Journal of Cleaner Production 165 (2017) 119–133

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Consequential LCA modelling of building refurbishment in New Zealand- an evaluation of resource and waste management scenarios

Agneta Ghose [a, b, *], Massimo Pizzol [c], Sarah J. McLaren [a, b]

[a] Institute of Agriculture and Environment, Massey University, Private Bag 11222, Palmerston North 4442, New Zealand
[b] The New Zealand Life Cycle Management Centre, c/o Massey University, Private Bag 11222, Palmerston North 4442, New Zealand
[c] Department of Planning, Aalborg University, Rendsburggade 14, Aalborg 9000, Denmark

ARTICLE INFO

Article history:
Received 28 January 2017
Received in revised form
12 July 2017
Accepted 13 July 2017
Available online 15 July 2017

Keywords:
Refurbishment
Consequential LCA
Construction
Waste management
Marginal supply
Recycling potential

ABSTRACT

Large scale building refurbishments are likely to become more common in New Zealand's building sector, and therefore it is relevant to assess the environmental impacts associated with these activities. The aim of this study was to investigate the environmental impacts arising from the increase in demand for building refurbishments in New Zealand using consequential Life Cycle Assessment (LCA). The study focused on the identification of resource constraints and marginal suppliers of construction materials using market information specific to New Zealand. Building refurbishment strategies related to waste minimization at construction sites and use of recycled materials at production sites were compared. According to the results, increasing the rates of construction waste recovery and re-use at site can reduce the overall environmental impact of a building refurbishment by 15–25% compared to use of construction materials with recycled content which only reduces the environmental impacts by approximately 5%. The net impact results were sensitive to the quality of recyclable material, location of the marginal supplier and marginal energy source. The study recommends stakeholders involved during early building design to focus on material sourcing and quality; and practical solutions to increase material recoverability at site e.g. planning for efficient on-site management for waste disaggregation, recovery and re-use.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

With increasing awareness about the environmental impacts related to the operational energy use of buildings, most OECD countries have prioritized adoption of energy efficiency strategies for the existing building stock (IEA, 2014). This has led to increased attention to construction activities as well, which use energy-intensive materials and generate large quantities of solid waste (UNEP, 2014). Whilst energy efficiency and renewable energy use in the operation of buildings is addressed by existing policies in OECD countries (IEA, 2014), better construction practices and sourcing of building construction materials (including extraction, production and waste management of these materials) is also required to reduce environmental impacts (Herczeg et al., 2014). This could reduce the life cycle energy consumption and GHG emissions by 42% and 35% respectively, and 50% of the extracted materials used in the building sector, and could even save up to 30% of water in some regions, as reported in a study by the European Commission (European Commission, 2011).

The New Zealand Government's Energy Efficiency and Conservation Strategy for 2011–2021 identifies transformation of the country's commercial buildings as a key strategy to improve energy security, and promote efficient energy use (Ministry of Economic Development, 2011). This strategy is mainly focussed on realising low energy use during building operation through the adoption of solutions such as well-designed building façades, and efficient air-conditioning and lighting systems (Amitrano et al., 2014). Besides contributing to improved energy security and reduced environmental impacts, reduction in operational energy has been shown to add market value to recent commercial building developments in New Zealand (Jewell, 2014; NABERS NZ, 2016). Currently in New Zealand, existing buildings outnumber new buildings by 50 to 1 (BRANZ, 2013; Isaacs and Hills, 2013). Therefore, national building policies have identified refurbishment as a potential strategy to improve the existing building stock as well as an opportunity to

* Corresponding author. Institute of Agriculture and Environment, Massey University, Private Bag 11222, Palmerston North 4442, New Zealand
E-mail address: A.ghose@massey.ac.nz (A. Ghose).

http://dx.doi.org/10.1016/j.jclepro.2017.07.099
0959-6526/© 2017 Elsevier Ltd. All rights reserved.

List of abbreviations

AD_{ff}	Abiotic Depletion (fossil fuels)
AD_r	Abiotic Depletion (resources)
AP	Acidification Potential
AISI	American Iron and Steel Institute
BAU	Business As Usual
BRANZ	Building Research Association of New Zealand
CCANZ	Cement and Concrete Association of New Zealand
CIS Russia	Commonwealth of Independent States (Russia)
EP	Eutrophication Potential
$ET_{freshwater}$	Eco-toxicity (freshwater)
FAO	Food and Agriculture Association
GWP	Global Warming Potential
HT carc	Human Toxicity (carcinogenic)
HT non carc	Human Toxicity (non- carcinogenic)
IAI	International Aluminium Institute
IEA	International Energy Agency
IR	Ionizing Radiation
LCA	Life Cycle Assessment
LED	Light Emitting Diode
MBIE	Ministry of Business, Innovation and Employment
NZ	New Zealand
ODP	Ozone Depletion Potential
OECD	Organization for Economic Cooperation and Development
PCOP	Photochemical Oxidation Potential
PET	Polyethylene Terephthalate
PMF	Particulate Matter Formation
RoW	Rest of the World
REBRI	Resource Efficiency in the Building and Related Industries
UNCOMTRADE	United Nations international COMmercial TRADE statistics
UNEP	United Nations Environmental Program
USGS	United States Geological Survey

meet global greenhouse gas emission targets by the adoption of recommended energy efficiency solutions (Bedford et al., 2016). Indeed, the consented building refurbishments of commercial buildings in New Zealand for 2011 and 2013 exceeded a total expenditure of 3.9 and 4.4 billion NZ$ respectively for each year (Whats On, 2013).

Construction activity in New Zealand is growing and is expected to continue in the next few years with particularly rapid development in the commercial building sector (Chaney, 2012; SafeSmart Access NZ, 2015; Statistics NZ, 2015a). New Zealand's Green Building Council (NZGBC) claims that, although awareness of sustainable and green building designs has increased, strategies that prioritize material procurement and waste management that potentially reduce environment impacts have been slow to percolate into the construction sector (Craven, 2015). In a recent study, Ghose et al. (2017) identified large scale energy efficiency refurbishment as a substantial contributor to the overall environmental performance of buildings in New Zealand. Most of these impacts were related to the construction materials with energy intensive production. Indeed, use of conventional building materials with high embodied energy still dominates the New Zealand's construction sector (Crampton, 2015), and approximately 1.7 million tonnes of construction waste is generated each year, which is nearly 50% of the total waste generated in New Zealand (BRANZ, 2014; Inglis, 2012). In general, large scale deployment of energy efficiency refurbishments will also be coupled with high levels of resource consumption and waste generation.

The aim of this study is to investigate the environmental impacts of an increase in construction activities arising from energy efficiency refurbishments in New Zealand. In particular, it addresses the following research questions: (a) What are the potential environmental impacts of an increase in resource demand associated with energy efficiency refurbishments? And, (b) Can material procurement and construction waste management strategies reduce these environmental impacts at the same time as delivering the benefits of more energy efficient buildings?

The study builds on previous research by Ghose et al. (2017) which used attributional Life Cycle Assessment to evaluate a large energy efficiency refurbishment of an office building. However, in contrast to the study by Ghose et al. (2017), and in order to address the research questions above, this study utilizes the consequential modelling approach to identify the expected change in activities linked to the refurbishment processes (ISO, 2012).

1.1. Use of consequential LCA modelling in the building sector

LCA is used for the comprehensive evaluation of environmental impacts related to activities and products, including construction activities and buildings. There are two major modelling choices in LCA: attributional and consequential (Finnveden et al., 2009). In attributional modelling, all relevant energy and material inputs are based on status quo (or average) supply data to quantify the environmental impacts of a specific construction (Ekvall et al., 2016; Ekvall and Weidema, 2004). This approach uses allocation factors to partition the impacts between by-products and recycled materials. Attributional modelling is the most common approach used in building sector LCAs (Cabeza et al., 2014; Peuportier et al., 2011). It is particularly useful to identify environmental hot spots in materials or life stages of specific buildings, and to optimize building designs (Blom et al., 2010; Junnila et al., 2006; Kofoworola and Gheewala, 2008; Scheuer et al., 2003). In consequential modelling, the focus is on the environmental impacts of discrete effects on production and supply due to changes in demand for construction (Gustavsson et al., 2015). Consequential modelling is used to identify a) the unconstrained (or marginal) suppliers in the studied system that can increase production if there is an increase in demand for a product or process, and b) products and processes which will be substituted in other systems (system expansion) due to additional production of by-products (Ekvall and Weidema, 2004). Although a well-founded methodology exists in the literature for consequential modelling (Ekvall, 2000; Ekvall and Weidema, 2004; Schmidt, 2008; Weidema, 2003b), the application of consequential LCA in the building sector was initially limited - but has been increasing in recent years. Examples of application of consequential LCA in the building sector can be found regarding the use of different heating systems (Rinne and Syri, 2013); the substitutability of different building materials, components and designs (Buyle et al., 2016; Kua and Kamath, 2014; Kua and Lu, 2016); and the promotion of policies for re-use or recycling of construction related demolition and waste (Kua, 2015; Sandin et al., 2014; Vieira and Horvath, 2008). Another common objective in each of the above mentioned studies is the comparison between using the consequential and attributional modelling approach to calculate the environmental impact of a building or a construction material. Whilst the variance in the results using the two modelling approaches in each of these studies was related to uncertainties in modelling assumptions and data, the choice between the modelling approaches was not as critical as expected (Vieira and Horvath, 2008). Yang (2016) and Buyle et al. (2016) suggested that the consequential approach was complementary to the attributional approach and a useful addition to inform policy makers on effects of different types of available decisions. Consequential LCA adds a future-oriented perspective to a study, and is therefore considered a useful methodological approach to assess transformation strategies (Earles and Halog, 2011; Gustavsson et al., 2015; Paulik and Hertwich, 2016).

Vieira and Horvath (2008) identified that the limited use of consequential LCA in the building sector was probably due to the fact that identifying marginal technologies and suppliers for all building construction materials can be challenging. It is interesting to note that LCA case studies on buildings often use substitution - which is most often associated with consequential modelling in LCA - to model the avoided burdens of recovered construction and demolition waste but do not specify the use of marginal or average data (Blengini and Di Carlo, 2010; Chau et al., 2016; Kucukvar et al., 2016). The lack of consistency and transparency in the modelling approach may also be traced back to the use of earlier versions of the ecoinvent database which was based on attributional modelling, and is commonly used as the generic background database in process-based LCA studies (Peuportier et al., 2011). The development of consequential datasets in the ecoinvent v3 database in 2013 has reduced the uncertainty related to choice of generic background datasets used in consequential modelling (ecoinvent, 2013). In addition the ecoinvent database is geographically differentiated i.e. it provides generic data on numerous products and processes in different geographic locations. This has increased the ability of modellers to choose geographically delimited, unconstrained technologies and suppliers to global or regional markets (ecoinvent, 2013; Weidema, 2016). However, the ecoinvent database still lacks New Zealand specific background data (Kellenberger, 2007; Nebel, 2009). Therefore the use of a consequential modelling approach in a New Zealand specific LCA study requires the use of domestic market information, and use of the recommended guidelines by Weidema (2003b) for market delimitation (i.e. market limits/constraints) and substitution, in order to approximate the marginal effects of a change in demand.

