Energy, Sustainability and Society
a SpringerOpen Journal

REVIEW

From coal to wood thermoelectric energy production: a review and discussion of potential socio-economic impacts with implications for Northwestern Ontario, Canada

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Abstract

The province of Ontario in Canada is the first North American jurisdiction with legislation in place to eliminate coal-fired thermoelectric production by the end of 2014. Ontario Power Generation (OPG) operates coal-fired stations in Ontario, with Atikokan Generating Station being the only facility slated to switch to 100% woody biomass. It is anticipated that this coal phase out policy will have socio-economic impacts. Because of these anticipated changes, in this paper, we review the current state of peer-reviewed literature relating to three burning scenarios (biomass, coal and co-firing) in order to explore the knowledge gaps with regard to socio-economic impacts and identify research needs which should elucidate the anticipated changes on a community level. We reviewed over 150 sources, which included peer-reviewed articles and non-peer-reviewed grey literature such as government documents, non-governmental organization reports and news publications. We found very few peer-reviewed articles related to Canadian studies (even fewer for Ontario) which look at woody biomass burning for thermoelectric production. We identify a number of socio-economic impact assessment tools readily available and present potential criteria required in selecting an appropriate tool for the Ontario context. For any tool to provide meaningful results, we propose that appropriate and robust local data must be collected and analyzed.

Keywords: Atikokan, Bioenergy, Boreal, Electricity generation, Energy security, Lignite coal, Social impacts, Wood pellets, Gross regional product

Review

The province of Ontario in Canada has demonstrated its will to expand renewable energy production, encourage energy conservation and create 'green' jobs with the passing of the Green Energy Act of 2009 [1,2]. These changes have been recognized by one of Canada's most visible environmental non-governmental organizations (ENGO), the David Suzuki Foundation, that Ontario's green energy policies are the most far reaching in North America in terms of clean energy, innovation and jobs [3]. The province is also the first jurisdiction in North America with legislation in place to eliminate coal-fired thermoelectric production, making coal use illegal by the end of 2014 [4-6]. In order to be in compliance, the facilities are required to follow all established certificates of approval for air, water and land emissions issued by the Ontario Ministry of the Environment (MOE). Although non-compliance would be highly unlikely after the legislation goes into effect, penalties could be established by the MOE, should a generating station burn coal after 2014.

It is anticipated that these coal phase out policy changes will have socio-economic impacts in all regions where Ontario Power Generation (OPG) operates coal-fired stations, with Atikokan Generating Station (AGS) being the only facility slated to switch to 100% woody biomass [7], while other coal-burning stations such as Lambton and Nanticoke are slated for decommissioning before the 2014 deadline. In this paper, we define socio-economic impacts in general terms as social and economic well-being of

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community members, with well-being defined, 'as a person's quality of life. This is influenced by a range of factors, including work, family, community, health, personal values, personal freedom and a person's financial situation [8]'. Positive socio-economic impacts provided by a company's involvement in a community can include creating jobs, inducing jobs in other sectors, providing physical infrastructure such as parks and recreation centres, paying municipal taxes and providing charitable donations to civic and community groups. Woody biomass in this paper refers to wood pellets produced from sawdust and forest harvest residues of commercial spruce, pine and fir species. Woody biomass is also obtained from harvesting other underutilized species like white birch (*Betula papyrifera* Marsh.) and poplar (*Populus* spp.). Depending on site conditions and tree species, Canadian boreal forest practices typically follow a 60- to 100-year harvesting cycle. The AGS will require a total of 90,000 oven-dried tonnes of biomass wood pellets per year for full conversion [9-12]. This value should be easily achievable. Alam and others demonstrated that there is adequate forest harvest residue and underutilized wood biomass feedstock available in Northwestern Ontario to meet the demand [13]. Furthermore, woody biomass stock would also likely come from sawmill residues and waste, further reducing the pressure on forest resources.

