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 an energy-efficient hybrid car (with regenerative braking) a better choice than a regular petroleum-only vehicle when considered from all three dimensions? Surprisingly, although each and all of these dimensions is clearly important to optimal 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 by a small class of primarily final-year undergraduate students on renewable vs. fossil–fuel based options for domestic heating to explore the actual economic and environmental advantages and disadvantages of each option. We analyzed 4 years of fuel consumption data for a household in Kingston, ON, 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. Consideration of projected fuel price rises and ongoing maintenance and replacement costs, however, strongly suggests that substantial overall cost savings would accrue, especially after the first decade of woodstove installation. Since wood can be a renewable resource, annual net CO_2 emissions associated with domestic heating were also reduced by 60%. 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 focused information on the critical economic, environmental, and lifestyle/social dimensions of that choice.

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Increasing energy costs as well as concerns about climate change associated with fossil fuel use have encouraged householders across North America and Europe to consider alternative options for domestic heating. Since European colonization in the mid-1800s, many isolated rural households in eastern North 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 of relatively cheap local wood fuel supply for heating in more urban locations may now be substantial.

Wood fuel is not just becoming more plentiful in this region, its use could help to mitigate fossil fuel carbon dioxide (CO_2) emissions to the atmosphere because most carbon released during fuelwood combustion would have been released during natural forest decomposition anyway. Therefore, if the fuelwood is taken from sustainably managed forests where the new tree growth rate matches or exceeds the harvesting rate, forest carbon uptake during growth of new trees in the harvested forest or woodlot offsets the CO_2 release from the wood resulting in negligible net emissions. Thus, woodfuel may be considered as a renewable resource, meaning that its supply is indefinite relative to fossil fuels, and its use has little net impact on CO_2 in the atmosphere. Finally, the introduction of secondary combustion "air tight" technology in wood stoves has reduced fine particulate pollutant emissions (particles <2.5 microns) by 70% relative to traditional wood stoves (USEPA, 2008a) as well increasing heat efficiency by 30% (USEPA, 2008b). In comparison to open fireplaces, fine particulate smoke emissions from such modern wood stoves are reduced by 95% (USEPA, 2008a). As a result, not only are pollutant emissions to the environment greatly reduced,

Impact Statement

How can we teach important life skills in an interactive way? Here, I describe a case study approach that proved very successful in engaging students and improving their independent-learning skills. The theme was examining the economic, environmental, and lifestyle/social factors that contribute to optimum long-term consumer choices. The focus was the choice between wood-burning and fossil fuel–based home heating systems.

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but the significant health concerns associated with wood smoke inside the house (Larson and Koenig, 1994) are largely eliminated (Traynor et al., 1987).

Accordingly, governments have introduced financial rebate systems in the United States and British Columbia to encourage householders to replace traditional woodstoves with advanced secondary combustion stoves (USEPA, 2008c). Nevertheless, there may be particular concerns where even modern woodstoves are being used at high densities in urban or other locations that experience inverted air masses and therefore trap smoke emissions in the lower atmosphere (Gulland, 2004).

Wood fuel for home heating may become increasingly financially attractive to consumers over the next few decades if fossil fuel prices increase due to supply–demand dynamics (Gulland, 2007) as well as possible government introductions of a "carbon tax." 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 by a small class of primarily final-year undergraduate students for a household in Kingston, ON, 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 2-year periods before and after the installation. In addition, we surveyed home occupants in the local area to identify and rank the factors that would most influence their decision when choosing a replacement heating system.

