rapidly approaching and energy security becoming a major issue in many countries, there is a need for techniques to explain the similarities, differences, impacts, and potential solutions to these two challenges. This paper presents a graphical technique for illustrating the relationship between energy security and greenhouse gas emissions within a jurisdiction.

To develop a security-emissions graph, two sets of jurisdictional-specific data are required: the levels of consumption of each type of energy known to be used in the jurisdiction and the greenhouse gas emissions associated with each of the energy sources. Determining how secure each energy source can be more subjective, requiring a detailed understanding of the state of supply, infrastructure, and affordability of the different energy sources. In this paper, a decision support tool, Analytic Hierarchy Process (or AHP), is employed to rank each energy sources in terms of its contribution to the energy security of a jurisdiction.

The remainder of the paper is organized as follows. The next section discusses energy-related greenhouse gas data and emissions factors. The third section describes how AHP can be employed to rank different energy sources in terms of their contributions to a jurisdiction's energy security. The graphical technique and its interpretation are presented in the fourth section, while the fifth section describes the software developed to generate security-emissions graphs. The paper is concluded with a discussion of our experiences presenting the security-emission graphs to the general public and policy makers.

2 Emissions factors

There is a mounting body of evidence that increasing concentrations of atmospheric greenhouse gases from energy-related activities are changing the planet's climate (IPCC, 2001). Most, if not all, energy sources contribute in some way to greenhouse gas emissions; for example, the combustion of fossil fuels, the energy needed to mine and process uranium ore, fugitive emissions from coal, hydroelectricity, or natural gas, and the energy required to build generating stations or manufacture wind turbines and photovoltaic panels.

Although the principal anthropogenic greenhouse gas is carbon dioxide (CO_2), there are other energy-related greenhouse gases, notably methane (CH_4) and nitrous oxide (N_2O). All of these gases have the ability to trap heat in the atmosphere; their individual strengths, relative to CO_2, are described in terms of their global warming potential or GWP (IPCC, 2001). Since the emissions from an energy source can be more than simply CO_2, they are often expressed as CO_2-equivalents or CO_2e, the sum of the masses and GWPs of the different gases it emits (for example, see (Environment Canada, 2007)).

An energy source's impact on the climate can be expressed in terms of its greenhouse gas emissions factor, in this case, the volume of greenhouse gases emitted per unit of energy consumed; for example, tonnes of CO_2e per MWh_{el} or kilograms of CO_2e per litre of fuel. The value of the emissions factor will depend upon what is deemed to constitute the emissions associated with the energy source, which can include any production, extraction, distribution, and combustion related emissions. To avoid misinterpretation of the results or suggestions of bias, all energy sources should be subject to the same analysis. To compare different energy sources, the individual intensities can be normalized to a common emissions factor, for example, kilograms of CO_2e per gigajoule.

For most energy sources, there is little dispute over the associated greenhouse gas emissions as they can be obtained empirically or theoretically. However, sources such as nuclear or renewables can be problematic, for although they appear to have no emissions, there are related emissions. In the case of nuclear, parts of the nuclear fuel cycle, notably mining and reprocessing, can be CO_2-intensive, while with hydroelectricity, the decomposing of vegetation in the reservoir can produce CH_4. Although the energy produced by renewables such as wind and solar is considered emissions-free, the energy used in the manufacture of the equipment (i.e., the embedded energy) can be associated with CO_2 emissions using full-energy chain analysis or FENCH (van de Vate, 1997).

3 Energy security

The state of energy security in a jurisdiction is dictated by its energy supplies, the cost of these supplies, and the infrastructure required for producing, distributing, and possibly storing the energy for the consumer. The relationship between supply and infrastructure leads to two corollaries. First, the lack of infrastructure will exclude the consumer from accessing those forms of energy that rely on the infrastructure, and second, the lack of affordable supply, regardless of the availability of infrastructure, will mean the consumer is unable to benefit from that energy source.