2. Methodology

The methodological approach used in this study was based on the guidelines presented by Weidema (2003b). The functional unit for the study was defined as demand for refurbishment and subsequent use of 1 m^2 gross floor area in an office building. Refurbishment is defined as '*modifications and improvements to an existing building or its parts to bring it up to an acceptable condition*' (EN 15 978, 2011). This study specifically analysed a major refurbishment as defined by Leifer (2003) that included complete remodelling and upgrading of the façade, and replacing and modernising the Heating, Ventilation and Air-Conditioning (HVAC) and lighting systems. The guidelines from the building standard EN 15 978 were used to define the system boundaries for building

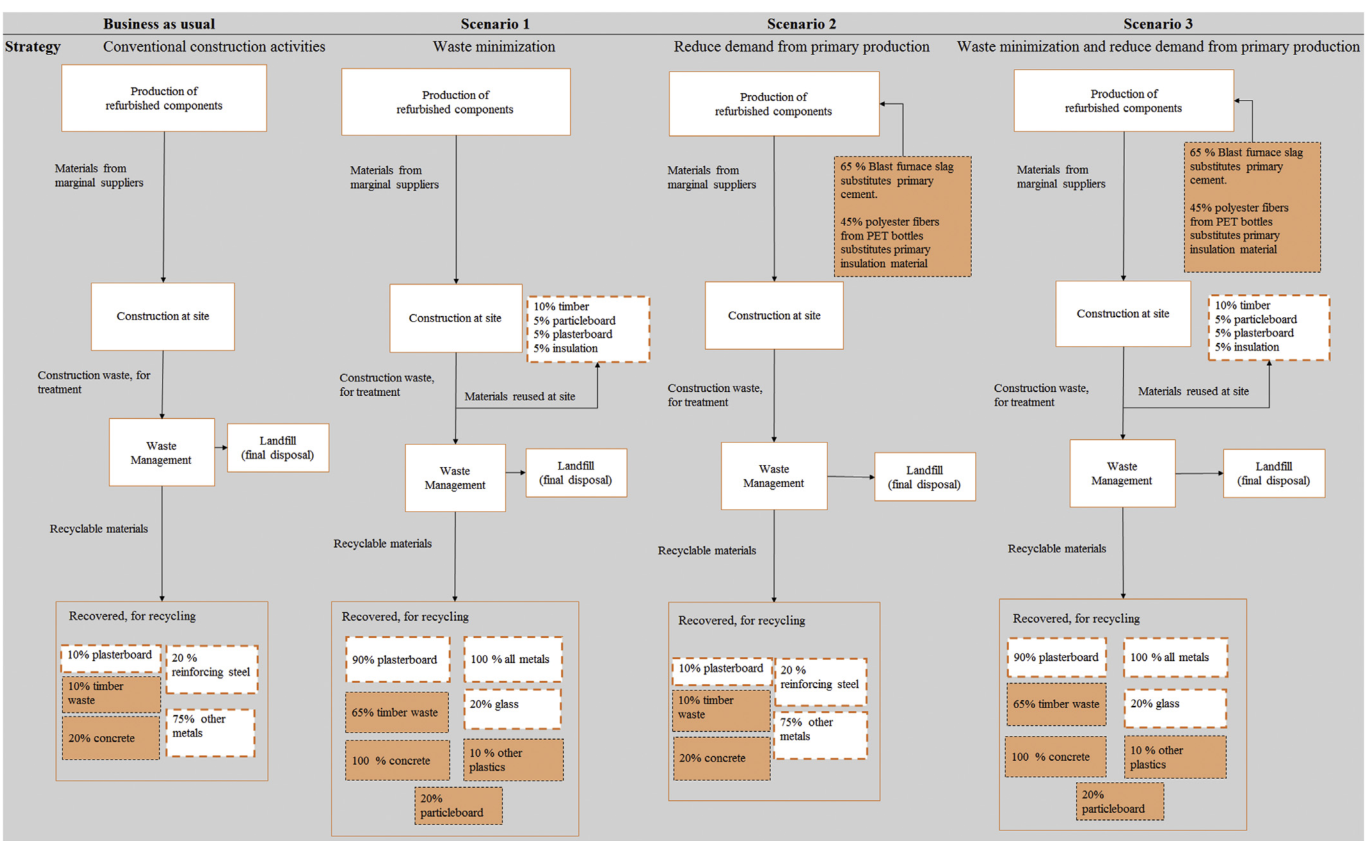

Fig. 1. The system boundary, base case and the three scenarios assessed in the LCA study. Each scenario highlights the share of materials recycled or re-used. The white boxes correspond to the activities in the system boundary and the arrows correspond to material flows. The orange dotted boxes correspond to the recovered materials that avoid burdens from primary production (for example, recovered metals sent for recycling avoid burdens related to primary production of metals) and the orange shaded boxes correspond to the avoided burdens from final disposal of the recovered material (for example, recovery of timber waste used as wood chips for landscaping or fuel does not avoid primary timber production for construction but corresponds to avoided burdens from landfilling of wood waste). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

refurbishment (see Fig. 1). The processes included in the system were: raw material extraction and processing, product manufacture; product transportation to the construction site and construction process; and transportation and waste management of demolished material produced during refurbishment (EN 15978, 2011).

2.1. Base case and scenarios

A standard set of energy efficiency measures recommended to reduce the operational energy consumption for New Zealand's existing commercial buildings by 60 per cent was assessed (Cory, 2016). The reference building used for this study was an office building located in Auckland. The refurbishment measures adopted in the building were: large scale transformation of the façade with increased insulation to building envelope (wall and roof); optimization of the Wall to Window Ratio (WWR); alteration of windows to an advanced glazing system and with a frame to enable natural ventilation; addition of solar shading to the North, East and West façades to avoid passive solar heat gain; change of the air conditioning system (heating and cooling) from a natural gas operated boiler and electric chiller to electric heat pumps; and replacement of existing compact fluorescent lamps with LED luminaires. Two prototypical models of this reference building, representing the existing and the refurbished constructions were also developed by Cory (2016) using the EnergyPlus energy simulation modelling tool (EnergyPlus 8.6.0, 2015) and the corresponding graphical interface OpenStudio SketchUp (Lammers, 2011). The building prototypes modelled in the EnergyPlus and SketchUp softwares provided the construction details and building geometry respectively. The refurbished and exiting building prototypes were used to estimate the material quantities required for refurbishment and produced as waste respectively. As there were no changes to the structural components of the building (i.e. foundation, load-bearing walls), they were not included in the study. Moreover, only the building components associated with the energy efficiency measures were included in the models; therefore, internal fit-outs (such as, office furniture, internal finishes to floors and ceilings) were excluded from this study. Details on calculations and assumptions made to determine the material quantities from the prototype models can be found in Ghose et al. (2017, Sections 2.3.1–2.3.4). A summary of the reference building's specifications and associated refurbishment measures is given in Table 1.

The base case was termed as the Business As Usual (BAU) scenario in which there were no specific conditions for waste recovery or material procurement. Data on conventional construction practices in New Zealand with respect to current waste recovery rates, generic transportation distances in New Zealand from last manufacturer or supplier, and typical values for energy required for construction sites (as compiled by Dowdell et al. (2016)) were used. Three other scenarios were developed to represent different waste handling and material procurement strategies for the refurbishment:

- ***Scenario 1: Best practice construction waste management which minimizes waste generation through re-use and recycling.*** This scenario was based on Resource Efficiency in the Building and Related Industries (REBRI) guidelines in New Zealand (BRANZ, 2014). REBRI's main focus is on reducing the quantity of building material wastes generated at construction and demolition sites that would be sent to landfill. The “best practice” for waste minimization by increasing waste recovery rates for recycling and reuse for construction materials (also compiled by Dowdell et al. (2016)) were used. The data were based on waste management case studies in New Zealand between 2009 and 2014. In comparison to the conventional practice, Dowdell et al. (2016) reported examples where higher waste recovery rates have been achieved for concrete, metals, timber, glass, plasterboard, particleboard and other plastics. Moreover, the proportion of materials such as plasterboard, particleboard, planed timber and insulation that could be re-used at site was also provided.
- ***Scenario 2: Reduced demand from primary production of construction materials by using substituted materials.*** This scenario was developed to investigate the influence of alternative material procurement. Alternative materials used for insulation and concrete production were modelled. Whilst most of New Zealand's construction industry still practices traditional material procurement strategies and management (Samarasinghe, 2014), dominant manufacturers of insulation and concrete products have increasingly considered the use of alternative raw materials to the conventional use of polystyrene polymers for insulation and Portland cement for concrete production respectively (Autex, 2016; CCANZ, 2015). These measures are developed to potentially create a market for recoverable waste as well as reduce the environmental and economic cost of primary raw material (Autex, 2016; CCANZ, 2015). Polyester fibres from recycled PET bottles and granulated iron blast furnace slag from national steel production are used to substitute primary materials in insulation and concrete production respectively. The proportion of polyester fibres bottles from recycled fibres was based on the sustainability report of Autex (2016), while the maximum proportion of blast furnace slag that could be used while maintaining the required

Table 1
Specifications of the existing and refurbished building and related refurbishment measures (Adapted from Ghose et al., 2017).

	Existing Building		Refurbished Building		Refurbishment measures
	Area (m^2)	R- value [a] (m^2 K/W)	Area (m^2)	R- value (m^2 K/W)	
External Walls	1021	3.6	1734 [b]	5.8	Non-bearing concrete walls replaced and adjusted to increase wall area. Overall insulation increased.
Windows	2113	0.172	1400 [b]	0.625	Large clear single glazed aluminium framed windows replaced with smaller low-e double glazed aluminium framed windows. Solar shading added.
Roof	730	2.9	730	3.65	Overall insulation increased with required waterproofing.
Heating	Natural gas boiler, electric chiller and radiators		Air source heat pumps, Under floor distribution system		Equipment replaced. Additional cement-based flooring added over floor distribution system
Lighting	Compact fluorescent lighting		LED lighting		Luminaires replaced

[a] R-Value is defined as a measure of thermal resistance for materials or assemblies of materials (such as walls, windows and roofs) (Desjarlais, 2008).
[b] The ratio of wall to window area changes (the total façade area remains the same).

functionality and durability of pre-cast concrete production was based on technical guidelines by Holcim NZ (2011).

