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Comparative life cycle assessment of compact fluorescent and incandescent light bulbs

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Full text	Michaud, R., Belley, C. (2007). *Analyse du cycle de vie comparative d'ampoules électriques : incandescentes et fluorescentes compactes* Final report for Hydro-Québec by the CIRAIG (October 2007), 59 pages, 3 appendixes.
Critical review	Lesage, P. (2008) for Hydro-Québec by Sylvatica, which oversaw the independent critical review committee.

1. Background

Hydro-Québec Distribution mandated the Interuniversity Research Centre for the Life Cycle of Products, Processes and Services (CIRAIG) to carry out a comparative life cycle assessment of incandescent and compact fluorescent light bulbs in the Québec context.

Specifically, the objectives of the Life cycle assessment (LCA) were to establish the environmental profile of both types of bulbs and identify and compare the "hot spots". The study aimed to enable Hydro-Québec to enhance its understanding of the life cycle impacts of the bulbs and provide insight into the possibility of substituting incandescent bulbs for compact fluorescent ones.

This comparative LCA was reviewed by an independent critical review committee, which confirmed the validity of the methods and of the results and conclusions.

2. Description of the life cycle assessment

Study objectives

1. Establish the environmental profiles of the two types of bulbs;
2. Identify the "hot spots" of the alternatives;
3. Compare the alternatives according to an analysis by scenario:
    a. The **baseline scenario** discounts the cross-effect of the heat generated when the bulb is lit.
    b. The **cross-effect** scenario takes into account the heat that is released by "crediting" the offset impact of an equivalent heat production by a heating system (or by adding the impact of a cooling process) to the life cycles of the bulbs (and therefore to the baseline scenario).

Life cycle phases

- The life cycle (production, distribution, use, and end of life management) of the two types of bulbs, including the production and transport of resources and the transport and management of the waste generated.

Data

- The specific data was essentially collected from various light bulb manufacturers whose products are available in Québec (Phillips, Globe, and Sylvania in particular).
- The data was completed with generic data modules (average data from commercial databases) available in the internationally-recognized LCA database, *ecoinvent*. This LCA database is the largest life cycle inventory database available on the market and contains data modules collected from a significant number of European industrial sectors. When required, these modules were adapted to the North American context.

Hypotheses

- A 60-W incandescent bulb is equivalent to a 13- or 15-W compact fluorescent in terms of the amount of light provided.
- A 60-W incandescent bulb has a service life of 1 000 hours. A 13- or 15-W compact fluorescent bulb has a service life of 10 000 hours.
- The basis for the comparison was defined as such:
    - **Providing between 500 and 900 lumens for 10 000 hours;**
    - We therefore compared one 13- or 15-W compact fluorescent bulb to ten 60-W incandescent bulbs.
- The bulbs were used in Québec (90% of the province's electricity is hydroelectric).
- According to the **cross-effect principle**, the heat released inside homes when the bulbs are lit reduces the demand on the heating systems (or increases the demand on the cooling systems).
- Approximately 90% of the energy consumed by both types of light bulbs is ultimately emitted as heat that the heating systems then do not have to produce (or heat treated by the cooling systems).

Environmental impact indicators

The life cycles of the two types of bulbs were assessed with IMPACT 2002+, an internationally-recognized impact assessment method. This method was used to convert the consumed resources and environmental emissions associated with the life cycle of the two types of bulbs (e.g.: mercury, CO_2, etc.) into potential environmental impacts (e.g.: global warming, acidification, etc.). The table below presents the environmental indicators that were used. The column on the right presents the different impact categories that were taken into account and the column on the left is the aggregation of the impacts into damage categories, which make it possible to reduce the amount of information to be communicated.

IMPACT 2002+	
Damage categories	**Impact categories**
Human health	Carcinogenic effect
	Non-carcinogenic effect
	Respiratory effects caused by inorganic substances
	Ionizing radiation
	Ozone layer depletion
	Photochemical oxidation
Ecosystem quality	Aquatic ecotoxicity
	Terrestrial ecotoxicity
	Acidification/terrestrial eutrophication
	Land use
Climate change	Global warming

Resources	Non-renewable energies
	Mining
No association with a damage category	Aquatic acidification
	Aquatic eutrophication

3. Results

Summary of the "hot spots" in the life cycles of the bulbs

The assessment of the individual environmental profiles can be summed up as follows:

- The **use** phase (electricity consumption in particular) is a major contributor to the life cycle impacts of both types of light bulbs. Depending on the category, this phase represents between 69 and 93% of potential damages in the case of the compact fluorescent bulb and between 93 and 99% in the case of the incandescent;
- Light bulb **production** is responsible for between 6 and 30% and between 1 and 5% of compact fluorescent and incandescent damages, respectively;
- **Distribution** and **end-of-life management** are negligible (they contribute to, at most, 1% of the potential damages in each case).