Determining the influence of an energy source on the energy security of a jurisdiction can be more subjective and not as easily quantifiable as determining the greenhouse gas emissions factor associated with the energy source. In its simplest form, an energy source can be classified as either “secure” or “insecure”; however, this distinction can be seen as arbitrary and without merit or basis. It also may hide the fact that energy sources can have “shades” of security, with some sources being more secure than others. Any methodology chosen to rank an energy source in terms of a jurisdiction’s energy security must be justifiable and should not be jurisdiction-specific.

The methodology employed here is the Analytic Hierarchy Process (AHP), a decision analysis tool that accounts for quantitative as well as qualitative aspects of a decision problem.

3.1 Analytic Hierarchy Process

The Analytic Hierarchy Process or AHP is a multi-criteria decision analysis technique commonly used for energy and environmental modeling (Saaty & Alexander, 1989; Zhou, Ang, & Poh, 2006). For example, Kagazyo et al. (1997) used AHP to evaluate and prioritize energy-related research projects in Japan, in less developed countries, and in the world as a whole. Poh and Ang (1999) carried out a study of alternative fuels for land transportation in Singapore. Kablan

(2004) presented an AHP based framework for the prioritization of energy conservation policy instruments in Jordan, while Elkarmi and Mustafa (1993) used AHP to select the best policies for increasing the utilization of solar energy technologies in Jordan.

AHP decomposes a decision problem into a hierarchical structure consisting of at least three levels: the objective, the main criteria, and the alternatives; one or more intermediate levels for sub-criteria can be added if and when required (Saaty, 1980). The following are the three levels of the decision hierarchy used to rank the energy sources in terms of energy security.

3.1.1 The Objective

AHP is to evaluate the different energy alternatives available to a jurisdiction and from this, rank their contribution to the jurisdiction's energy security. The objective is therefore "energy security". Applying AHP to the criteria and alternatives will result in the ranking of each energy source, in terms of energy security, for the jurisdiction's energy portfolio.

3.1.2 The Criteria

The second level, the main criteria, must be broad enough to encompass all aspects of energy security. For the proposed methodology, the IEA's definition of energy security is used, notably the reliable supply of energy at an affordable price (IEA, 2001; Constantini, 2007). This definition suggests that energy security depends upon two criteria: supply and affordability. However, given the energy security corollaries discussed above, the supply criteria is further decomposed into supply and infrastructure. No sub-criteria are used.

The following guidelines are recommended when examining each of the energy security criteria:

- Supply. The ranking of supply should be based upon the importance attached to the quality of a given energy source, what is known about the reliability of the supplier(s), and the state of the resource. If supplies are problematic, it is necessary to include the possibility of alternative suppliers. Supply can be discussed in terms of present or future possible supplies—the timeline is chosen must be applied to all criteria consistently. The quantity of supply is not considered here, as it is addressed later.

- Infrastructure. Infrastructure ranking should focus on the significance placed upon the resilience, age, quantity, and accessibility of the infrastructure. The infrastructure to be considered is that found within the jurisdiction and refers to anything that moves energy from the point of production to the point of consumption; this can include loading depots, pipelines, roadways, transmission grids, railways, and fuel tankers. The infrastructure outside the jurisdiction's boundary is treated as part of supply.
- Affordability. Affordability refers to the cost of an energy source and can be interpreted in a number of different ways; two frequently used are the cost per unit energy and the impact on the jurisdiction or end-user. In jurisdictions where energy is subsidized, the affordability can be considered less of an issue to the consumer; however, since it can become an issue to those generating the subsidies, it should be considered in the comparison.

3.1.3 Alternatives

The third (and final) level consists of the alternatives, that is, the different energy sources available to the jurisdiction. The choice of energy sources are at the discretion of the user and will vary from jurisdiction to jurisdiction.