- ***Scenario 3: Both best practice waste management (Scenario 1) and sustainable material procurement (Scenario 2).***

The above mentioned strategies were combined in this scenario which was developed to quantify the environmental implications if both the measures were adopted during refurbishment. This was deemed important to highlight the potential total benefit achievable with the combination of all best practice measures available.

A summary of the three scenarios is given in Fig. 1.

2.2. Inventory analysis

In consequential modelling, the inventory is developed based on how the flows and activities are affected by a change in demand for a product or process. This study assumes an increase in demand for refurbishment in each scenario, which leads to the increase in demand for raw materials and energy required for production of refurbished components; and waste management of construction waste available at site. The foreground processes included all the activities and flows as shown in Fig. 1. The marginal suppliers of construction materials and energy required for the refurbishment were identified as discussed in Section 2.2.1. Moreover, substitution was applied to the production and use of recyclable/re-usable materials as described in Section 2.2.2. The ecoinvent v3 database, consequential version, was used to model background processes (ecoinvent, 2013). For the detailed inventory of the refurbished building in each scenario see section I in the Supplementary Information (SI).

2.2.1. Identification of marginal suppliers

The identification of marginal suppliers was based on the guidelines for stepwise market-based system delimitation (Weidema, 2003a). In summary, the ability of suppliers to respond to a marginal increase in demand may be constrained by shortage of resources, the high financial cost of production, use of redundant technology, and/or regulatory policies (European Commission, 2013; Weidema, 2003a). A marginal supplier is identified as the most competitive with a steady increase or constant trend that is unaffected by such constraints (Schmidt and Thrane, 2009; Weidema, 2003a, 2003b).

2.2.1.1. Marginal supply of construction materials and products. Market information on annual domestic production and trade data for New Zealand for different construction materials was gathered from New Zealand Statistics (2015b), international survey report (USGS, 2013), international commodity trade statistic (UN COMTRADE, 2015), and industry annual reports (Bluescope steel, 2015; Fletcher Building NZ, 2015). In New Zealand's industrial sector, the share of production and fabrication activities related to pre-fabricated building components (e.g., the production of precast concrete or the fabrication of aluminum to produce window frames or solar shading) has increased in proportion to the increase in demand from the New Zealand's building sector (Fletcher Building NZ, 2015; Ministry of Business Innovation and Employment, 2013). However, a decline in the domestic production of some key construction materials (e.g., aluminium, cement) has been reported due to financial constraints related to the increase in cost of resource inputs (USGS, 2013). Therefore, the increase in demand for constrained materials and products in the domestic market were modeled using imports from 2008 to 2015. By default it was assumed that materials/products with a low value-to-weight ratio are traded in the regional market (i.e. close geographic locations, for example Australia, South East Asian countries and China were considered as the regional market for New Zealand) to reduce freight costs (e.g., glass, aggregates), and materials/products with a high value-to-weight ratio are traded in the global market where freight costs do not affect the value of the product (e.g., metals, electric equipment) as suggested by Weidema (2003a). Therefore, the marginal suppliers in the regional market were identified using simple linear regression on the 2008–2015 import trends from Statistics New Zealand (2015b). If there was a constraint in the domestic production of globally traded materials/products (e.g., aluminium, plastics), the global marginal supplier was identified from existing studies which provide the current and future trends in production of these materials (Galiè and Trabucchi, 2014; Schmidt and Thrane, 2009). If market information was insufficient from the suggested sources, ecoinvent processes with consequential modeling were used as these include the generic life cycle inventories for global marginal suppliers of all resources. Table 2 shows the list of identified marginal suppliers used in the model.

2.2.1.2. Marginal supply of energy. Each of the modeled activities has an energy input sourced from electricity and/or fossil fuels. The geographic market for grid electricity is regional (Weidema, 2003a), i.e. transmission and trade of grid electricity is limited by location therefore the marginal source of electricity production varies in different countries or regions. Table 3 shows the marginal electricity supply for each of the material and product suppliers identified in Table 2. The marginal electricity supply for New Zealand was identified using the method suggested by Schmidt et al. (2011). The business-as-usual approach in this method assumed the increase in share of sources for electricity production to be similar to the recent past. Thus the marginal electricity supply for New Zealand was based on differences in the share of sources for electricity production between 2008 and 2015 as reported by Ministry of Business, Innovation and Environment (MBIE) for New Zealand (MBIE, 2015). Similarly the marginal electricity supply was identified for regions South East Asia and the Middle East was identified based on the electricity production reported in IAE reports for the respective regions (IEA, 2013a, 2013b). The geographic market for fossil fuels is global (Weidema, 2003a), therefore the marginal supply of energy directly sourced from fossil fuels such as diesel and natural gas was modeled as given in ecoinvent v3's consequential database.

2.2.2. Substitution and avoided burdens

In consequential modelling, substitution is applied to model the environmental burdens avoided due to the availability of by-products. In general, there is no distinction between the modelling approach applied to by-products, waste, and recyclable materials (Weidema, 2003a, 2015). If a by-product is not utilized or there is no demand for it, this implies that any additional amount produced would be sent to final disposal and thus can be described as waste. If the by product is a recyclable material and is recycled into a new product or material, primary production of this product or material is avoided, i.e. the recycled product/material substitutes the primary one. The substitution ratio can be up to 1:1 if the recycled and the primary product/material are functionally equivalent. If the recyclable material is not functionally equivalent to the primary product/material, the burdens avoided are related to final waste treatment. Recycling efficiency varies for different materials; the recycling efficiency for different types of metal scrap is reported in Table 4.

2.3. Impact assessment

Characterised results at midpoint were calculated with the CML

Table 2
Marginal suppliers of construction materials and products.

Material	Market	Marginal suppliers	Comment
Aluminium	Global	China (60%), CIS Russia (22%) and Middle East (18%)[a]	New Zealand aluminium production capacity is 360 000 tons annually of which nearly 87% is exported. Due to increase in production costs and global drop in aluminium prices there has been a sharp decline in national production since 2011 (MBIE, 2012; USGS, 2013).
Steel	Global	New Zealand (100%)	New Zealand steel production capacity is 650, 000 tons annually which primarily supplies the domestic market. Domestic production capacity has steadily increased over the years due to abundance of iron sand ore on the West coast (Bluescope steel, 2015; USGS, 2013; World Steel Association, 2015).
Portland Cement	Regional	South East Asia (72%) and China (28%)[b,e]	One of New Zealand's dominant cement producers shut down their manufacturing in 2016 due to financial constraints and high energy costs. New Zealand is now investing in infrastructure to facilitate cement import from overseas (Scanlon, 2016; USGS, 2013).
Aggregates (Sand, Gravel)	Regional	New Zealand (100%)	Mining for aggregates has steadily increased by nearly 10% over the last eight years (USGS, 2013).
Float Glass	Regional	China (45%), Middle East (43%) and New Zealand (12%)[b,e]	New Zealand is mainly dependent on float glass imports. However there has been a recent investment in domestic production since 2015 (Galloway, 2012; Metro Glass ltd, 2015).
Sawn timber	Regional	New Zealand (100%)	New Zealand sawn timber production capacity is 4,050, 000 cubic metres which is sufficient for both domestic consumption and exports (FAO, 2011)
Particleboard	Regional	New Zealand (100%)	New Zealand particleboard production capacity is 240, 000 cubic metres which is sufficient for both domestic consumption and exports (FAO, 2011).
Gypsum	Regional	Australia (100%)	New Zealand has no exploitable gypsum reserve and imports over 300, 000 tons of gypsum from Australia. As gypsum is a low unit cost product, future supplies will likely continue from Australia (Sansbury and Boyle, 2001; USGS, 2013)
Expandable polystyrene Polyethylene Polyvinylchloride (PVC)	Global	Middle East (77%) and USA (23%)[c]	New Zealand imports all raw materials for plastic manufacturing (Plastics NZ, 2011).
LED luminaires Heat pumps	Global	RoW (66%) and Europe (33%)[d]	There are no large scale regional manufacturers of electrical appliances such as commercial lamps and heat pumps, and so the supply is dependent on imports (Bakshi et al., 2013; Ministry for the Environment (NZ), 2009).

Source: [a]Schmidt and Thrane (2009), [b] Statistics NZ (2015b), [c]Galiè and Trabucchi (2014), [d]ecoinvent (2013); [e]Derived from import trends given in SI section II.

Table 3
Marginal electricity supply of identified material and product suppliers.

Technology	New Zealand[aa]	South East Asia[2]	Middle East[b]	China[c]	CIS (Russia)[d]	Australia[d]	North America[d]	Europe[d]	RoW[d]
(in %)									
Coal	–	36	–	76.4	7.5	86	62.4	79.5	48.5
Oil	–	1	40	0.8	0.3	–	–	–	–
Natural Gas	6	53	60	–	8.6	6	1	–	0.7
Nuclear	–	–	–	2.3	3.1	–	1.4	–	12
Hydro	16	9	–	20	80	6	35.2	7.9	37.4
Geothermal	38	–	–	–	–	–	–	–	0.23
Wind	40	1	–	0.5	–	2	–	12.6	1.11

[a] The inventory for New Zealand's different electricity production sources was obtained from Sacayon Madrigal (2016).
Source:[a]MBIE (2015) [b]IEA (2013a), [c]IEA (2013b), [d] ecoinvent (2013).

impact assessment method for Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Photo-chemical Oxidation Potential (POCP), Acidification Potential (AP), Eutrophication Potential (EP) and Abiotic Depletion (resources and fossil fuels (AD_r and AD_{ff})). Instead, Human toxicity carcinogenic (HT-carc), Human toxicity non-carcinogenic (HT-non carc) and Eco-toxicity freshwater ($ET_{freshwater}$) results were calculated using the UseTox method. The impacts on Particulate Matter Formation (PMF) and Ionizing Radiation (IR) were calculated using the ILCD 2011 + and ReCiPe (H) method respectively. These categories and methods were recommended for use by the New Zealand whole building whole of life framework project (Dowdell, 2014).

