An integrated analysis of the use of woodstoves to supplement fossil fuel-fired domestic heating

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Abstract

Consumers are constantly being presented with choices that have economic, environmental and lifestyle/social dimensions. For example, is a hybrid car a better choice than a regular petroleum-only vehicle when considered from all three perspectives? Surprisingly, although each and all of these dimensions is clearly important to successful long-term choices, integrated analyses are rare, and there is a great need for better education on how best to approach such consumer decisions. Here, we present a case study on renewable versus fossil-fuel based options for domestic heating to explore the actual economic and environmental advantages and disadvantages of each option. We analysed four years of fuel consumption data for a household in Kingston, S.E. Ontario, Canada that installed a wood stove to supplement (i.e. reduce their reliance on) natural gas for domestic heating. Furthermore, we conducted a survey of local householders to identify those factors that are most important to consumers in deciding on future heating options.

Supplemental use of the woodstove for home heating reduced natural gas consumption by 60%. Total annual operating costs before and after installation were similar because woodfuel costs matched the savings from lowered natural gas consumption. However consideration of projected fuel price rises and ongoing maintenance and replacement costs strongly suggests that substantial overall cost savings would accrue, especially after the first decade of woodstove installation.

Since wood is a renewable resource, annual net CO_2 emissions associated with domestic heating were also reduced by 60%. Our data indicate that this substantial reduction would decrease the average Canadian's overall ecological footprint by ~5%. Survey respondents consistently ranked 'heating effectiveness', 'operating costs' and 'environmental issues' among the most important factors in choosing a replacement heating system, but those who do not currently have a woodstove ranked safety as the primary concern. Together, these results suggest that promotion of eco-friendly options for consumers could be greatly enhanced by supplying clearly focussed information on the critical economic, environmental and lifestyle/social dimensions of that choice.

Introduction

Increasing energy costs as well as concerns about climate change associated with fossil fuel use have encouraged householders across N. America and Europe to consider alternative options for domestic heating. Since European colonisation in the mid-1800s, many isolated rural households in eastern N. America have relied heavily on wood fuel from local forests (Keddy, 1993). Given the widespread abandonment of farmland in this region (Osborne, 1978) and its natural regeneration back to forest (Parson, 1999), the potential for relatively cheap, local, wood fuel supply for heating in more urban locations may now be substantial. Wood fuel is not just becoming more plentiful. It is also a renewable resource meaning that relative to fossil fuels its supply is indefinite, and its use has little net impact on CO_2 in the atmosphere because whatever carbon is released in combustion is taken up during growth of new trees in the harvested forest or woodlot. Therefore, the use of wood fuel may become increasingly attractive to consumers over the next few decades (Gulland, 2007). But would switching from fossil fuels to wood sources make economic sense? Just how significant are the ecological benefits of switching from a fossil fuel to a renewable resource? What are the most important factors that influence householders in deciding on whether to make such a switch? Here we present a case study for a household in Kingston, S.E. Ontario that installed a wood stove to supplement (i.e. reduce their reliance on) natural gas for domestic heating in September 2005. We determined the economic and environmental impacts of this change by comparing fuel consumption over two year periods before and after the installation. In addition, we surveyed home occupants in the local area to identify and rank the factors the most influence their decision when choosing a replacement heating system.

Methods

Case study details

A medium-sized, advanced secondary combustion, non-catalytic wood stove was installed in an early 1900s detached single family home (3200 sq. ft) with 5 residents in Sept. 2005. Natural gas

consumption records for domestic forced-air heating using a modern high-efficiency furnace and for water heating were available for two year periods before (August 2003-05) and after the woodstove installation (December 2005-2007). Air-dried split logs of Sugar Maple (*Acer saccharum*, Marsh) and Red Oak (Quercus rubra, L.), and some Ash (*Fraxinus americana*, L.), Elm (*Ulmus americana*, L.), Ironwood (*Ostrya virginiana*, (P. Mill) K. Koch) and White Birch (*Betula papyrifera*, L.) were supplied in half cord loads from a local woodlot ~40 km north of the residence using a pick-up truck. Our analysis of these data assumes that electricity and maintenance costs associated with the furnace were negligible, that gas consumption for water heating was constant over the four year study period, and that home heating requirements in the winters before and after wood stove installation were similar. Total cost rates for natural gas supply fluctuated somewhat but were similar between the two periods of the study (mean = \$0.488 per m^3 for 2006-07). Wood fuel costs increased slightly over that period (mean = \$266 per full cord). No other infrastructural changes were made to the dwelling since 2005.