3.1.4 Obtaining the ranking

Once the decision hierarchy is formed, pair-wise comparisons are performed at each level to determine the weights of the different criteria and alternatives. First, the different main criteria are compared, in pairs, with respect to the objective. This is followed by pair-wise comparisons of the alternatives with respect to each criterion. As a result of these pair-wise comparisons priorities (or weights) will be obtained for each criterion and alternative. AHP then takes the priorities of the criteria and the alternatives to produce the final ranking of the energy sources. The ranking refers to the contribution of each energy source to the energy security of the jurisdiction.

4 Creating a security-emissions graph

Creating an energy security-climate change graph is a three step process. The first step involves obtaining the emissions factors for each energy source used in the jurisdiction. The second step requires the different energy sources to be ranked by AHP to determine their energy security index. The final step creates the graph by plotting each energy source in terms of its energy security index and associated emissions. The following example shows how security-emissions graph can be created.

The jurisdiction used in this example is Nova Scotia, a small province of about one million people on Canada's Atlantic coast. Table 1 lists Nova Scotia's portfolio of primary energy sources and associated energy suppliers. From the table, it is clear that Nova Scotia relies almost exclusively on imported energy sources.

Table 1: Nova Scotia's energy portfolio (Hughes, 2007)

Source	Demand		Supplier
Refined petroleum products (oil)	178.3 PJ	63.1%	North Sea, Venezuela, Middle East, Newfoundland, U.S.
Coal (imported)	69.1 PJ	24.5%	Colombia, Venezuela, U.S.
Renewables (non-utility)	16.6 PJ	5.9%	Nova Scotia
Coal (domestic)	10.3 PJ	3.7%	Nova Scotia
Primary electricity	2.7 PJ	1.0%	Nova Scotia
Natural gas	5.4 PJ	1.9%	Nova Scotia
Total	282.4 PJ	100.0%	

4.1 Emissions factors

The first step in creating the graph is to determine the emissions factors for the fuels used in the jurisdiction. The emissions factors for Nova Scotia are shown in Table 2.

Table 2: Nova Scotia's normalized emission factors

Source	Emission factor	Multiplier	Normalized kg CO_2/GJ
Refined petroleum products (oil)[1]	2.5 kg CO_2/l	0.035 GJ/l	71.4
Coal (imported)[1]	2.288 kg CO_2/kg	0.0277 GJ/kg	82.6
Renewables (non-utility)[2]	31 kg CO_2/MWh	3.6 GJ/MWh	8.6
Coal (domestic)[1]	2.249 kg CO_2/kg	0.0277 GJ/kg	81.2
Primary electricity (hydroelectric)[2]	16 kg CO_2/MWh	3.6 GJ/MWh	4.4
Natural gas[1]	1.891 kg CO_2/m^3	0.0371 GJ/m^3	50.9

[1] Emission factor from (Environment Canada, 2007) and multiplier from (NEB, 1999)
[2] Emission factor and multiplier from (van de Vate, 1997)

4.2 Calculating energy security index for different energy sources

The energy sources are then ranked in terms of their energy security index using AHP. In this example, five regional energy analysts were contacted and their responses to the AHP energy security survey for Nova Scotia were obtained. The results of the main criterion rankings are shown in Table 3, with supply being the most important and affordability the least.

Table 3: Ranking of main criterion

Supply	Infrastructure	Affordability
0.51	0.31	0.18

The pair-wise comparisons were then performed for the energy sources with respect to each of the three criteria. The total consumption associated with each energy source was ignored during the ranking process. The rankings are shown in Table 4.

Table 4: Ranking of alternatives with respect to each of the main criterion

Source	Supply	Infrastructure	Affordability
Oil	0.08	0.17	0.09
Domestic coal	0.25	0.12	0.20
Imported coal	0.11	0.17	0.15
Natural gas	0.09	0.09	0.10
Hydro	0.28	0.28	0.32
Renewables (non-utility)	0.19	0.17	0.13

The final step is the calculation of the energy security index (i.e., ranking) for each energy source. In this example, hydroelectricity was considered the most secure, followed by domestic coal, and non-utility renewables. Oil had a low ranking because only a small portion is from Canadian sources (from Newfoundland and Labrador), while natural gas has limited infrastructure in Nova Scotia and supply is in decline (NEB, 2007).