2.3.1. Sensitivity analysis

To limit uncertainties and increase robustness of the study, a number of sensitivity analyses were performed based upon modification of the recycling efficiency, marginal suppliers mix based on trading partners, and prospective electricity mix:

- Recycling efficiency (S1_RER): the recycling efficiency of aluminium was set to 70%, steel was set to 78%, reinforcing steel was set to 67% and copper was set to 53% as reported in UNEP (2011).
- Marginal suppliers (S2_TP): the marginal supply of construction materials dominated by imports was modified. Based on the marginal suppliers identified in Table 2, it was assumed that each material/product was supplied from a single supplier and the choice of supplier was restricted to the top trading partners for imports to New Zealand. Since 2012, China has been the largest principle trading partner for imports to New Zealand followed by Australia, USA, Japan and the European Union (Statistics NZ, 2015b; Treasury NZ, 2015).

The marginal supply for aluminium, Portland cement and float

Table 4
Summary of modelling assumptions for secondary materials produced from the recovery of demolition waste or used to substitute primary materials during refurbishment and associated avoided burdens.

Materials for waste treatment	Secondary material after recycling	Substitution ratio	Recycling efficiency (%)	Avoided burdens from[a]
Aluminium scrap	Aluminium	1:1	98 [a]	Primary aluminium production from alumina
Steel scrap	Steel	1:1	90 [b]	Primary steel production from pig iron
Copper scrap	Copper	1:1	64 [c]	Primary copper production from copper ore
Glass	Glass cullet	1:1	–	Primary glass production from sand
Concrete	Aggregates and steel	1:<1 and 1:1	70 for reinforcing steel [b]	Aggregates sent to landfill and primary steel production
Blast furnace slag	Granulated slag cement	1:<1		Blast furnace slag sent to landfill
Timber, for recycling	Wood chips for landscaping or fuel	1:<1	–	Wood chips sent to landfill
Timber, reused at site	Planed sawn wood	1:1	–	Primary sawn wood production from forestry processes
Plasterboard, for recycling	Gypsum	1:1	–	Primary gypsum production
Plasterboard, reused at site	Plasterboard	1:1	–	Primary plasterboard production from gypsum
Particleboard, for recycling	Wood chips for landscaping or fuel	1:<1	–	Wood chips sent to landfill
Particleboard, reused at site	Particleboard	1:1	–	Primary particleboard production
Insulation, reused at site	Polystyrene insulation	1:1	–	Primary insulation production from polystyrene polymers
Other plastics, recycled	Plastic polymers	1:<1	–	Inert waste sent to landfill
Insulation fibers, recycled PET bottles	Polyester insulation	1:<1	–	Inert waste sent to landfill

[a] Total avoided primary material = Recovery rate x Recycling efficiency (Rigamonti et al., 2009).
Source: [a] IAI (2009), [b]AISI (2014),[c] Ruhrberg (2006).

glass was only from China; gypsum was from Australia; and mixed plastics and electrical equipment were from USA and the European Union respectively. The remaining construction materials were considered to be sourced from New Zealand which was identified as the dominant marginal supplier (Table 2).

- Prospective electricity mixes (S2_TP (el)): for the marginal suppliers identified in the second sensitivity analysis, the marginal electricity supply was re-calculated based on differences in the share of sources for electricity production between 2015 and the IEA projected 2020 scenario (see SI Tables S–3). This scenario assumes that the countries have adopted a low carbon electricity grid mix (IEA, 2013b).

3. Results

3.1. Contribution analysis

Fig. 2 presents the contribution analysis of refurbished components and associated activities for building refurbishment, and the net value for the twelve environmental impact categories in each of the four scenarios. The production of refurbished components contributes over 90% of the total results (in all scenarios) in ten out of twelve impact categories in all four scenarios. Among these, the refurbished façade components (insulated flat roof, pre-cast concrete walls, double glazed windows and solar shading devices) make $\geq$ 50% contribution to six impact categories (GWP, POCP, EP, AD_{ff}, HT carc and PMF). The refurbished heating and lighting components (heat pumps, heat distribution system and LED luminaries) make $\geq$ 50% contribution to four impact categories (ODP, HT non carc, AD_r, and $ET_{freshwater}$). The contribution of the refurbished façade and the heating and lighting components is similar for the impact categories AP ($\approx$47%) and IR ($\approx$25%). Transport of materials to site and construction at site together make a noticeable contribution to IR ($\approx$54%) and AD_{ff} ($\approx$15%); negligible contributions to ($\leq$10%) to six impact categories (GWP, POCP, AP, EP, HT non carc and PMF); and no contribution to the other four impact categories (ODP, AD_r, HT carc and $ET_{freshwater}$). Waste management includes impacts from energy for demolition, transport of construction waste to treatment site, sorting, recycling processes and benefits from avoided primary production or final disposal. The avoided waste reduces the total impact for ten categories (GWP, POCP, AP, EP, AD_r, AD_{ff}, HT carc, HT non carc, PMF and IR) by at least 20%. However, this activity has negligible benefits for ODP (<1%), and makes a large contribution to $ET_{freshwater}$ ($\geq$250%). The absolute characterized impact results per kg of material and products used for refurbishment and per kg of material recycled, re-used or used for alternative production are given in SI Tables S-4 and S-8 respectively.

3.2. Scenario analysis

The net impact results indicate that the three scenarios that are supposed to provide environmental benefits i.e. reduced environmental impacts due to improved waste management and sustainable material procurement (or both), show better results than the BAU for six out of the twelve impacts (GWP, POCP, AP, AD_{ff}, PMF and IR). For ODP, there is no difference in the results for any scenario. For $ET_{freshwater}$, scenarios 1 and 3 have the highest net impact followed by scenario 2 compared with BAU; the main contribution is from increased recycling during waste treatment. For EP, scenarios 2 and 3 have higher impacts for EP compared with BAU and scenario 1; the main contribution is from refurbished façade elements. For AD_r, HT carc and HT non carc scenarios 1 and 3 have a lower impact compared to BAU but scenario 2 impact has no difference compared to BAU.

Due to the benefits of waste minimization, the net impacts for scenario 1 compared with the BAU scenario are 15–25% lower for GWP, AD_{ff}, HT carc, PMF and IR; 8–12% lower for POCP, AP, EP, AD_r and HT non carc; and 56% higher for $ET_{freshwater}$. Alternative procurement in scenario 2 compared with the BAU scenario yields negligible benefits ($\leq$5%) for GWP, POCP, AP, AD_{ff}, PMF and IR; and 10% higher impacts for EP. Although avoiding the final disposal of

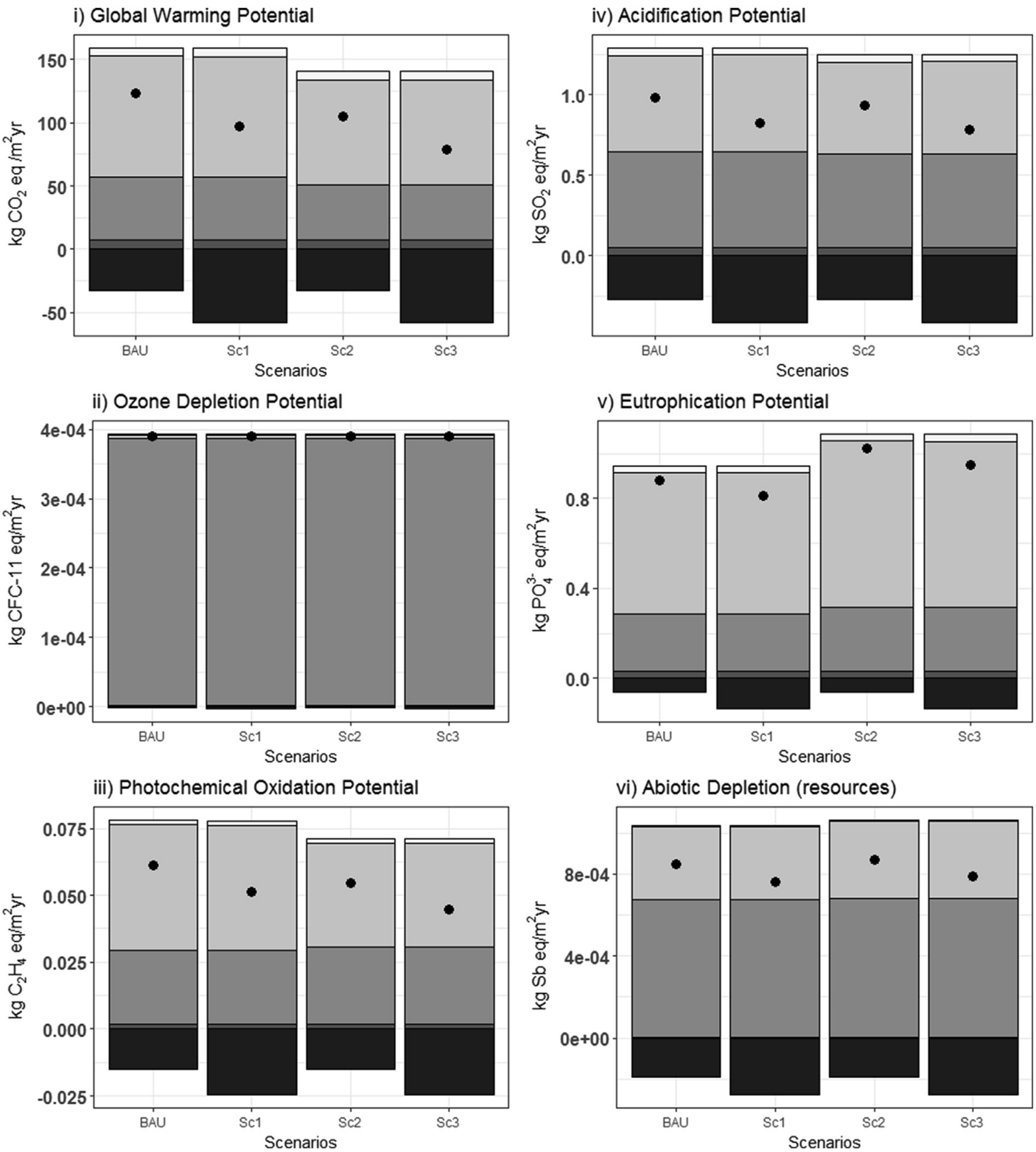

Fig. 2. a) Impact assessment results for the building refurbishment in Business As Usual scenario (BAU), waste minimization scenario (Sc1), alternative material procurement scenario (Sc2) and combination of waste minimization and alternative material procurement scenario (Sc3). The results are shown for: i) Global Warming Potential, ii) Ozone Depletion Potential, iii) Photochemical oxidation potential, iv) Acidification potential, v) Eutrophication Potential, vi) Abiotic depletion (resources). The dot marked in each bar indicates the net impact in each scenario. b) Impact assessment results for the building refurbishment in Business As Usual scenario (BAU), waste minimization scenario (Sc1), alternative material procurement scenario (Sc2) and combination of waste minimization and alternative material procurement scenario (Sc3). The results are shown for: i) Abiotic depletion (fossil fuels) ii) Human toxicity (carcinogenic) iii) Human toxicity (non-carcinogenic) iv) Ecotoxicity (freshwater) v) Particulate matter formation and vi) Ionizing Radiation. The dot marked in each bar indicates the net impact in each scenario.

plastic and blast furnace slag to landfill also reduces impacts (see SI Tables S–8), it is insufficient to substantially offset the net impact of the refurbishment.