Ecological footprint calculations are based on data from Wackernagel and Rees (1996): 1 cubic meter of natural gas (primarily CH_4) contains 40 MJ of energy, and releases 2.66 kg CO_2 during combustion. 1 litre of petroleum contains 35 MJ, and releases 2.3 kg CO_2. On average, 1 m^2 of land containing growing forest on Earth typically takes up 0.66 kg CO_2 (0.18 kg C) in net primary production per year. We have assumed that 1 air-dried full cord (3.6 m^3) of mixed hardwood has a mass of ~1600 kg and is 42% carbon.

Social survey details

We used an anonymous survey of 63 local residents representing several demographic groups (based on urban/rural location of residence, type of housing, size of household, age, education, and household income). The survey focussed on the factors that would be considered in deciding on whether to install a wood fuel stove if the current heating system had to be replaced. Respondents were asked to rank the following factors: Safety; Current illnesses and disabilities; Installation costs; Operating costs; Health risks; Environment; Convenience of use; Esthetics; Fuel storage; Effectiveness of the heating system. Additional questions were aimed at identifying the respondent's demographic group (urban/rural

location, dwelling type, number of householders, age, income, level of education) and details about their current heating system.

Results and Discussion

How were total heating costs affected by the use of a wood stove to supplement natural gas heating in a single family home?

The supplemental use of the woodstove reduced natural gas consumption for home heating by 60% (from ~4700 to ~1800 m^3 y^{-1}). Mean annual natural gas costs were reduced from ~$2260 to ~$880, but annual wood consumption (5 full cords – 18 m^3) amounted to ~$1330. Consequently, the use of the wood stove resulted in a slight reduction (~$50 yr^{-1}) in total annual fuel costs over the two years after its installation.

Both natural gas and wood prices are subject to change, and can strongly influence the financial outcome of using a wood stove. Natural gas prices have risen at an average rate of ~9% per year since Sept 2001 (Anonymous, 2008). Although current development of Canada's substantial natural gas reserves may restrict future price rises (Environment Canada, 2008), some analysts predict that these supplies will be depleted by as early as 2030 (Bhargava, 2008). Furthermore, government implementation of a 'carbon tax' to counteract rising CO_2 emissions would obviously raise natural gas prices. In the very short term, recent announcements indicate that natural gas prices in Ontario will rise by 20% from 2008 to 2009 (Pritchett, 2008). We estimate that if such an annual increase had occurred from 2006 onward, use of the wood stove in this case study would have reduced overall domestic heating costs by 25% by the third year, resulting in total savings of $920. Thus, the economic savings associated with use of the woodstove are highly sensitive to future changes in fuel cost rates.

The above analyses are based on fuel supply expenses only, and do not include the initial costs for the woodstove and its installation (~$4750). Furthermore, we can also expect some future increases in wood prices due to harvesting, transportation and labour expenses. Nevertheless, even with the

conservative assumption that expenses for natural gas increase at an annual average rate of 6% more than wood, the initial wood stove installation costs (without interest charges) would be recovered within a decade. Those householders who are willing and able to harvest their own wood (as often happens in rural homes) could recoup their initial investment in just over three years. Finally, the above analyses did not include costs for maintenance and repair of the natural gas furnace, nor for its replacement which is typically every ~15 years at a cost of at least $5500. Clearly, inclusion of such longer term factors in our analyses would only further increase the economic benefits of installing and using a wood stove. In summary, we conclude that this preliminary analysis of the economic implications of supplementing domestic heating with wood fuel indicates substantial cost savings especially after the first decade of installation.

