Assessment of the Life Cycle-Based Environmental Impacts of New Zealand Electricity

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Edgar Eduardo Sacayon Madrigal

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ABSTRACT

The life cycle-based environmental impacts of New Zealand electricity arise from the different energy generation systems used to provide electricity to the national grid, and construction, maintenance and operation of the national electricity transmission and distribution system. Due to the high share of hydropower in the New Zealand electricity mix, base load electricity is rainfall dependent and its variable supply is balanced by generation from fossil fuelled power plants, geothermal, and to a lesser extent from wind, biogas and biomass power. This temporal variability of energy sources in the mix changes the Life Cycle Assessment (LCA) results for New Zealand electricity when the environmental impacts are assessed over different time periods. Therefore, this research had two main objectives: to conduct an LCA of electricity generation, and to assess the influence of temporal variation in the electricity mix on LCA results. Using the ecoinvent v 3.1 database and New Zealand-specific data, an LCA model of electricity generation and use was developed for the year 2013. The LCA results, using the CML 2001 – Apr. 2013 impact assessment method, showed that coal and natural gas power plants contributed 10 to 90 % in all impact categories. Electricity transmission and distribution (T&D) infrastructure contributed more than 50 % of the result for Abiotic Depletion Potential (ADP), Terrestrial Ecotoxicity Potential (TETP) and Human Toxicity Potential (HTP) impact categories. The Climate Change Potential (CCP) for 1 kWh of low-voltage electricity was 186 g CO_2-eq; for high and medium-voltage electricity, the CCP results were 172 and 176 g CO_2-eq per kWh respectively. To investigate the variability in LCA results over different time periods 3, 5 and 10 year moving averages (MAVG) were calculated; as expected, the variability decreased as the time period increased. The analysis showed that the 10 MAVG was associated with the lowest variability in LCA results. However a 10 MAVG will not reflect changes in installed power plant capacity. Therefore for attributional LCA studies of products using electricity over a year-to-year time frame, a representative average of the electricity mix or a 3, 5, or 10 year MAVG can be used as long as there are no changes in installed power plant capacity. This information aids New Zealand´s electricity industries understand environmental impacts associated with transitions to renewable energy technologies and meet greenhouse gas reduction targets.

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LIST OF ABBREVIATIONS

INSTITUTIONS

IEA = International Energy Agency
EA= Energy Authority
MBIE = Ministry of Business Innovation and Employment
MFE = Ministry for the Environment
MED = Ministry of Economic Development
OECD = Organization for Economic Co-Operation and Development
BRANZ = Building Research Association of New Zealand
NZGA = New Zealand Geothermal Association
NZWEA = New Zealand Wind Energy Association

COUNTRIES

CH = Switzerland
NZ = New Zealand
DE = Germany
RoW = Rest of the World
GLO = Global

LIFE CYCLE ASSESSMENT METHODOLOGY

LCA = Life Cycle Assessment
LCI = Life Cycle Inventory
LCIA = Life Cycle Impact Assessment
GHG = Greenhouse Gases
ADP Elements = Abiotic Depletion Potential of mineral resources
ADP Fossil = Abiotic Depletion Potential of fossil fuel resources
AP= Acidification Potential
EP = Eutrophication Potential
FAETP = Freshwater Aquatic Ecotoxicity Potential
GWP = Global Warming Potential excluding biogenic carbon
HTP= Human Toxicity Potential
MAETP = Marine Aquatic Ecotoxicity Potential
ODP = Ozone Layer Depletion Potential
POCP = Photochemical Ozone Creation Potential
TETP = Terrestrial Ecotoxicity Potential

POWER AND ELECTRICITY TECHNOLOGIES

1-Flash = Single Flash
2-Flash = Double Flash
3-Flash = Triple Flash
CCGT = Combined Cycle Gas Turbine
OCGT = Open Cycle Gas Turbine
BORC = Binary Organic Rankine Cycle
CCST = Conventional Condensing Steam Turbine
Dec. = Decommissioned
H = Hybrid (referring to the combination of flash and organic cycles in geothermal power production)
T&D = Transmission and Distribution Network
RoR = Run-of-river hydroelectric power plant

UNITS

kg = kilograms
CO_2-eq =carbon dioxide equivalents
k = kilo
t = tonnes
g = grams
kWh = Kilowatt hour.
GWh = Gigawatt hours
MW = Megawatt.
m = metres
km = Kilometres
V = Volts
AC = Alternating Current
DC = Direct Current

GLOSSARY

LCA of energy systems requires a basic understanding of underlying terminology. This Section introduces some of the key concepts and general conventions used throughout this work, so the reader gains a better comprehension of the topic.