Methods

Case Study Details

A medium-sized, high efficiency secondary combustion, EPA-certified non-catalytic wood stove (Pacific Energy Classic, Burnaby, BC, Canada) was installed as a "stand-alone" heating system in the ground floor living space of an early 1900s detached single family home (3200 ft^2, 300 m^2) with five residents in September 2005. Natural gas consumption records for domestic forced-air heating using a modern high-efficiency furnace and for water heating were available for two 24-month periods before (August 2003–2005) and after the woodstove installation (December 2005–2007). The stove was installed in mid-September and the gas meter was read every 2 months, so we began the post-stove analysis period after the following actual meter reading to be sure there was no overlap in the pre-and post-stove data. Mean monthly local winter air temperatures were similar between years. Air-dried split logs that had been seasoned over ~6 months 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. The stove was run almost continuously through the winter months to maximize its contribution to household heating. Our analysis of these data assumes that electricity and maintenance costs associated with the furnace and the stove were negligible, that gas consumption for water heating was constant over the 4-year study period, and that home heating requirements in the winters before and after wood stove installation were similar. Consumer price rates for natural gas supply fluctuated somewhat, but mean values for the two periods of the study were similar (mean = \$0.488/m^3 for 2006–2007). Wood fuel costs increased slightly during that period (mean = \$266/full cord). All economic values in this manuscript are in Canadian dollars. No other infrastructural changes were made to the dwelling since 2005.

Ecological footprint calculations are based on data from Wackernagel and Rees (1996): 1 m^3 of natural gas (primarily CH_4) contains 40 MJ of energy, and releases 2.66 kg CO_2 during combustion. One liter 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 carbon) in net primary production per year. We have assumed that 1 air-dried (20% moisture) full cord (3.6 m^3) of mixed hardwood has a mass of ~1600 kg, contains 16 MJ of energy per kg, and is 42% carbon (Anonymous, 2009).

Social Survey Details

We distributed an anonymous survey among colleagues and friends who were local householders or students within Kingston and its rural environs, representing several demographic groups (based on urban/rural location of residence, type of housing, size of household, age, education, and household income). The survey was focused on the following question: "If your current heating system had to be replaced, what factors would be most important in deciding to use a wood-burning heat source?"

Respondents (n = 63) 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; and 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, and 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/year). Mean annual natural gas costs were reduced from ~\$2260 to ~\$880, but annual firewood consumption (5 full cords = 18 m^3) amounted to ~\$1330. Consequently, the use of the wood stove resulted in a slight reduction (~\$50/year) 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 in Canada have risen at an average rate of ~9%/year since September 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 December 2005 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 certified installation with appropriate chimney (~$4750). Furthermore, we can also expect some future increases in wood prices due to harvesting, transportation, and labor expenses. Nevertheless, even with the 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 (Fig. 1). Furthermore, our analyses demonstrate that 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 3 years (Fig. 1). 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.

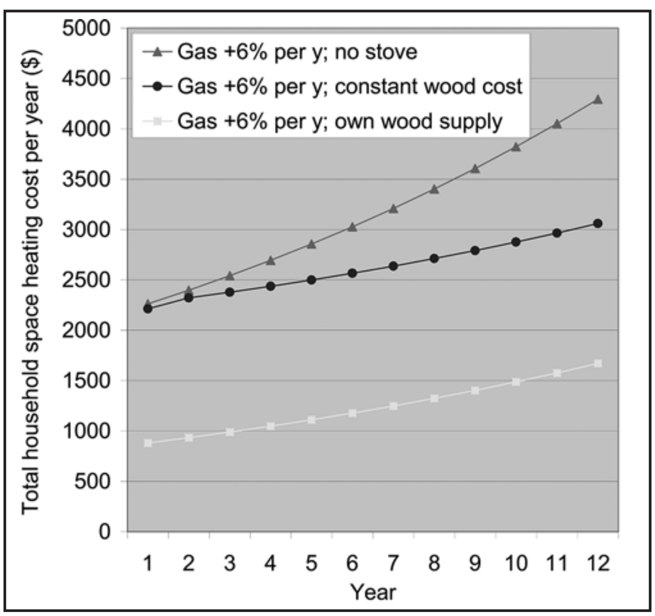

Fig. 1. The effect of increasing natural gas prices (6%/year) on total home heating costs over successive years for householders with no woodstove, a woodstove supplied with wood at constant current cost, and a woodstove supplied with wood from their own land (i.e., no cost).