For the combined waste minimization and alternative procurement scenario (scenario 3) compared with the BAU scenario the net results are 20–30% lower for GWP, POCP, AD_{ff} and IR; 8–16% lower for AP, AD_r, HT carc, HT non carc; and 68% and 10% higher for $ET_{freshwater}$ and EP respectively.

3.3. Sensitivity analysis

Fig. 3 presents the sensitivity of the net impact results to the recycling efficiency, specific marginal suppliers, and potential change in electricity grid mix in each scenario. The net impact results are sensitive to changes in the three parameters modified for the analysis, but the modification of the parameters does not affect the ranking of net impact results of the scenarios. The impacts of

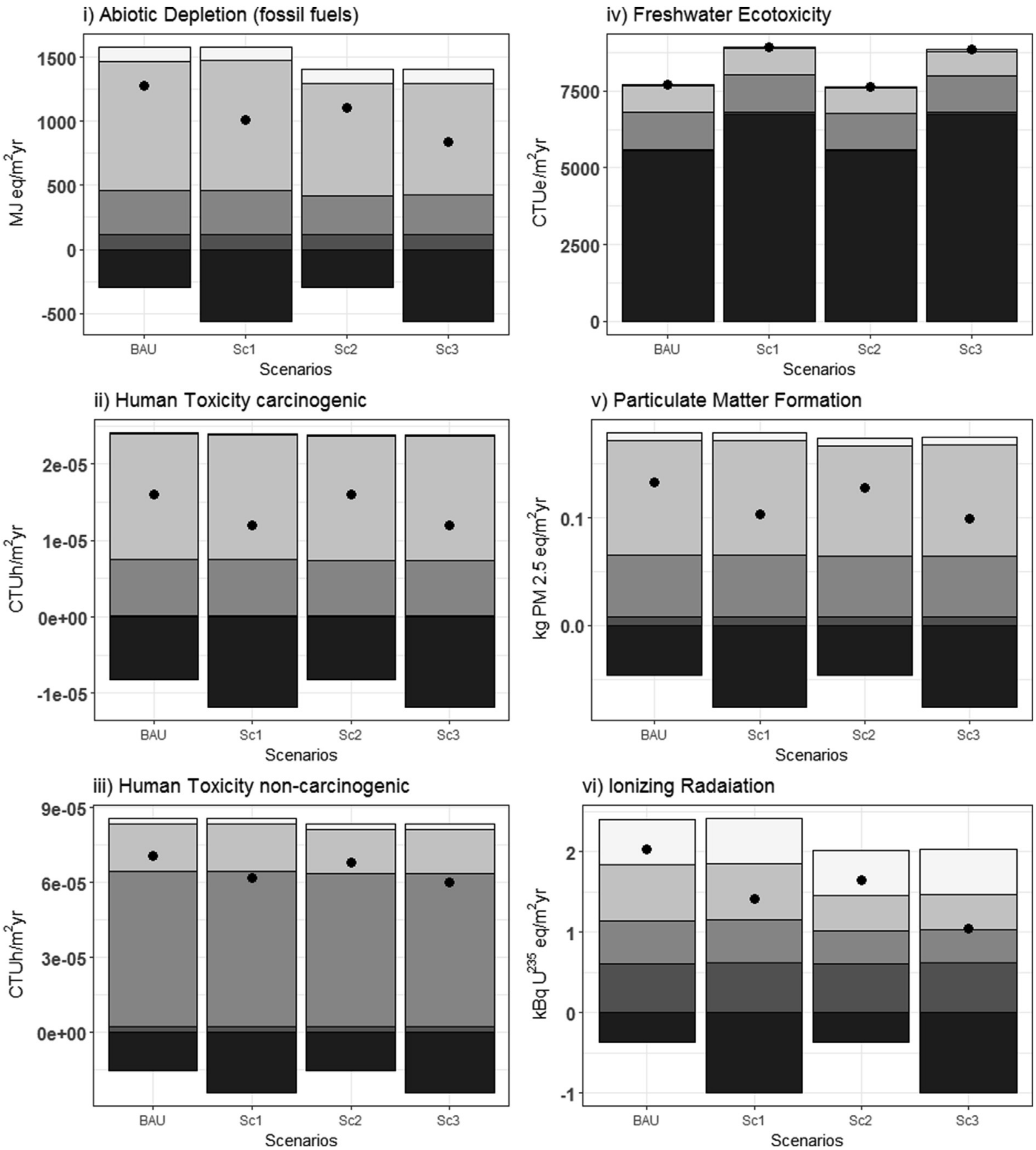

Fig. 2. (*continued*).

BAU and Scenario 3 are highest and lowest in most impact categories respectively as indicated in section 3.1. Moreover, the net results for ODP remained the same across all the scenarios for all three parameters considered in the sensitivity analysis. The absolute characterized impact results with respect to the sensitivity analysis in each scenario are given in SI Tables S–4.

A decrease in the recycling efficiency of metals (S1_ RER) leads to a 10–20% increase to nine of the impact categories (GWP, POCP, AP, AD_{ff}, AD_r, HT carc, HT non carc, PMF and IR) compared with the results in section 3.1. Limited or negligible changes were observed in the remaining impact categories (≤5%).

If the marginal suppliers are limited to the top New Zealand trading partners (S2_TP), the impacts increase compared with the results in section 3.1 for PMF (≈50%), AP (≈23%), GWP and POCP (≈5–15% in both categories). There is also a major decrease in IR (≥100%). In the alternative electricity grid mix considered for each of the top trading partners (S3_TP (el)), there is a major decrease in the results in each scenario for PMF (≈50–70%), GWP, POCP, AP and AD_{ff} (≈30–40% in all categories); at the same time, there is a major increase in IR (≥600%) and smaller increases in AD_r and $ET_{freshwater}$ (≈4–8% in both categories). The results for EP, HT carc and HT non-carc (≤1%) are not sensitive to the change in electricity grid mix. The absolute characterized impact results per kg of material and products with respect to the trading partners required are given in SI Tables S-6 and 7.

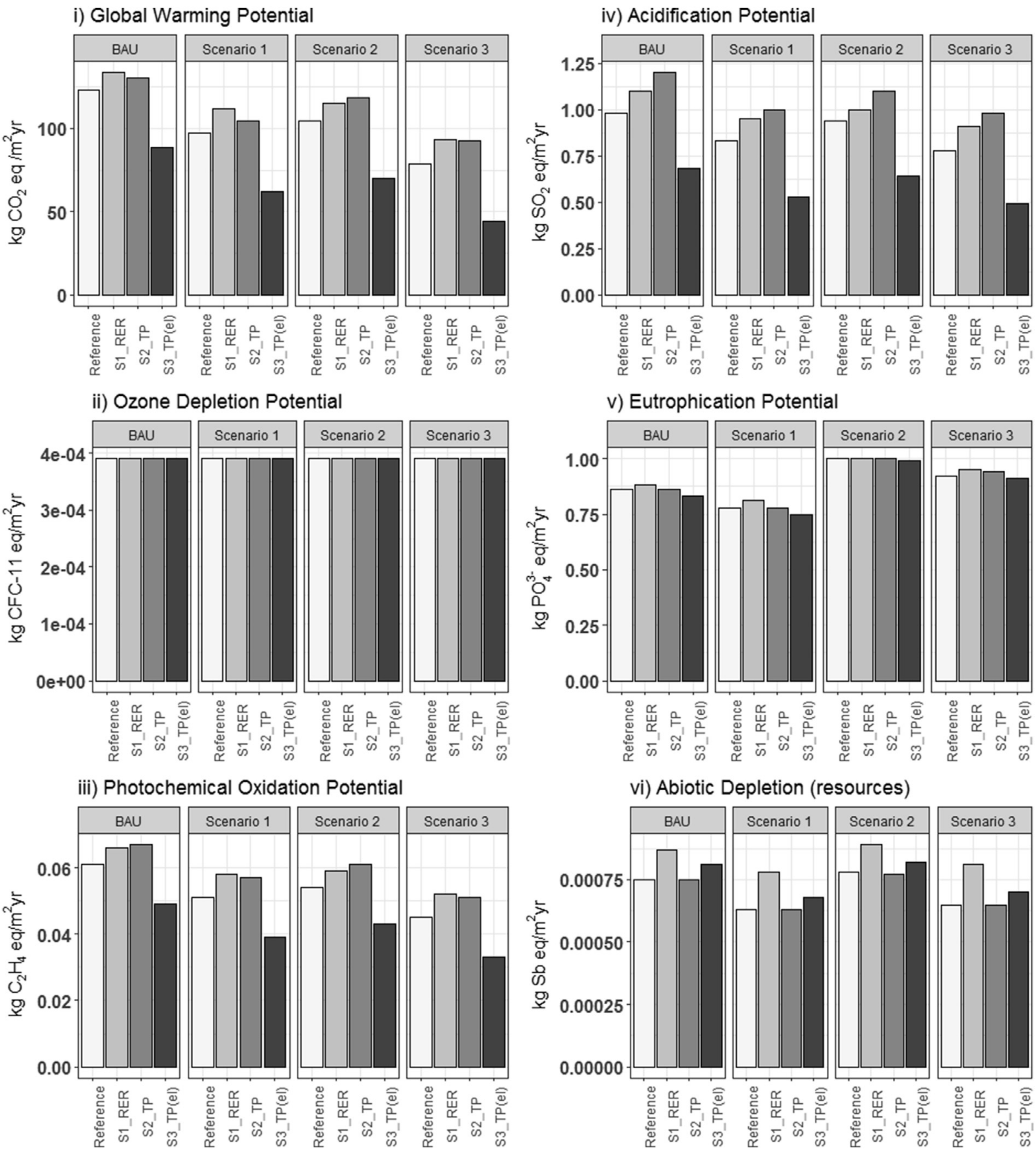

Fig. 3. a) Net impact results (per functional unit) in each scenario for sensitivity analysis of a) recycling efficiency (S1_ RER), b) specific marginal suppliers (S2_ TP) and c) potential change in electricity grid mix of specific marginal suppliers (S3_ TP (el)). The results are shown for: i) Global Warming Potential, ii) Ozone Depletion Potential, iii) Photochemical oxidation potential, iv) Acidification potential, v) Eutrophication Potential, vi) Abiotic depletion (resources). b) Net impact results (per functional unit) in each scenario for sensitivity analysis of a) recycling efficiency (S1_ RER), b) specific marginal suppliers (S2_ TP) and c) potential change in electricity grid mix of specific marginal suppliers (S3_ TP (el)). The results are shown for: i) Abiotic depletion (fossil fuels), ii) Human toxicity (carcinogenic) iii) Human toxicity (non-carcinogenic) iv) Ecotoxicity (freshwater) v) Particulate matter formation and vi) Ionizing Radiation.