How much were net CO_2 emissions reduced by the use of wood fuel to supplement natural gas heating?

Carbon content of a typical air-dry full cord was estimated at 677 kg C. Total annual energy consumption for heating prior to the woodstove installation (~190 GJ in natural gas) did not change appreciably afterwards (~128 GJ in wood plus ~74 GJ in natural gas), suggesting that the heating efficiencies of the two systems were similar. Furthermore, our numbers are consistent with published values for annual heating loads for a house of this type in E. Canada (Natural Resources Canada, 2002).

Annual *gross* CO_2 emissions increased from 12610 kg to 17330 kg after the installation of the wood stove. However, the wood was supplied from a local forest in which tree regeneration and growth will eventually result in atmospheric carbon uptake equivalent to the original fuel wood carbon content. Therefore, the emissions associated with wood combustion may be considered neutral in terms of their overall impact on atmospheric CO_2 concentrations. Furthermore, we estimate that CO_2 emissions associated with the fossil fuel requirement for local transport (~190 kg CO_2) are very small compared to those for the natural gas heating (4%). On this basis, annual *net* CO_2 emissions associated with domestic heating were reduced by 60% (to ~5100 kg) by the use of the woodstove.

The environmental impact of a human activity can be characterised using the ecological footprint approach which estimates the area of land containing growing plants that would be required to produce the required resources for that activity and to assimilate the CO_2 produced from fossil fuel use during that activity[6]. In this case study, each resident's ecological footprint was reduced from 0.38 to 0.15 hectares (60%) through the use of the woodstove. To put that in context, the average Canadian's ecological footprint for all of life's activities (food production and supply, transport, housing, manufacturing and supply of consumer goods, services etc.) was initially estimated at 4.3 hectares (Wackernagel and Rees, 1996). Recent studies using more comprehensive, elaborate, and refined methodologies for footprint analysis indicate higher national values (Chambers, et al 2000), but our preliminary analysis here is also an underestimate in that all of the case study's footprint components were not included (e.g. energy and resources required to extract and supply the natural gas). Therefore, assuming that the full national and case study footprints are underestimated by the same proportion, our data indicate that deciding to install and use a wood stove to supplement fossil-fuel based domestic heating could reduce the average Canadian's total ecological footprint by ~5%.

Which factors are most frequently considered when choosing a replacement heat system, and do they differ between those who are already using a wood-burning heat source and those using another type of heating?

Effectiveness of the heating system, operating costs and environmental issues were the factors most frequently ranked within the top three in choosing a replacement heating system (Figure 1). These factors were ranked within the top three in 40-45% of all surveys. However, there were also some very strong differences between those who already had a wood stove and those who did not. The latter group identified safety as a paramount concern (ranked within the top three factors in 43% of surveys) while those already using a wood stove rated 'convenience of use' very highly (ranked within the top three factors in 63% of surveys among wood stove owners). Notwithstanding the small sample size of the population who use a wood-burning heat source (n=5), these data suggest strong differences in safety

concerns amongst the two groups. Total energy consumed was similar before and after the wood stove installation (see above), strongly suggesting that heating effectiveness was unaltered. In fact, heating effectiveness of a wood stove may be superior when one considers the distinctive 'cosy atmosphere' that glowing fires create. In any event, since our analyses above indicated substantial economic and environmental benefits in using a wood stove to achieve the same overall heating effect, the emergence of safety concerns as the other primary factor in choosing a wood stove to replace or supplement one's current heating system is particularly important. Together, these results indicate that consumers would benefit from information that directly addresses safety concerns associated with wood burning, as well as details on heating effectiveness, operating costs and environmental benefits.