Table 5: Energy security index for the energy sources

Source	Index
Oil	0.11
Domestic coal	0.20
Imported coal	0.14
Natural gas	0.09
Hydro	0.29
Renewables	0.18

4.3 Creating the security-emissions graph

The energy security index, the emissions factor, and the consumption values for the different energy sources available to the jurisdiction can be represented in a tabular format, such as that shown in Table 6.

Table 6: Energy data for a sample jurisdiction

Energy Source	Security index	Emissions factor (kg CO_2/GJ)	Consumption (PJ)
Oil	0.11	690	178
Domestic coal	0.20	940	10
Imported coal	0.14	940	69
Natural gas	0.09	460	5
Hydro	0.29	16	3
Renewables	0.18	30	17

The values of the security index and emissions associated with each energy source can be plotted as a series of data-points on an X-Y graph. Together, these give an indication as to the position of each energy source, relative to the other energy sources in terms of their security and emissions. The graph for the data in Table 6 is shown in Figure 1.

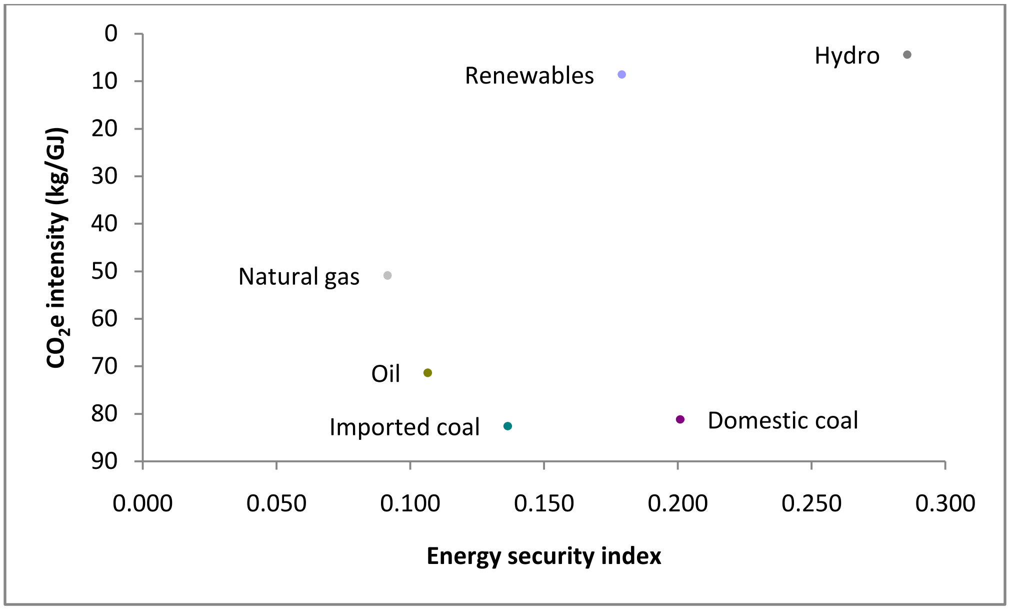

Figure 1: Graph of energy security index vs. emissions factor

In this figure, the horizontal axis represents the energy security index, running from least secure (left) to more secure (right). The vertical axis represents the emissions factor, running from high-intensity CO_2e sources (bottom) to low-intensity CO_2e sources (top).

Energy sources found towards the upper-right region of the graph can be more secure and less carbon-intensive than those found elsewhere in the graph. These energy sources can include, for example, nuclear, hydroelectric, biomass, wind, solar PV, and solar thermal. Depending upon the state of the resource, it can also include natural gas.