Mercury and the electronic components

By comparing the environmental profiles according to the baseline scenario (not taking into account the cross-effect of the heat generated when the bulbs are lit), the **compact fluorescent** bulb is a better choice than the incandescent when considering all of the damage indicators.

The advantages of the compact fluorescent (i.e.: damage reduction through energy saving) markedly outweigh the new issues that it brings about (i.e.: additional damage caused by mercury and the electronic components). It is therefore important to put the significance of the mercury and electronic ballast into perspective, since they represent no more than 1% of the potential environmental damages. However, this issue should not be overlooked and strategies to recycle and recover compact fluorescent bulbs at the end of their service life should be implemented.

Cross-effect of the heat "lost" when the bulbs are lit during colder months

The objective of the "cross-effect" scenario was to assess the degree to which the energy loss (and heat loss) would favour the use of incandescent bulbs in colder months. Though the amount of heat released in homes when the bulbs are lit reduces the demand on the heating systems, the cross-effect of the heat generated by the light bulbs is not always present, such as in wood-heated homes and also possibly in inadequately insulated homes (in which the thermostat's set point is never reached). In addition, when the cross-effect is present, practically all of the energy consumed by both types of bulbs would ultimately be recovered by the heating systems. It therefore becomes necessary to assess the degree to which the additional heat that is released by the incandescent bulbs constitutes a net advantage that offsets the damages associated with the waste of energy. More specifically:

1- Because baseboard heating is more efficient than bulb heating, the additional heat released by the incandescent bulbs does not constitute an advantage in homes heated by electricity (the energy recovered is supposed to be equal to 90% of the energy consumed by the bulbs and a baseboard's efficiency is 100%). **The compact fluorescent light bulb is therefore the best option, even in the colder months for homes heated by electricity**.

2- Because heating with oil or natural gas is less efficient (70% at best according to the information received from Hydro-Québec) and has more overall damaging effects than electric heating by bulbs, the additional heat released by the incandescent bulb is an advantage (in particular when considering climate change and resources). However, it is important to mention that **this advantage of the incandescent over the compact fluorescent light bulb is only valid in the colder months and in homes heated with natural gas or oil**.

4. Conclusions and recommendations

Given our results, it therefore seems preferable to **foster the use of compact fluorescent light bulbs in Québec.** In fact, for the 84% of Québec homes that do not rely on oil or natural gas for heating, the compact fluorescent bulb is the best alternative throughout the entire year. For the other 16% of homes (heated with oil or natural gas), the compact fluorescent is the best choice in the milder months – approximately 36% of the year in Québec. For these homes, in the winter, the conclusions are less cut and dry because the incandescent bulb is a good option given certain indicators, especially climate change and resources. This being said, promoting the use of compact fluorescent light bulbs in Québec is highly recommended presuming that each kWh saved could substitute for forms of energy that are more polluting or less efficient than heating with oil or gas (thermal energy in particular).

The promotion of compact fluorescent light bulbs should be taken one step further:

1. Hydro-Québec should devote more efforts to raising awareness about the fact that compact fluorescent light bulbs are considered to be hazardous waste and require that certain precautions be taken. Hydro-Québec should also continue its collaboration with stakeholders to develop recovery and recycling methods for these bulbs at the end of their service life; and
2. Hydro-Québec should foster the promotion of bulbs with modular ballasts (reusable) when the technology becomes available. These electronic components proved to be the main contributor in the production phase, increased the total weight of the transported products, and heightened the potential impacts associated with end of life heavy metal leaching. The potential reuse of the ballasts by the consumer could better the environmental performance of the compact fluorescent light bulbs.

Implementing these recommendations would foster overall energy efficiency and minimize the new issues associated with the use of compact fluorescent bulbs, rather than rejecting them based on the fact that they are not perfect.

Limits

The conclusions of this study can only be applied to light bulbs used in the Québec context. Extrapolating these results to other Canadian provinces or the North American context first requires a verification of the validity of the hypotheses. The results of the LCA present the potential environmental impacts and not the actual ones. They also do not express the individual risk incurred after exposure when a compact fluorescent light bulb is accidentally broken in a closed environment, nor do they express the influence of certain parameters that may be more or less important from a consumer's perspective (e.g.: interference with infrared devices, operating temperature (min-max), use with dimmers, and harmonic distortion).