Although Ontario is fully converting to non-coal options, many jurisdictions employ co-firing (burning coal along with woody biomass), which is often seen as more environmentally desirable than burning 100% coal, since a portion of the greenhouse gas (GHG) emissions will be from fossil fuels and a portion from renewable energy [14]. Co-firing is becoming more common and is being practised at a commercial scale in many countries such as the USA, Finland, Denmark, Germany and Belgium [15]. The ratio of coal to woody biomass is very site specific, and it depends on a number of factors such as furnace and boiler design, physical and chemical fuel characteristics, fuel handling and milling units [15]. Utilizing a life cycle approach at AGS, Zhang and others [16] indicated that co-firing woody biomass (as an alternative to 100% coal) can be an economically feasible option to reduce GHG emissions in the Ontario context.

At present (2011 values), nuclear power generating stations[a] meet 56.9% of demand and are running at full load throughout a full 24-h period in order to meet energy base load demand. [17]. Base load is considered the minimum level of power demand. Nuclear power ideally meets this base load demand since it has a high electrical production capacity and relatively low production cost. However, nuclear power has less capacity to adjust to fluctuations in demand. Hydroelectric power generation meets 22.2% of demand and responds to variations in load to meet the peak demand. Peak production stations are employed to make up capacity at maximum demand periods and in emergency situations [17]. These can transition from idle to full power production in short periods to meet these temporary and sometimes unpredictable demands. Peak demand is variable over the course of daily and yearly cycles and is in part contingent on weather conditions and is managed to a degree with time-of-use pricing.

As an important renewable energy source, hydroelectric plants provide 'flexibility in base loading, peaking and energy storage applications' [18]. Many smaller hydroelectric generating stations reduce production overnight, storing water to meet peak demand during the following day, with only the largest hydroelectric stations running throughout the night. If the demand exceeds supply by smaller hydroelectric stations, the natural gas generating stations, which meet 14.7% of demand, begin production. Under this regime, coal, which only meets 2.7% of demand, is used as a last resort for voltage support[b]. The use of coal for power generation has been on a steady decline (Figure 1). Recent additions to Ontario's power mix include wind, which meets 2.6% of demand, with all other energy sources (including solar power) meeting 0.8% of Ontario's power demand [4,19,20].

Regardless of the electrical energy fuel source, each option has its own environmental consequences such as release of GHGs, particulates, nitrous oxides and/or sulphur dioxide [22,23]. As public support for coal and other fossil fuels continues to wane, renewable sources are being sought [24-28] with biomass-fired power becoming a viable renewable energy option partially because this technology is 'rapidly deployable, low-risk, regionally indigenous, and inherently grid-compatible [29]'. Wind and solar energy do not possess these characteristics since they depend on weather conditions [17]. Furthermore, woody biomass can provide (1) reserve capacity during peak demand, (2) capacity during routine maintenance at other generating stations and (3) resilience in the power grid, should other generating stations go offline in an emergency.

Whenever the use of woody biomass for power generation is introduced, a variety of public opinions may arise. On the one hand, woody biomass for power generation has many of the above-mentioned benefits; on the other, there is documented public opposition [30,31]. The Greenpeace report, 'Fueling a Biomess', is critical of Canadian provinces' efforts to stimulate biomass fuel for electricity production [32]. The report critiques are directed to the government's 'biomass extraction policies and subsidies [32]', and it outlines a number of recommendations to government, many of which represent socio-economic impacts. These include (1) suspend the approval of new bioenergy proposals and conduct a review of existing projects, their wood allocations and