To our surprise, those who do not have a wood stove did not rank the issue of 'convenience of use' very highly in deciding whether to install a wood-based heating system to replace or supplement their current system. By contrast, most of those who currently use a wood stove ranked convenience as critically important suggesting that although there are convenience benefits (e.g. local fuel supply, ongoing active operator control of fuel load and heat output, independence of heating system from electricity supply breakdowns caused by ice-storms, negligible system maintenance) there are also inconveniences. For example, we expected concerns about the inconveniences of having to arrange for supply and having to store wood fuel to be rated highly amongst those who do not have a wood stove. Furthermore, we expected that the apparent inconvenience of having to light and maintain a wood fire rather than 'flicking a switch' and relying on automatic thermostatic and/or timer control would be an important concern. Finally, we expected that health impacts related to wood fire fumes and dust circulation would be common (even though modern secondary combustion systems probably minimise these concerns). Thus, these survey data could be interpreted as highlighting a considerable lack of awareness amongst those who do not currently have a woodstove of the conveniences and inconveniences associated with using wood fuel for heating. Furthermore the extent of the inconvenience caused by each of these concerns is likely to vary demographically (e.g. by age, household size etc.) although our survey population was too small to analyse for this. We conclude that policies leading to successful development,

implementation and long-term use of wood fuels for domestic heating should be based on supplying appropriate information not just on the safety, economic and environmental factors highlighted above, but also on the convenience implications.

Reflections on the educational experience

Goals and structure of the exercise

This study was conducted as a group-based exercise by a small class (n=9) of final year undergraduate and first-year graduate students with an interest in Biology/Environmental Sciences for half a semester. Although the conclusions above were informative from economic, environmental and social dimensions, there was also a great value in the educational experience that it provided. The learning objectives for this exercise were to enhance each student's ability to: a) understand and explain some of the economic, environmental and social factors that influence consumer choice; b) to participate in developing incisive, focussed and feasible research questions; c) to gather and analyse the appropriate data to address those questions; d) to participate in interpreting, writing and orally presenting the conclusions according to time deadlines; and e) to contribute effectively to seminar discussions.

Initial class 'brain-storming' discussion sessions quickly highlighted each of the three different dimensions and the importance of their interactions in evaluating and determining the impacts of such a consumer choice. Subsequently, the class divided into groups who spent several crucial sessions developing and refining specific research questions that they could feasibly address within the constraints of data availability and time allotted to this project. Students used raw data (e.g. utility supply bills), internet sources and library facilities as well as computational and presentation software to mathematically analyse, write and present their data. Guidelines for the reports and seminars were provided in advance, but groups were encouraged to develop and manage their projects independently. Seminar presentations by each group were made to the full class and included extensive discussion of methods, critical interpretation of data and conclusions, and synthesis in the context of the overall study.

Identification of critical assumptions and potential limitations of each group's conclusions was emphasised throughout.

Other opportunities

The exercise provided a wealth of possibilities because of its environmental and social components. For example, apart from the questions addressed above, students also investigated: Are there particular pollutant issues associated with burning wood in a modern combustion stove, as compared to fossil-fuel based furnaces? What economic incentives to promote woodstoves are provided in Canada compared to other countries, and to what extent are they successful? Is there sufficient wood production in E. Canada to support wide-scale use of wood stoves? How would different forestry management practices influence the latter? Do the factors deemed most important in choosing a household heating source vary by social determinants: age, education level, and household income level? Furthermore, the development of simple spreadsheets allowed each group to do various 'sensitivity analyses' including exploring: a) the economic impacts of increases in natural gas and wood prices; b) the importance of interest and discount rates in economic analyses; c) the influence of wood transport distance from forest to household on overall net CO_2 emissions.

Assessment

Post-exercise asssessment confirmed that students were clearly genuinely excited about the exercise because: a) it related to a 'real world' situation of clear potential interest to any householder, including themselves in the future; b) raw data was available or could be collected (e.g. by survey); and c) it was a collaborative project that integrated differing perspectives. Students enjoyed the opportunities to enhance their skills in project management and group work, and to learn economic principles of interest and discount rates, and ecological concepts such as the 'ecological footprint'. Assessment results indicated that all students rated their enjoyment of this exercise as above 'Average' (i.e. as either 'Good' 63% or 'Excellent' 37%). Amongst the written comments one wrote: "*The most interesting aspect about the exercise was that we were able to approach the same topic from 3 different perspectives. It was great to see all three parts come together to give a comprehensive understanding. I feel the project has*

developed me to become a better critical thinker, as we continually asked questions and tried to include all possible factors related to the subject."