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 carbon. Total annual energy consumption for heating prior to the woodstove installation (~190 GJ in natural gas) did not change appreciably afterward (~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 eastern Canada (Natural Resources Canada, 2002).

Annual *gross* CO_2 emissions increased from 12,610 kg (i.e., ~2.5 metric tons CO_2/person per year) to 17,330 kg after the installation of the wood stove. However, since most of the carbon in the harvested wood would have been released through natural decomposition on the forest floor anyway, and the wood was supplied from a local sustainably managed woodlot in which the tree harvesting rate is less than or equal to the new tree growth rate, ongoing forest carbon uptake from the atmosphere should be at least equivalent to the original fuel wood carbon content. Therefore, the CO_2 emissions associated with burning wood in a stove can be considered as replacing the natural CO_2 release that would have occurred anyway during decomposition of that wood, and thus the emissions associated with wood combustion may be considered neutral in terms of their overall impact on atmospheric CO_2 concentrations. Assuming aboveground tree biomass of 12.5 kg carbon/m^2 (Kurz and Apps, 1999) and a mean tree regeneration time of 130 years, wood production is ~96 g carbon/m^2 per year for forests in the Kingston region, meaning that the equivalent of a 16.4 by 16.4 m area would need to be harvested each year to supply annual wood fuel demand, and an area of ~3.5 ha of woodlot or forest would provide an indefinite supply. We estimate that CO_2 emissions associated with the fossil fuel requirement for local transport from the woodlot are ~190 kg CO_2, and have not included any corresponding figure for emissions associated with extraction and transport of the natural gas to the house. On this basis, annual *net* CO_2 emissions associated with domestic heating were reduced by 60% (to ~5100 kg; i.e., 1.0 metric tons CO_2/person per year) by the use of the woodstove.

The environmental impact of a human activity can be characterized 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. 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%. This conclusion about the overall magnitude of the environmental impact is strongly supported by the alternative approach of determining the effect on mean Canadian total CO_2 equivalent emissions per capita (23.1 metric tons/person per year in 2005; Environment Canada, 2009) which would be reduced by 6% (1.5/23.1) by the use of the woodstove.

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 (Fig. 2). These factors were ranked within the top three in 40 to 45% of all surveys. Respondents who did not have a wood stove identified safety as a paramount concern (ranked within the top three factors in 43% of surveys). Total energy consumed was similar before and after the wood stove installation (see above), strongly suggesting that heating effectiveness was unaltered. In fact, perceived heating effectiveness of a wood stove with a see-through ceramic "glass" door may be superior when one considers the distinctive "cozy atmosphere" that glowing fires create. In any event, since our analyses above indicated some potential for economic savings and substantial 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.

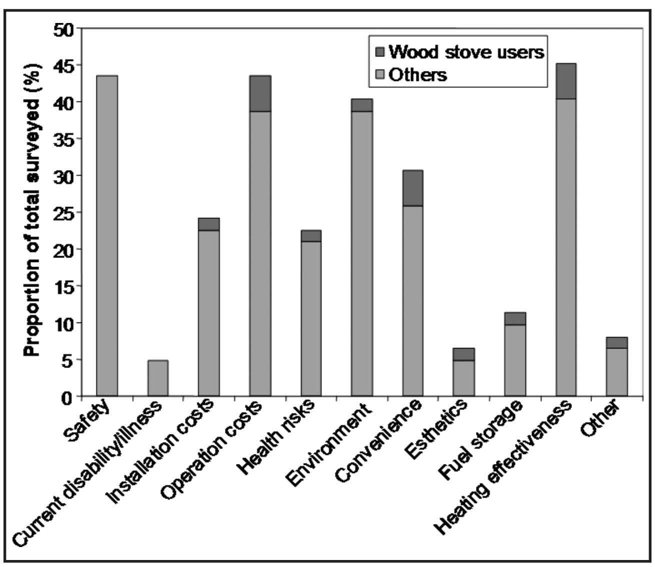

Fig. 2. The factors that are most important to householders when choosing a replacement heating system. Each column indicates the proportion of total surveys that included that factor within the top three ranked factors, and is subdivided into respondents that currently use wood stoves (n = 5) and those who do not (n = 58).