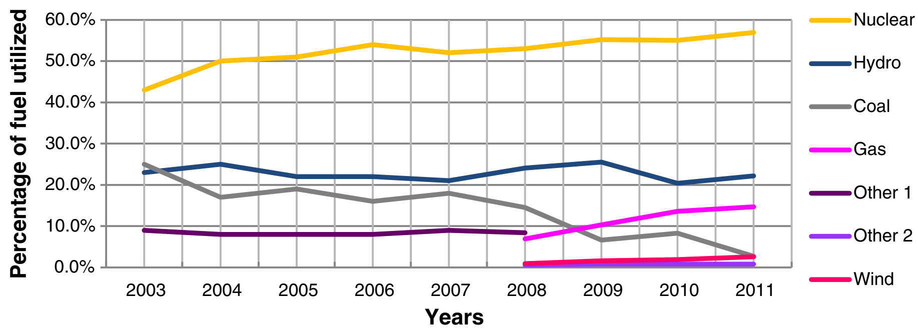

Figure 1 Historical changes in fuel supply used for electricity production from 2003 to 2011. Raw data from Ontario's Independent Electricity System Operator News Releases from 2004 to 2012 [21] were used to establish a 9-year tread (2003 to 2011) for Ontario's electricity power mix in order to provide an Ontario context. Nuclear (yellow line) and hydro (blue line) production levels have remained relatively constant over the period. Electricity produced from coal (grey line) has been steadily decreasing over the time period. In 2008, IESO ceased to report natural gas, oil, wind and alternative fuel sources together (Other 1, dark purple line) and broke it apart to report gas (pink line), wind (magenta) and Other 2 (light purple) separately.

their impacts on communities, climate and forests, (2) preclude low-efficiency electricity-only production from forest biomass and require that waste heat of biomass electric plants be utilized locally and (3) support the production of higher value wood products from public forests to optimize job creation, minimize resource extraction and develop sustainable solutions for forest-based communities [32].

Recommendations such as these imply that the forest management planning process does not routinely incorporate socio-economic considerations. In contrast, forest practitioners, with the responsibility for managing public forests in Ontario, operate under the Crown Forest Sustainability Act (1994) [33] that includes requirements for public consultation and recognizes the necessity for both economic and ecological sustainability. This legislation is implemented through a series of management guides [34] developed to ensure the protection of multiple forest values including cultural heritage [35], resource-based tourism [36], biodiversity [37], natural disturbance pattern emulation [38] and species of interest (e.g. marten [39], woodland caribou [40]). Guide revision is ongoing, science-based, overseen by a joint committee (which includes government, industry, First Nations, academia) and subject to review every 5 years [41]. Despite the processes in place, challenges such as those raised by Greenpeace need to be addressed through standard research protocols.

Therefore, the objectives of this paper are (1) to determine the current state of peer-reviewed literature relating to coal, biomass and co-fire burning in Ontario and to relate the current state of knowledge nationally and globally, looking outside of Ontario when necessary for insights into the Ontario context and (2) to explore the knowledge gaps with regard to socio-economic impacts, under three scenarios which include 100% biomass burning, 100% coal burning and co-firing.

Methods

In order to determine generally the current state of peer-reviewed literature relating to biomass burning for thermoelectric generation in Ontario and to identify knowledge gaps in the peer-reviewed literature, the Thomson Reuters (ISI) Web of Knowledge[c] [42] was used to find articles covering the utilization of wood-based biomass in thermoelectric power generating stations. This preliminary search was carried out by following the Boolean search string: 'biomass', 'wood*' and 'thermoelectric*'. Asterisks were used as they provide the function of a 'wildcard' thus increasing the likelihood of words with suffixes being included in the search. We also preliminarily searched simply 'Atikokan' in order to help us establish a baseline of all studies conducted in the Atikokan region.

Secondly, since Ontario policy dictates that alternatives to coal must be implemented, we also conducted a more in-depth literature search related to three common burning scenarios:

- 100% coal: this was searched since coal is the fuel source that is being phased out at AGS. Although it is not widely used in Canada, it is globally the second most important fuel after oil accounting for 27% of world primary energy demand [4],
- 100% biomass: this was searched since biomass is being phased in at AGS. Furthermore, biomass is experiencing more attention globally, for example, increases in demand in Europe as they seek to power industry and reduce GHG emissions concurrently [43] and
- Co-firing coal with biomass: this was searched since co-firing has been an experimental intermediate

stage at AGS and is employed in many jurisdictions as a shorter term low-cost option to reduce GHG emissions [44].