On the other hand, energy sources found more towards the lower-left region of the graph are typically less secure and more carbon-intensive than those found elsewhere in the graph. Energy sources in this region are the least desirable for the jurisdiction in that they are both less secure and high-carbon emitters. Sources can become more insecure and higher-carbon emitters as they move further to the bottom-left; for example, shifting from imported oil to imported coal.

The graph, as it now stands, shows the relative positions of the different energy sources, but gives no indication as to the jurisdiction's reliance on each source. This can be achieved by making the size of each data point represent the consumption of that particular energy source. Figure 2 shows the effect of adding consumption to the graph; here, the size of each circle represents of the total consumption of the energy source in the jurisdiction (the actual consumption, expressed in petajoules has been included with the name of each energy source).

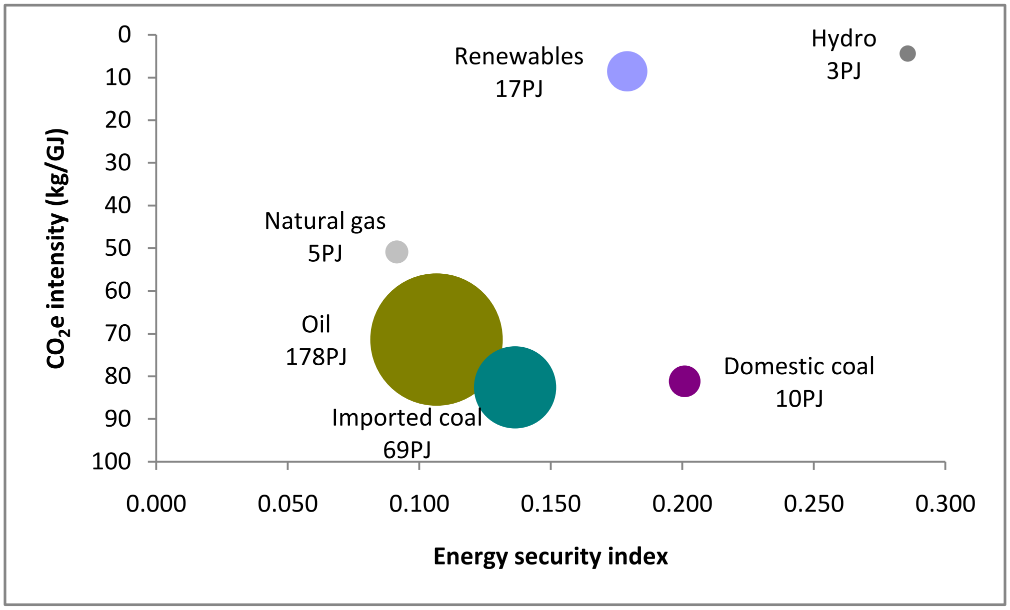

Figure 2: A security-emissions graph for Nova Scotia

The security-emissions graph shows how reliant the jurisdiction is on CO_2-intensive energy sources and the relative security of each energy source. It also shows the magnitude of each energy source and, by extension, where the jurisdiction should put its efforts in addressing improving security, reducing emissions, or both.

Ideally, a jurisdiction's replacement strategies should be moving energy supply towards the more-secure, low-carbon region of the graph. However, with the widespread availability of coal, many jurisdictions are either already in or shifting into the more-secure, high-carbon area of the graph. Jurisdictions that are relying on greater quantities of imported coal are staying in the less-secure, high-carbon region.

5 Examples

As discussed earlier, security-emissions graphs can be applied to jurisdictions. They can also be applied to energy suppliers. This section gives examples of each.

An example of a security-emissions graph is shown for Canada in Figure 3.