4. Discussion

4.1. Contribution analysis

The largest contribution to most impact category results for the refurbished façade components is from the aluminium used in window frames and shading devices, followed by reinforced concrete walls which make a high contribution to EP; float glass units for windows makes a contribution to HT non carc and polystyrene insulation makes contributions to POCP and AD_{ff}. The largest contribution to the results from the heating and lighting elements is also from metals, particularly copper and aluminium production. Impacts from copper production make a particularly high contribution to HT non carc, AD_r and $ET_{freshwater}$; while aluminium production contributes to all these categories. Use of refrigerant HFC 134a in heat pumps was the single highest contributor to ODP. All

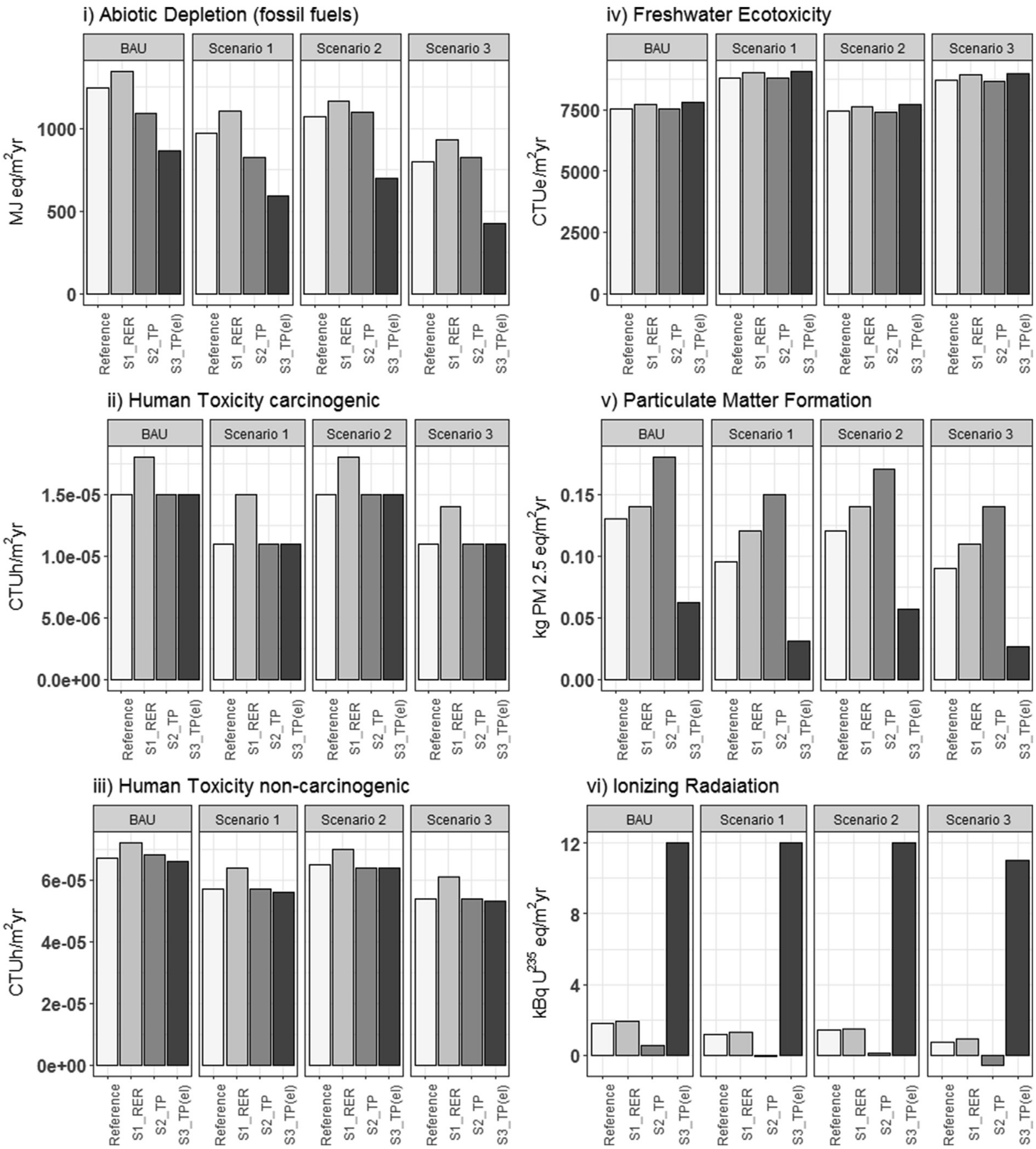

Fig. 3. (*continued*).

impacts related to transportation and construction at site are associated with fuel use. Most benefits related to waste management are associated with aluminium recycling; followed by steel and copper recycling. However, metal recycling contributes to $ET_{freshwater}$. Recycling of other materials such as glass, concrete and timber also provides additional benefits by reducing impacts for GWP, POCP, AP, EP, AD_r, AD_{ff}, PMF and IR (see SI Tables S–8).

The impact of materials that require energy intensive production (e.g. aluminium, steel, cement) is determined by the energy source at the site of production. For example: the marginal energy source of the identified suppliers of primary aluminium is mainly from coal (China), oil and natural gas (Middle East) or nuclear and hydro power (Russia). The high proportion of fossil fuel use makes a significant contribution to GWP, POCP, AP, AD_{ff} and PMF; the impact to IR is contributed from the marginal electricity sourced from nuclear power plants in CIS Russia. Impacts from pre-cast concrete production were associated with both Portland cement and reinforcing steel production. Identified marginal suppliers for cement (China and South East Asia) have a high share of fossil fuel in their electricity mix considered for production which contributes to GWP. New Zealand was identified as the marginal supplier for steel; here steel is produced from a basic oxygen furnace with primary inputs of pig iron (extracted from iron sands) and liquid oxygen. The process is highly energy intensive and results in 4.2 kg CO_2 eq/kg compared to 2.0 kg CO_2 eq/kg of global average primary steel production (World Steel Association, 2011). Waste gas from the production of liquid oxygen required for steel production contains nitrogen which was the main contributor to EP. While the demand for other materials such as insulation and float glass production is also dominated by imports, energy use during production has a smaller contribution to the associated environmental impacts. Polystyrene polymers produced from fossil fuels contribute to AD_{ff}, and pentane emissions used to expand the polymers (foam blowing) is a prominent volatile organic compound (VOC) which contributes to POCP. Impacts from polyester insulation to POCP, EP, AD_r, and HT carc arise from organic chemicals such as ethylene glycol and terephthalic acid used during production (Webb et al., 2013). The contribution to HT non carc from float glass production is associated with the use of crystalline soda ash. The impacts from copper production are mainly related to mining and smelting which leads to leachate wastes and loss of heavy metals which are key agents in toxicity pollution (Ayres et al., 2013; Nriagu, 1989) and resource depletion (Northey et al., 2014). The refrigerant HFC 134a itself does not contribute to ODP but its production involves the emission of other chlorinated hydrocarbons (Saner et al., 2010).

The major hotspots identified in the contribution analysis were also similar to those identified in a previous LCA performed on the same case study using attributional modelling (Ghose et al., 2017); however, the net impacts calculated in this study for the BAU scenario were substantially different (see SI Tables S–9) for GWP, AP, AD_r, AD_{ff}, HT carc, PMF and IR as these categories were influenced by the identified marginal suppliers and substitution of recyclable and re-used materials. While the attributional modelling focused on the status quo of current suppliers of construction materials in New Zealand, the consequential modelling identified resource constraints and marginal suppliers and therefore focuses on future trends in the building sector. The results of the contribution analysis with respect to the activities considered in this study are also similar to the findings of Blengini (2009) and Thormark (2001). The findings of both studies on the LCA of low energy buildings indicated the significant contribution of façade elements to the overall results.

4.2. Scenario analysis

The scenario analysis results indicated that in general waste minimization measures (scenario 1) had higher benefits compared to resource efficiency measures (scenario 2) and BAU. Current waste minimization measures in New Zealand primarily focus on recovery of metallic wastes which have high market demand and value. This study additionally quantifies the additional benefits related to recovery and re-use of non-metallic wastes (for example, glass, concrete, concrete, timber, plastics), which form the bulk of the construction waste sent to landfills in New Zealand (BRANZ, 2014). Moreover, the re-use of construction waste specifically at the building site decreases the demand for primary production, and thus directly avoids environmental burdens from primary production (Weidema, 2014).

As shown in the scenario 2 results, use of materials with low market demand in alternative material production (blast furnace slag and discarded PET bottles) avoids the impacts related to landfilling. Benefits were mainly associated with the use of blast furnace slag; while the use of polyester insulation containing recycled fibres from discarded PET bottles actually increased the contribution to EP arising from use of organic chemicals such as ethylene glycol and terephthalic acid during polyester production.

Scenario 3 shows substantial benefits of combined resource efficiency and waste minimization measures to reduce the burdens in most impact categories compared to BAU. Lack of local recycling facilities, limited communication with staff at site, unavailability of separate waste bins, and additional primary costs are some of the current challenges associated with limited recovery of construction materials from construction sites in New Zealand (Inglis, 2012; Napier, 2014). For example, feasibility studies on non-metallic waste recovery suggest the need for additional investments for effective supervision and planning at construction sites, which is still lacking for the bulk of construction activities in New Zealand (Hanne and Boyle, 2001; Sansbury and Boyle, 2001). Moreover, a tendency to continue with the cheap conventional materials is a major obstacle to the use of alternative construction materials (Samarasinghe, 2014).