In this second search, we used the following Boolean topic search in Thomson Reuters (ISI) Web of Knowledge: ('biomass', 'wood*', 'coal' or 'co-fire') and ('employ*', 'product*' or 'community*') and ('electric*'). We used the search term 'electric*' rather than 'thermoelectric*' as we did in the preliminary search in order to broaden our results. Then, this search was narrowed down separately two more times, the first one by only adding the term 'Canada' to the original topic search and the second one by only adding the term 'Ontario' to the original search. Results where then presented in a pie graph.

Following this, we identified and used relevant articles indicated through forward and backward citations in Thomson Reuters (ISI) Web of Knowledge and Google Scholar[d] [45]. Google Scholar was used in order to reduce the likelihood that related sources would be missed. Additionally, we also investigated the non-peer-reviewed literature such as grey literature and news publications as oftentimes useful information relevant to studies such as ours can be found in these source types.

From the retrieved sources utilizing the various above-mentioned methods, only those relevant to this paper were included and used to establish a relative abundance of articles categorized by *Literature Type*, *Location*, *Impacts*, *Fuel* and *Combinations*. Then, based on the current state of knowledge and gaps, we discuss potential methods for future work, which should elucidate the anticipated policy changes on a community level.

Results and discussion

Our findings from the preliminary Thomson Reuters (ISI) Web of Knowledge search indicate that very few Canadian peer-reviewed articles investigate biomass burning in thermoelectric generating stations. For example, the search ('biomass' and 'wood*' and 'thermoelectric*') yielded six articles of which only one [46] has any direct bearing to this review. The search 'Atikokan' retrieved 45 articles, with only 8 of these articles having any bearing on this review further indicating that limited work has been conducted to date which is Atikokan-specific [7,46-51].

The secondary search ('biomass' or 'wood*' or 'coal' or 'co-fire') and ('employ*'or, 'product*' or 'community*') and ('electric*') was followed by the narrowing term (and 'Canada'), and again, the narrowing term (and 'Ontario') indicated that out of the 4,954 articles retrieved, only 93 addressed Canada and only 10 addressed Ontario (Figure 2), of which many from Canada or Ontario were actually not suitable sources for this study. Since the literature indicates that most research has been conducted outside of Ontario, Canada, we had to rely primarily on these studies from other jurisdictions.

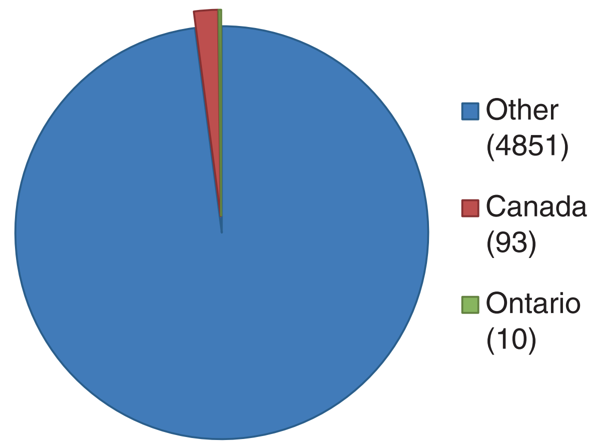

Figure 2 Relative abundance of Canada- and Ontario-based peer-reviewed papers. The search ('biomass' or 'coal' or 'co-fire') and ('employ*'or 'product*' or 'community*') and ('electric*) yielded 4,954 articles, of which 4,851 articles were from outside Canada [42]. The first narrowed down search which included the search term 'Canada' yielded 93 articles. The second narrowed down search which included the search term 'Ontario' yielded 10 articles.