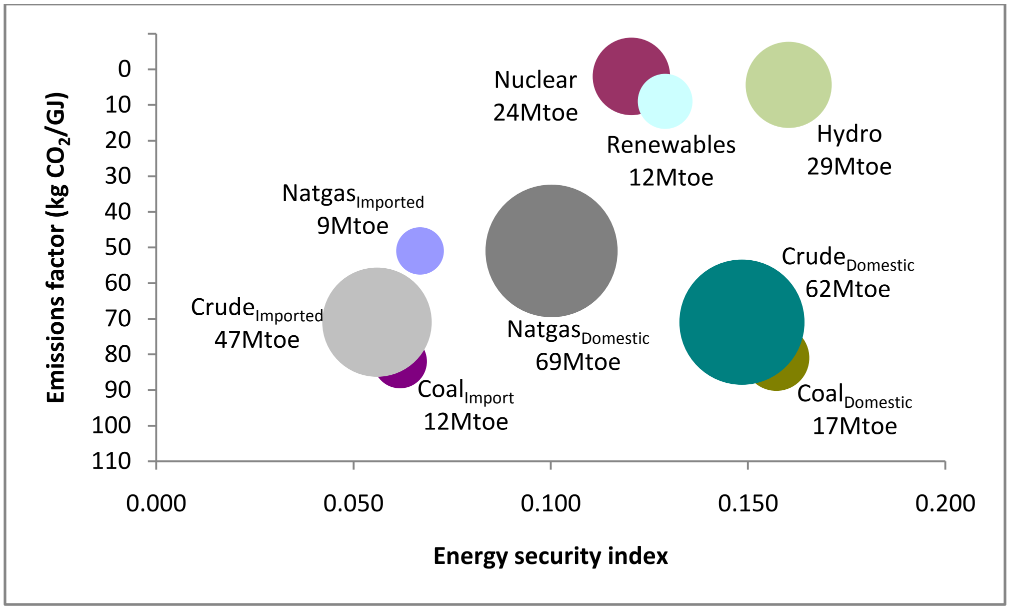

Figure 3: A security-emissions graph for Canada (IEA, 2007)

The security index values were determined by the authors using the known state of the supply, infrastructure, and affordability of the different energy sources. This meant that, for example, domestic natural gas had a lower security rating than domestic crude because of natural gas reserves are in decline, whereas crude oil reserves (both conventional and tar sands) are forecast to experience a slight growth over the next decade. Similarly, nuclear does not have a high security index value as part of Canada's nuclear fleet is being decommissioned. The graph suggests that as a nation, Canada is relatively secure in terms of its energy supply and meets much of its energy demand from sources that have low emissions factors. Despite this, since energy supplies and infrastructure are not uniformly distributed across the country, some regions, such as the province of Nova Scotia, have limited energy security and are major emitters of greenhouse gases, as shown in Figure 2 (above).

Security-emissions graphs need not be restricted to jurisdictions. In Figure 4, the authors have constructed a security-emissions graph for NSP, a vertically-integrated electricity supplier in the province of Nova Scotia.