4.3. Sensitivity analysis

With respect to the sensitivity of the net results to a decrease in recycling efficiency, the impacts increase in scenarios with higher metal recovery rates (scenarios 1 and 3). Material recovery rate and recycling efficiency are the two main factors that determine the benefits of recycling (Graedel and Reuter, 2011; Intini and Kühtz, 2011). For example, in this study assuming a low recovery rate (75%) but a high recycling efficiency (98%) per kg aluminium scrap will result in the avoidance of 0.74 kg of primary aluminium production; in comparison, a high recovery rate (100%) but a low recycling efficiency (70%) per kg aluminium scrap will avoid 0.70 kg of primary aluminium production. Metal alloys or coatings used in specific building components (e.g. aluminium in window frames) could affect the recycling efficiency (Gilmer, 2005; Stacey, 2015). Poor quality of recovered material affects its recyclability, hence another obstacle to the availability of secondary material to substitute primary production (Horvath, 2004; Vieira and Horvath, 2008).

The study also highlights the sensitivity of the results to the choice of marginal suppliers and primarily the policies on energy production for the material production. The contribution to most impact categories was largely dominated by the share of coal used as the marginal source of electricity for the production of construction materials. If coal is phased out, the overall impact for GWP, PCOP, AP, AD_{ff} and PMF is reduced. However, the marginal source of electricity from nuclear power and other renewables (e.g. wind and geothermal) will contribute to IR and AD_r. The high sensitivity to the source of electricity production are in line with findings of Buyle et al. (2016) and Srinivasan et al. (2012) which also highlighted how alternative energy used for production influences the total environmental impact of building materials.

4.4. Limitations

Limitations of this study were related to data quality and availability. At the time of this study, the data quality with respect to non-GHG emissions in New Zealand was limited and generic data from ecoinvent was used. Availability of New Zealand specific data could have increased the quality of the results. For instance, New Zealand's Ministry of Environment is striving to develop data on emissions from New Zealand landfills (Ministry for the Environment, 2015). Availability of this data might have indicated additional benefits or trade-offs of avoiding final disposal to landfill. Moreover, the reference case was restricted to a single building to maintain the consistency in the physical characteristics and functionality of the building as comparisons of buildings are often difficult as each building is characteristically different (Leipziger, 2013). Applying the same methodological approach to substantially different types of buildings, such as buildings constructed largely from bio-based materials such as timber, could show different results. With respect to the methodology, there is a consensus on the general methodology and application of consequential LCA for policy making (Ekvall et al., 2016), but the appropriate method for identification of marginal suppliers is still a contested topic (Mathiesen et al., 2009; Suh and Yang, 2014). Recent work by Pizzol and Scotti (2016) discusses current challenges in the identification of marginal suppliers, and proposes the use of international trade databases (for example, UN COMTRADE (2015) and FAO (2011)) and a trade network analysis as a potential approach to increase the robustness of the process for identifying marginal suppliers.

5. Conclusion

This study investigated the environmental impacts of large scale energy efficiency refurbishment and the best practice measures that will reduce the overall impacts of this type of refurbishment. Regarding the first research question about the environmental impacts associated with increase in resource demand, this study corroborates the ideas of Horvath (2004) who highlighted that, although major construction material resources may be plentiful globally, construction material constraints at a regional level are a major concern. Thus the potential environmental impact of the refurbishment depends on where these materials are imported from and the energy used to produce them. With respect to the second research question, the results highlight the need for policymakers and stakeholders to focus on waste management to compensate for the impacts of increasing construction activity related to refurbishment.

The outcome of this study can assist both policy makers and stakeholders in the building sector, and LCA practitioners. Utilization of information on local or regional constraints in the modelling can provide insightful information for policy makers and stakeholders to support avoidance of problem shifting in future policies. To the knowledge of the authors of this study, shortages and constraints in the availability of materials have not been considered in existing LCA case studies of New Zealand buildings. The information on marginal suppliers of major construction materials provided in this study could therefore be used for the assessment of refurbishment or new construction for other building types in New Zealand in future. In future it might be possible to extend the knowledge from this study to economic and social implications using other methods such as Life Cycle Sustainability Assessment (LCSA) when appropriate data are available.

Acknowledgements

This study was financially supported by the Building Research Levy, through BRANZ Inc and New Zealand Life Cycle Management Centre. The contribution and support of Jannick Schmidt (Aalborg University), David Dowdell (BRANZ) and Shaan Cory (Victoria University) is greatly acknowledged.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2017.07.099.

References

AISI, 2014. American Iron and Steel Institute, Profile-2014. Retrieved from. www.steel.org/about-aisi/reports.aspx. (Accessed 5 March 2015).

Amitrano, L., Isaacs, N., Saville-Smith, K., Donn, M., Camilleri, M., Pollard, A., Babylon, M., Bishop, R., Roberti, J., Burrough, L., Au, P., Bint, L., Jowett, J., Hills, A., Cory, S., 2014. Building Energy End-use Study (BEES) Part 1:Final Report. Retrieved from Judgeford: http://www.branz.co.nz/cms_show_download.php?id=182d3ae296d4d92be905477582ae2453c0671d58. (Accessed 2 February 2015).

Autex, 2016. GreenStuf® Insulation- Facts about Autex Insulation. Retrieved from. http://www.autexindustries.com/greenstuf. (Accessed 29 September 2016).

Ayres, R.U., Ayres, L.W., Råde, I., 2013. The Life Cycle of Copper, its Co-products and Byproducts. Retrieved from. http://pubs.iied.org/pdfs/G00740.pdf. (Accessed 29 October 2016).

Bakshi, N., Vale, R., & Vale, B. (2013). Which heater should I use? Paper presented at the International Conference of the Architechtural Science Association, Australia. http://anzasca.net/wp-content/uploads/2014/08/43.pdf (Accessed 29.11. 2015).

Bedford, R., Sims, R., Bennett, P., Isaacs, N., Kerr, S., Leaver, J., Resinger, A., Stephenson, J., Higham, J., Mason, E., 2016. Transition to a Low-carbon Economy for New Zealand. Retrieved from New Zealand: http://www.royalsociety.org.nz/media/2016/06/Report-Transition-to-Low-Carbon-Economy-for-NZ.pdf. (Accessed 15 October 2016).

Blengini, G.A., 2009. Life cycle of buildings, demolition and recycling potential: a case study in Turin, Italy. Build. Environ. 44 (2), 319–330. http://dx.doi.org/10.1016/j.buildenv.2008.03.007.

Blengini, G.A., Di Carlo, T., 2010. The changing role of life cycle phases, subsystems and materials in the LCA of low energy buildings. Energy Build. 42 (6), 869–880. http://dx.doi.org/10.1016/j.enbuild.2009.12.009.

Blom, I., Itard, L., Meijer, A., 2010. Environmental impact of dwellings in use: maintenance of façade components. Build. Environ. 45 (11), 2526–2538. http://dx.doi.org/10.1016/j.buildenv.2010.05.015.

Bluescope steel, 2015. Annual Report- 2014/15. Retrieved from Australia: https://www.bluescope.com/investors/annual-reports/. (Accessed 5 February 2016).

BRANZ, 2013. Building Energy End-use Study. Retrieved from. http://www.branz.co.nz/cms_display.php?sn=128&st=1. (Accessed 5 July 2014).

BRANZ, 2014. REBRI Guides- Waste Reduction and Recovery. Retrieved from Porirua, Wellington: http://www.branz.co.nz/cms_display.php?st=1&sn=240&pg=12349. (Accessed 5 October 2016).

Buyle, M., Braet, J., Audenaert, A., Debacker, W., 2016. Strategies for optimizing the environmental profile of dwellings in a Belgian context: a consequential versus an attributional approach. J. Clean. Prod. 1–10. http://dx.doi.org/10.1016/j.jclepro.2016.08.114.

Cabeza, L.F., Rincón, L., Vilarino, M.V., Perez, G., Castell, A., 2014. Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: a review. Renew. Sustain. Energy Rev. 29, 394–416. http://dx.doi.org/10.1016/j.rser.2013.08.037.

CCANZ, 2015. Technical Information: Cements- Types and Use. Retrieved from. http://www.ccanz.org.nz/page/Cements.aspx. (Accessed 10 October 2016).

Chaney, K., 2012. Push for energy efficiency commercial buildings. Retrieved from BUILD 128, 42–43. http://www.buildmagazine.org.nz/assets/PDF/Build128-42-Push-For-Energy-efficient-Commercial-Buildings.pdf. (Accessed 12 October 2016).

Chau, C.K., Xu, J.M., Leung, T.M., Ng, W.Y., 2016. Evaluation of the impacts of end-of-life management strategies for deconstruction of a high-rise concrete framed office building. Appl. Energy. http://dx.doi.org/10.1016/j.apenergy.2016.01.019.

Cory, S., 2016. An Exploration of the Feasibility of Converting the New Zealand Commercial Building Stock to Be Net Zero Energy (Doctor of Philosophy in Architecture Monograph). Victoria University Wellington. Retrieved from. http://restrictedarchive.vuw.ac.nz/handle/123456789/9092. (Accessed 3 March 2016).

Crampton, A., 2015. Exciting time for materials. Retrieved from BUILD 149, 4. http://www.buildmagazine.org.nz. (Accessed 3 September 2016).

Craven, D., 2015. Do we rate environmentally? BUILD 146. Retrieved from http://www.buildmagazine.org.nz/articles/show/do-we-rate-environmentally. (Accessed 3 September 2016).

Desjarlais, A.O., 2008. Insulation Fact Sheet. Retrieved from Oak Ridge, Tennesse: http://web.ornl.gov/sci/buildings/docs/factSheets/Insulation-FactSheet-2008.pdf. (Accessed 3 October 2016).

Dowdell, D., 2014. New Zealand Whole Building Whole of Life Framework: Life Cycle Assessment Based Indicators. Retrieved from Porirua, New Zealand: http://www.branz.co.nz/cms_display.php?sn=198&st=1&pg=13289. (Accessed 3 July 2014).

Dowdell, D., Berg, B., Marston, N., Shaw, P., Burgess, J., Roberti, J., White, B., 2016. New Zealand whole Building Whole of Life Framework - Development of Datasheets to Support Building Life Cycle Assessment (SR 351). Retrieved from Judgeford, New Zealand: http://www.branz.co.nz/cms_display.php?sn=198&st=1&pg=13289. (Accessed 3 August 2016).