From the results of our second query, it was noted that the top five countries' institutional affiliations are (1) United States, (2) People's Republic of China, (3) England, (4) Germany and (5) Sweden. However, this list might be misleading since it reflects countries where universities and other research institutions are located but not necessarily where the research is taking place on the ground. This list also does not indicate where biomass utilization is currently being employed on a production scale although 'abundant resources and favourable policies' have allowed Northern Europe and the United States to expand biomass utilization for power [52]. Wherever possible, we have generalized and related these findings to the Ontario context, addressing the local socio-economic impacts relating to 100% biomass burning, 100% coal burning and co-firing biomass with coal.

We reviewed over 150 sources in depth, which included peer-reviewed articles and non-peer-reviewed grey literature such as government documents, non-governmental organization (NGO) reports and news publications. Of those sources, 74 bearing relevance to our study were cited and summarized in Table 1. It became apparent that a gap exists in the peer-reviewed literature related to Canadian studies investigating woody biomass burning for thermoelectric production. We found eight sources which discuss biomass burning in Canada (relevant to this study), of which only three are peer-reviewed journal articles. Out of the 74 sources cited in this paper, only 27 of these are peer-reviewed journal articles, with the other articles being classed as

Table 1 Publications identified and reviewed based on fuel location and impacts

	Number	Percent
Literature type		
Peer review	27	36.49
Government publication	16	21.62
Academic textbook	6	8.11
Corporation publication	5	6.76
NGO publication	7	9.46
International Governmental Agency	3	4.05
Trade publication	3	4.05
Newspaper/magazine	3	4.05
Other	4	5.41
Total	74	100.00
Location		
Canada	35	47.30
Generalized global	15	20.27
Abroad	9	12.16
US	6	8.11
Multiple jurisdictions	5	6.76
N/A	4	5.41
Total	74	100.00
Fuel		
N/A	22	29.73
Biomass	18	24.32
Multiple fuels	17	22.97
Coal	10	13.51
Co-fire	4	5.41
Other	3	4.05
Total	74	100.00
Combinations		
Peer review and Canada	9	
Canada and biomass	8	
Peer review, Canada and biomass	3	

Over 150 articles were reviewed, and 74 are cited here and tagged to literature type, location, fuels and novel combinations.

academic text books or government, NGO, corporation and trade publications (Table 1). Although non-peer -reviewed literature is an excellent source for knowledge, it is not always subject to the same academic critical review as peer-reviewed journal articles are subjected to.

A primary factor in assessing local socio-economic impacts is the extent to which economic activities remain within the region. In Canada, thermoelectric stations are often built near the fuel source, commonly known as mine-mouth [53], examples include Boundary Dam Power Station and Poplar River Power Station in Saskatchewan and Sheerness Thermal Generating Station in Alberta. However, AGS has no nearby mine and uses lignite coal, which is shipped approximately 1,000 km on rail from Bienfait, Saskatchewan. Although lignite coal and wood pellets tend to have similar energy density (Table 2), woody biomass is still more expensive to produce and hence generally requires short transportation distances to be most cost-effective [17,54] in the absence of subsidies or other incentives. The data in Table 2 are primarily quantitative in nature and generally a good indicator of differences in the three burning scenarios. However, a potential weakness of the values presented is related to varying market conditions. It is possible that these values for coal, biomass and co-firing may fluctuate, potentially rendering these values less helpful in reality and in the Ontario context.

The phase out from coal to biomass in Atikokan has the potential to provide new local benefits such as necessitating a local biomass supply chain [15], and it is speculated that it could not only secure current jobs but also create new ones [54]. It has been reported that a greater number of people can benefit from woody biomass production since direct labour inputs for woody biomass production can range anywhere from 2 to 3 times [65] up to 20 times [15] greater than coal.