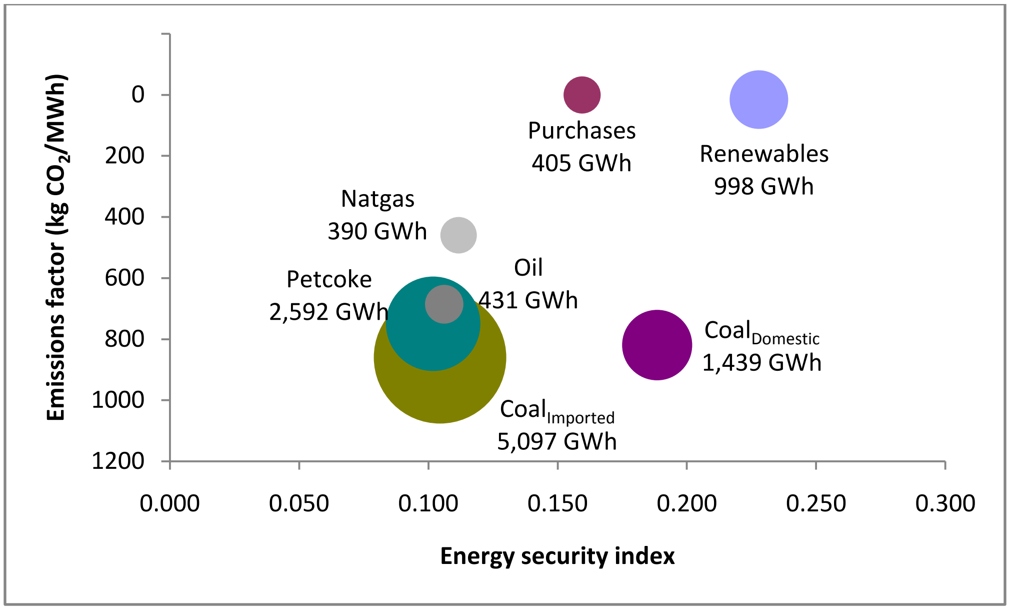

Figure 4: A security-emissions graph for NSP (Emera, 2007)

The graph shows that NSP's reliance on imported coal and (imported) petcoke make it energy insecure and are both significant contributors the company's greenhouse gas emissions. NSP's energy insecurity has been highlighted twice over the past three years, first with the loss of petcoke supplies from the US Gulf coast refineries after Hurricane Katrina, and more recently with the Venezuelan state-owned coal company, Carbozulia, notice to NSP that it is "suspending 2008 shipments pending a review of the contract" (Emera, 2008).

6 Software implementation

A software tool has been developed in VBA and Excel by the authors to both the energy security index and the graph for a given set of input data.

There are five distinct steps in the implementation. First, the user is expected to list the names of the jurisdiction's energy portfolio, the emissions factor, and the consumption associated with each energy source. Second, the user performs a pair-wise comparison of the main criteria (supply, infrastructure, and affordability), from this, the software generates the ranking of the criteria. In the third step, the rankings of the different energy types (the alternatives) are determined for each of the main criteria from the user-supplied pair-wise comparisons of all the energy types. Fourth, the final rankings of each energy type are calculated from the rankings of the main criteria and the rankings of the different energy types. In the final step, the security-emissions graph is generated from the supplied emissions factor, the consumption data, and the security ranking of each energy type. Any step can be repeated as required.

Copies of the software and instructions on its operation can be obtained by contacting the authors.

7 Concluding remarks

Humanity's seemingly unquenchable demand for energy is manifesting itself, both directly and indirectly, in a number of different ways: food shortages, energy shortages, rising energy prices, and increasing levels of greenhouse gases. Regardless of the issue, most, if not all, of them can be traced back to the need for energy security—the reliable supply of energy at an affordable price.

The apparent lack of understanding and confusion on the part of the general public, politicians, and policymakers over both the commonality and the differences between energy security and climate change motivated this work. The graphical technique developed in this paper offers a clear and understandable way of explaining this relationship for any jurisdiction, using both quantitative (greenhouse gas emissions factors and energy consumption) and qualitative (security of supply) data. The resulting security-emissions graphs allow the viewer to understand the state of a jurisdiction's energy security, its greenhouse gas emissions factor, and the consumption of each fuel source. It also allows the viewer to appreciate the effort needed to improve energy security, reduce emissions, and change consumption habits.

Ranking a jurisdiction's energy portfolio is probably the most challenging component of the graphs. AHP offers a straightforward and reasonable approach to determining the rankings of the criteria and the alternatives.

The availability of a software tool that implements the AHP algorithms for up to 15 energy alternatives and then generates the associated security-emissions graph is both a time-saver and allows "what-if" type questions to be answered.

The authors have been using security-emissions graphs to describe the state of Nova Scotia's and Canada's energy security to various groups and organizations since late 2007. Our experience with presenting the graphs at public events has been that they are easily explained and understood. It has raised awareness of the security of Nova Scotia's energy portfolio, the impact of these sources on the climate, and the challenges associated with becoming more secure and reducing greenhouse gas emissions.

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