To our surprise, the issue of "convenience of use" was not ranked very highly in deciding whether to install a wood-based heating system to replace or supplement their current system by those who do not have a wood stove. By contrast, most of those who currently use a wood stove (n = 5) ranked convenience highly, 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 etc., 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 among 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 wood stove systems minimize these concerns (Traynor et al., 1987). Thus, these survey data could be interpreted as highlighting a considerable lack of awareness among 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 analyze for this. Overall, our results suggest that policies leading to effective development, implementation, and successful 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 interests in biology/environmental sciences for half a semester. Although the conclusions above were informative from economic, environmental, and social dimensions, the study also provided a valuable educational experience. The learning objectives for this exercise were to enhance each student's ability to: (1)

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understand and explain some of the economic, environmental, and social factors that influence consumer choice; (2) to participate in developing incisive, focused, and feasible research questions; (3) to gather and analyze the appropriate data to address those questions; (4) to participate in interpreting, writing, and orally presenting the conclusions according to time deadlines; and (5) to contribute effectively to seminar discussions.

Initial class "brain-storming" discussion sessions quickly highlighted the economic, environmental, and social 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 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 analyze, write, and present their data. Brief guidelines for the reports and seminars were provided in advance, but groups were encouraged to develop and manage their projects by themselves so that they could learn those essential life skills. 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 were emphasized 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: (1) Are there particular pollutant issues associated with burning wood in a modern combustion stove, as compared with fossil fuel–based furnaces? (2) What economic incentives to promote woodstoves are provided in Canada compared with other countries, and to what extent are they successful? (3) Would it have been better, economically and environmentally, to have invested the installation costs of the woodstove in reducing home heat losses by improving the house's thermal insulation? (4) Is there sufficient wood production in eastern Canada to support wide-scale use of wood stoves? (5) How would different forestry management practices influence the latter? (6) 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: (1) the economic impacts of increases in natural gas and wood prices (e.g., Fig. 1); (2) the importance of interest and discount rates in economic analyses; (3) the influence of wood transport distance from forest to household on overall net CO_2 emissions.

Evaluation of the Exercise

Post-exercise assessment using a questionnaire confirmed that students were clearly genuinely excited about the project because: (1) it related to a "real world" situation of clear potential interest to any householder, including themselves, in the future; (2) raw data was available or could be collected (e.g., by survey); and (3) 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%). Among the written comments, one wrote:

> The most interesting aspect about the exercise was that we were able to approach the same topic from three 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. I really enjoyed how the students took a larger role in deciding how they will conduct the project. I really had a sense of ownership when working on it, and the results of our work.

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., oil or coal both of which are less refined fuels that have higher carbon contents per unit energy than natural gas and therefore larger CO_2 emissions; solar; geothermal, etc.) would likely be worthwhile. Furthermore, the general approach could be successfully and usefully applied to analyses of a very wide range of other consumer choices. From a teaching perspective, clearer guidelines and expectations at each stage would have helped student learning. Better educational use could have been made of the very small sample size for the wood stove user group that invalidated interpretation and comparison with the other group. Furthermore, making the written report due some days after the final seminar presentations (rather than simultaneously) would have greatly benefitted the learning experience by permitting the students to reflect on the seminar discussions and incorporate salient points into their reports. Finally, the small class size ($n = 9$) helped the process in terms of student motivation and "ownership" (i.e., individual responsibility) for the components of each group theme. It is hard to imagine that there is not a trade-off between class size and individual student ownership that would severely hamper the success of the teaching exercise if there were more than ~15 students.

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