The utilization of woody biomass in co-firing, as with 100% biomass, has the potential to develop localized wood pellet industries (albeit on a smaller scale) which can benefit local rural economies [70]. However, local benefit from woody biomass may not always be realized. If the quantity of required wood pellets is low relative to coal, it may be more feasible to transport biomass a greater distance rather than create a local production facility.

The World Business Council for Sustainable Development (WBCSD) recently published a report evaluating 10 assessment tools for evaluating a company's socio-economic impact [71]. Their criteria for inclusion were twofold. Firstly, for a tool to be included, it had to focus solely on socio-economic impacts, and secondly, it had to be developed primarily for business. The document presents and defines the 10 tools, assessing them on 9 dimensions. The dimensions fall under two broad categories: (1) strategic fit (i.e. secure licence to operate, improve business enabling environment, strengthen value chains, fuel product and service innovation) and (2) applicable levels (i.e. site, value chain, business line, company operations at the national level and company). For each tool, the document also outlines the degree of guidance provided, data requirements, level of effort and example case studies.

In order to properly evaluate the impacts of AGS transition from coal to biomass, choosing the most appropriate method is imperative. Of the nine dimensions outlined in the WBCSD report, we identified ‘maintaining license to

Table 2 Comparison of local socio-economic impact factors of burning scenarios

Fuel	Gross calorific value (MJ/kg)	Cost per weight ($/kg)	Cost per caloric value ($/MJ)	Transportation in Canada	Transportation to Aikokan, ON	Relative GHG emissions and carbon neutrality hypothesis (g CO2/kWh*h)	Waste by-products and disposal
Coal	25 to 27 [17,55,56] 7 to 18 (lignite) [57]	0.05 [58]	$0.0019/MJ to $0.0020/MJ (lignite)	Mine mouth in many instances 1,000 s of km primarily by rail, with some road depending on where production facility is located [53,59]	Lignite coal is currently shipped approximately 1,000 km from Benoit, SK. All fuel production is located well outside Atikokan's jurisdiction.	850 to 1116 [22,60] Coal releases carbon which was sequestered 225 to 345 million years ago [55,61].	Fly ash can be used in environmental applications where markets dictate [49,50,62].
Wood Pellets	17 to 22 [15,17,55]	0.21 to 0.30 [63,64]	$0.012/MJ to $0.014/MJ	Transported 100 s of km primarily by road with some rail [54]	Relatively high cost per unit energy ($/MJ) necessitates relatively short transportation distance from wood pellet production facility.	39 to 80 [22] May be carbon neutral [51,65,66] Releasing carbon which was sequestered within the past 200 years [67]	Can be used for agricultural and forestry purposes [68,69]
Co-fire	Depending on fuel mix, values will vary between coal and wood pellets.	Depending on fuel mix, values will vary between coal and wood pellets.	Depending on fuel mix, values will vary between coal and wood pellets.	Depending on fuel mix, values will vary between coal and wood pellets.	Depending on fuel mix, values will vary between coal and wood pellets.	883 to 906 [22]	A potential concrete additive [46]

MJ/kg, Megajoule per kilogramme; $/kg, dollars per kilogramme; $/MJ, dollars per megajoule; g CO_2/kWh*h, grammes of carbon dioxide per kilowatt hour, hour.

operate' as a key dimension for evaluating potential methods for an impact assessment at AGS since this dimension is concerned with determining how business activities create 'net benefits for the economies and societies in which they operate [71]'. Furthermore, the 'site' level is most appropriate for the Atikokan context since we are most concerned with how the provincial coal cessation legislation affects the AGS site and nearby community. Selecting and employing a tool which address these two dimensions should effectively capture how changes at AGS affect the community.