Greenhouse gases (GHGs): The term refers to gases that contribute to climate change. The main greenhouse gases are carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrogen oxides (NO_x), nitrous oxide (N_2O) and non-methane volatile organic compounds (NMVOCs) and sulphur dioxide (SO_2). Sulphur hexafluoride (SF_6) is a greenhouse gas associated with the distribution infrastructure and therefore is mentioned separately.

Carbon footprint: total contribution of different greenhouse gases to potential climate change. It is usually measured by multiplying different quantities of greenhouse gases by their respective Global Warming Potential (GWP). Both "carbon footprint" and "climate change potential" are used throughout this work to refer to the same environmental impact. The unit of measure of the carbon footprint is grams of Carbon Dioxide Equivalents (g CO_2-eq), being the climate change potential impact associated with emission of greenhouse gases. Another term that appears in the literature is "Life Cycle Greenhouse Gases".

Biogenic carbon: source of carbon that follows the natural flow of the carbon cycle through the biosphere, atmosphere, ocean and lithosphere (EPA, 2014).

Electricity grid mix: The "electricity grid" or the "electricity mix" refers to the technologies used to produce high, medium and low-voltage electricity. In New Zealand high-voltage electricity ranges from 400 – 220 kV AC; medium-voltage electricity ranges from 110 – 11 kV AC and low-voltage electricity ranges from 400 – 230 V.

Capacity factor: a measure of how efficiently the power plant produces electricity. This index is estimated by dividing the electricity generated in one year, against the total generation if the power plant was operated at its full capacity.

Abiotic Depletion Potential (ADP Elements): Impact category that quantifies the depletion potential of non-renewable resources found as elements within the earth´s crust. It is defined as the ratio of resource extraction rate and the recoverable reserves of that resource; it is expressed in kg of a reference antimony equivalent (Guinée, 2002).

Depletion of non-renewable resources (ADP Fossil): Impact category that quantifies the amount of fossil energy consumed by the system, and is expressed in mega joules (MJ) (Guinée, 2002).

Acidification Potential (AP): Environmental impact category that quantifies the potential of pollutants to produce hydrogen ions and therefore, acidification on the environment. Expressed in sulphide dioxide equivalents (Guinée, 2002).

Eutrophication Potential (EP): Environmental impact category that quantifies the potential of organic matter, nitrogen and phosphate to cause nutrient enrichment on the environment. Expressed in phosphate equivalents (Guinée, 2002).

Freshwater Aquatic Ecotoxicity Potential (FAETP): Impact category that quantifies the potential impact of toxic substances to aquatic ecosystems (Guinée, 2002). Expressed in kg of 1,4-dichlorobenzene equivalents.

Human Toxicity Potential (HTP): Environmental impact category that quantifies the potential of toxic emissions to cause health risks in human beings (Guinée, 2002).

Marine Aquatic Ecotoxicity Potential (MAETP): Environmental impact category that quantifies the potential of toxic substances to produce damaging effects on marine ecosystems (Guinée, 2002).

Ozone Layer Depletion Potential (ODP): Environmental impact category that quantifies the effects of anthropogenic emissions on the reduction of the earth's ozone layer in the stratosphere(Guinée, 2002). It is expressed in kg CFC-11-equivalents.

Photochemical Ozone Creation Potential (POCP): Environmental impact category that quantifies the potential formation of reactive chemical compounds by the action of sunlight on volatile organic compounds in the troposphere (Guinée, 2002). Expressed in kg of ethylene equivalents.

Terrestrial Ecotoxicity Potential (TETP): Impact category that quantifies the potential impact of toxic substances to terrestrial ecosystems (Guinée, 2002). Expressed in kg of 1,4-dichlorobenzene equivalents.