Overall, the exercise was a very valuable educational experience that had the added value of providing a potentially very useful set of research results. Similar approaches to the same general topic for other locations or for other sources of heating (e.g. solar, oil, geothermal etc.) would also be worthwhile. Furthermore, the general approach could be successfully and usefully applied to analyses of a very wide range of other consumer choices.

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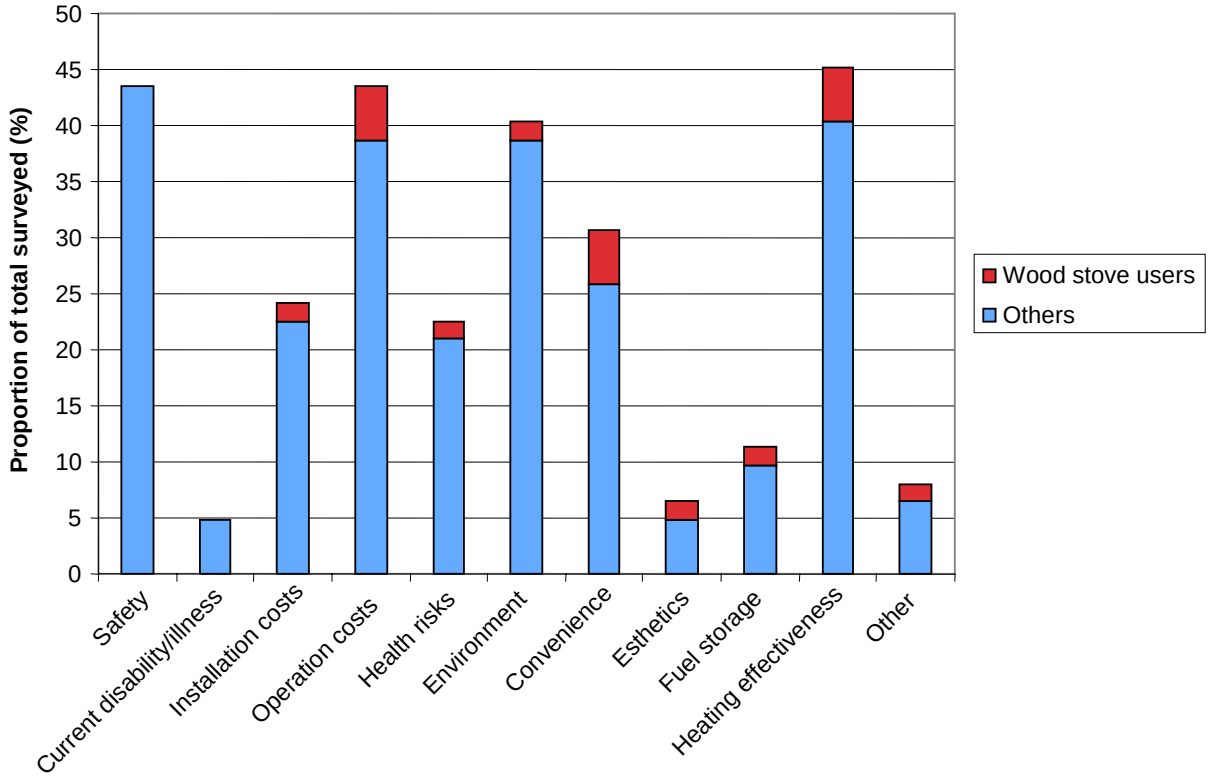
Figure legend

Figure 1. The factors that are most important to householders when choosing a replacement heating system. Each column indicates the proportion of total surveys that included that factor within the top three ranked factors, and is subdivided into respondents that currently use wood stoves (n = 5) and those who do not (n = 58).

Figure



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