Also, when evaluating a major change in a small town's primary industry, we feel that the selected tool must be readily available in order to expedite implementation and allow for future comparative analysis across other sites or contexts. A tool for the Atikokan context also needs to best lend itself to a developed country scenario. For example, one of the tools, 'Progress out of Poverty (PPI)' [71] would not likely be a viable option for Atikokan. Based on these criteria, possible candidate tools exist and may include the Global Environmental Management Initiative (GEMI) Metrics Navigator [72], measuring impact framework [73], or socio-economic assessment toolbox (SEAT) [74]. Regardless of the tool, each needs to be evaluated on its own merit and 'on functionality, fit for purpose, and cost and complexity of implementation [71]'.

Conclusions

In this review paper, we explored the literature related to burning coal and woody biomass for thermoelectric production with specific reference to socio-economic impacts. It was identified that changes in Ontario's energy policy which include the total ban on coal burning will have wide-reaching effects on how electricity will be produced in the province. Since there is very little peer-reviewed research that directly relates to the province of Ontario (and Canada) and the transitions set to take place at AGS, we see this as a timely research opportunity.

We propose that the use of a carefully selected socio-economic impact tool could effectively characterize potential socio-economic impacts as a community anticipates transitions related to a wholesale change in fuel utilization in its local thermoelectric generating station. In order for socio-economic impact assessment tools to be valid and meaningful, appropriate and robust local data must be collected through various means, following an accepted and proven approach, such as one or more of the tools presented by WBCSD [71] that will require local community involvement and support. This proposed research is necessary in order to address concerns raised by groups such as Greenpeace and to gain insight into the impacts of the transition from coal to woody biomass. Future research should explore these issues at a greater depth, using AGS as the only North American case study of this scale currently available.

Endnotes

[a]It should be noted that nuclear power proponents often promote this energy source as 'green'.

[b]All OPG thermoelectric plants produce solely electricity, with no facilities currently producing heat under a combined heat and power (CHP) system, although the Ontario Power Authority is interested in developing CHP in Ontario. *c.f.* http://www.powerauthority.on.ca/update-chpcesop.

[c]The Thomson Reuters (ISI) Web of Knowledge is described as a premier literature and abstract database platform, which has been designed to help researchers to 'quickly find, analyze, and share information in the sciences, social sciences, arts, and humanities'.

[d]Google Scholar is a Google search engine optimized for searching scholarly literature across disciplines and sources such as articles, theses, books, professional societies and online repositories.

Abbreviations

AGS: Atikokan Generating Station; CO_2: Carbon dioxide; ENGO: Environmental non-governmental organization; GEMI: Global Environmental Management Initiative; GHG: Greenhouse gases; kWh: Kilowatt hour; MJ: Mega joule; MOE: Ontario Ministry of the Environment; OPG: Ontario Power Generation; PPI: Progress out of Poverty Indicator; SEAT: Socio-economic assessment toolbox.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors contributed to this review. JEED and CS collected and sorted the sources and information material and prepared the manuscript. HL provided critical revisions and provided technical input related to literature analysis and socio-economic impacts. NL provided critical revisions and technical input related to forest management practices in Ontario. All authors read and approved the final manuscript.

Acknowledgements

The corresponding author, a PhD candidate, was funded by the Natural Resources and Engineering Research Council of Canada through an Industrial Postgraduate Scholarship in partnership with Ontario Power Generation. The authors are very grateful for the ongoing support to this project provided by Daryl Gaudry, Brent Boyko, Jane Todd and the entire staff at OPG Thunder Bay and Atikokan Generating Stations. Additional funding was provided by the Centre for Research and Innovation in the Bio-Economy (CRIBE). The authors also wish to thank the two anonymous reviewers whose critiques have greatly improved the manuscript.

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Received: 25 October 2012 Accepted: 8 May 2013
Published: 30 May 2013

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doi:10.1186/2192-0567-3-11
Cite this article as: Dampier *et al.*: **From coal to wood thermoelectric energy production: a review and discussion of potential socio-economic impacts with implications for Northwestern Ontario, Canada.** *Energy, Sustainability and Society* 2013 **3**:11.