Earles, J.M., Halog, A., 2011. Consequential life cycle assessment: a review. Int. J. Life Cycle Assess. 16 (5), 445–453. http://dx.doi.org/10.1007/s11367-011-0275-9.

ecoinvent, 2013. Ecoinvent Version 3. The Ecoinvent Database: Overview and Methodology, Data Quality Guideline for the Ecoinvent Database Version 3. Retrieved from. www.ecoinvent.org.

Ekvall, T., 2000. A market-based approach to allocation at open-loop recycling. Resour Conserv Recycl. 29 (1–2), 91–109. http://dx.doi.org/10.1016/S0921-3449(99)00057-9.

Ekvall, T., Weidema, B.P., 2004. System boundaries and input data in consequential life cycle inventory analysis. Int. J. Life Cycle Assess. 9 (3), 161–171. http://dx.doi.org/10.1007/BF02994190.

Ekvall, T., Azapagic, A., Finnveden, G., Rydberg, T., Weidema, B.P., Zamagni, A., 2016. Attributional and consequential LCA in the ILCD handbook. Int. J. Life Cycle Assess. 21 (3), 293–296. http://dx.doi.org/10.1007/s11367-015-1026-0.

EN 15978, 2011. Sustainability of Construction Works. Assessment of Environmental Performance of Buildings. 3.26 System Boundaries. U.K: British Standards Institution.

EnergyPlus 8.6.0, 2015. Whole Building Energy Simulation Program. Retrieved from.

https://energyplus.net/.
European Commission, 2011. Final Communication from the Commission: Roadmap to a Resource Efficient Europe- Flagship Initiative under the Europe 2020 Strategy. Retrieved from Brussels: http://ec.europa.eu/resource-efficient-europe/pdf/resource-efficient_europe_en.pdf. (Accessed 13 October 2016).
European Commission, 2013. Protecting the Environment and Economic Growth: trade-off or Growth-enhancing Structural Adjustment? Retrieved from Brussels: http://ec.europa.eu/economy_finance/publications/publication7726_en.pdf. (Accessed 5 September 2016).
FAO, 2011. In Depth Country Study- New Zealand Forest Industries. Retrieved from. http://www.fao.org/docrep/003/W5546E/W5546E04.htm. (Accessed 5 March 2016).
Finnveden, G., Hauschild, M.Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., Suh, S., 2009. Recent developments in life cycle assessment. J. Environ. Manage. 91 (1), 1–21. http://dx.doi.org/10.1016/j.jenvman.2009.06.018.
Fletcher Building NZ, 2015. Annual Report. Retrieved from. http://www.fbu.com/media/45502/FBU-Annual-Report-FINAL.pdf. (Accessed 15 March 2016).
Galiè, F., Trabucchi, C., 2014. World Polymers Outlook. Retrieved from. http://www.icis.com/contact/world-polymers-market-outlook/. (Accessed 15 March 2016).
Galloway, A., 2012. Windows for energy efficiency. BUILD 132, 32–33. Retrieved from. http://www.buildmagazine.org.nz/articles/show/windows-for-energy-efficiency/. (Accessed 15 October 2015).
Ghose, A., Mclaren, S., Dave, D., Phipps, R., 2017. Environmental assessment of deep energy refurbishment for energy efficiency- A case study of an office building in New Zealand. Build. Environ. http://dx.doi.org/10.1016/j.buildenv.2017.03.012.
Gilmer, W.B., 2005. Aluminium Alloys. Retrieved from. http://www.thealuminumsource.com/tech/alloys.htm. (Accessed 2 November 2015).
Graedel, T., Reuter, M., 2011. Metal Recycling- Opportunities, Limits, Infrastructure. Retrieved from. www.unep.org/resourcepanel. (Accessed 22 September 2016).
Gustavsson, L., Dodoo, A., Sathre, R., 2015. Report on Methodological Issues in Determining the Climate Change Effects over the Lifecycle of a Building. Retrieved from Växjö, Sweden: https://www.diva-portal.org/smash/get/diva2:859945/FULLTEXT01.pdf. (Accessed 19 October 2016).
Hanne, S., & Boyle, C. (2001). Source separation of construction wastes in New Zealand. Paper Presented at the Waste MINZ Auckland. (Accessed 21.09.16).
Herczeg, M., McKinnon, D., Milios, L., Bakas, I., Klaassens, E., Svatikova, K., Widerberg, O., 2014. Resource Efficiency in the Building Sector. Retrieved from Rotterdam: http://ec.europa.eu/environment/eussd/pdf/Resource%20efficiency%20in%20the%20building%20sector.pdf. (Accessed 10 September 2016).
Holcim, N.Z., 2011. Safety and Technical Datasheet: Cements- Rapidcem, Ultracem, Duracem. Retrieved from Christchurch: www.holcim.co.nz. (Accessed 10 August 2016).
Horvath, A., 2004. Construction material and the environment. Annu. Rev. Energ Environ. 29 (1), 181–204. http://dx.doi.org/10.1146/annurev.energy.29.062403.102215.
IAI, 2009. International Aluminium Institute- Global Aluminium Recycling: a Cornerstone of Sustainable Development. Retrieved from. www.world-aluminium.org/media/filer_public/2013/01/15/fl0000181.pdf. (Accessed 10 March 2016).
IEA, 2013a. International Energy Agency- South East Asia- Energy Outlook. Retrieved from. www.worldenergyoutlook.org. (Accessed 10 September 2016).
IEA, 2013b. International Energy Agency- World Energy Outlook. Retrieved from. www.worldenergyoutlook.org. (Accessed 10 September 2016).
IEA, 2014. International Energy Agency- Transition to Sustainable Buildings. Retrieved from. www.iea.org/etp/buildings. (Accessed 22 March 2015).
Inglis, M., 2012. Construction and Demolition Waste – Best Practice and Cost Saving. Retrieved from 23 Kate Sheppard Place, Wellington, New Zealand: http://www.cmnzl.co.nz/assets/sm/2260/61/057-INGLISMahara.pdf. (Accessed 18 October 2016).
Intini, F., Kühtz, S., 2011. Recycling in buildings: an LCA case study of a thermal insulation panel made of polyester fiber, recycled from post-consumer PET bottles. Int. J. Life Cycle Assess. Assess. 16 (4), 306–315. http://dx.doi.org/10.1007/s11367-011-0267-9.
Isaacs, N., Hills, A., 2013. Understanding the New Zealand non-domestic building stock. Build. Res. Inf. 42 (1), 95–108. http://dx.doi.org/10.1080/09613218.2013.831274.
ISO 14049, 2012. Environmental Management Illustrative Examples on How to Apply ISO 14044 to Goal and Scope Definition and Inventory Analysis, p. 48.
Jewell, C., 2014. Green Property Index: Green Buildings Outperforming Market. Retrieved from. http://www.thefifthestate.com.au/archives/59419/?utm_source=The+Fifth+Estate+-+newsletter&utm_campaign=573679299b-13_February_2014&utm_medium=email&utm_term=0_5009254e4c-573679299b-30762029. . (Accessed 15 October 2016).
Junnila, S., Horvath, A., Guggemos, A.A., 2006. J. Infrastruct. Syst. 12 (1), 10–17. http://dx.doi.org/10.1061/(ASCE)1076-0342(2006)12:1(10).
Kellenberger, D. (2007). Modelling principles for the collection of consistent and comprehensive LCI data. Paper presented at the New Zealand sustainable building conference Auckland. http://www.branz.co.nz/cms_show_download.php?id=332161fcb8c527148bb80919f0746d8811bf2907.
Kofoworola, O., Gheewala, S., 2008. Environmental life cycle assessment of a commercial office building in Thailand. Int. J. Life Cycle Assess. 13 (6), 498–511. http://dx.doi.org/10.1007/s11367-008-0012-1.
Kua, H.W., 2015. Integrated policies to promote sustainable use of steel slag for construction—a consequential life cycle embodied energy and greenhouse gas emission perspective. Energy Build. 101, 133–143. http://dx.doi.org/10.1016/j.enbuild.2015.04.036.
Kua, H.W., Kamath, S., 2014. An attributional and consequential life cycle assessment of substituting concrete with bricks. J. Clean. Product. 81, 190–200. http://dx.doi.org/10.1016/j.jclepro.2014.06.006.
Kua, H.W., Lu, Y., 2016. Environmental impacts of substituting tempered glass with polycarbonate in construction – an attributional and consequential life cycle perspective. J. Clean. Product. 137, 910–921. http://dx.doi.org/10.1016/j.jclepro.2016.07.171.
Kucukvar, M., Egilmez, G., Tatari, O., 2016. Life cycle assessment and optimization-based decision analysis of construction waste recycling for a LEED-certified university building. Sustainability 8 (1), 89. http://dx.doi.org/10.3390/su8010089.
Lammers, H., 2011. OpenStudio Visualizes Energy Use in Buildings. Retrieved from. http://phys.org/news/2011-03-openstudio-visualizes-energy.html. (Accessed 8 June 2015).
Leifer, D., 2003. Building ownership and facilities management. Facilities 21 (1/2), 38–41. http://dx.doi.org/10.1108/02632770310460531.
Leipziger, D., 2013. Comparing Building Energy Performance Measurement- a Framework for International Energy Efficiency Assessment Systems. Retrieved from Washington, DC: www.imt.org. (Accessed 8 August 2016).
Mathiesen, B.V., Münster, M., Fruergaard, T., 2009. Uncertainties related to the identification of the marginal energy technology in consequential life cycle assessments. J. Clean. Product. 17 (15), 1331–1338. http://dx.doi.org/10.1016/j.jclepro.2009.04.009.
MBIE, 2012. New Zealand's Energy Outlook- Energy Insight. Retrieved from Wellington: http://www.mbie.govt.nz/info-services/sectors-industries/energy/energy-data-modelling/modelling/new-zealands-energy-outlook. (Accessed 8 October 2015).
MBIE, 2015. Energy in New Zealand. Retrieved from. www.mbie.govt.nz/info-services/sectors-industries/energy. (Accessed 12 March 2016).
Metro Glass ltd, 2015. Metro Performance Glass- Annual Report 2015. Retrieved from. www.metroglass.co.nz. (Accessed 5 March 2016).
Ministry for the Environment, 2015. Environment Aotearoa 2015- Current Reporting Limitations. Retrieved from. http://www.mfe.govt.nz/publications/environmental-reporting/environment-aotearoa-2015. (Accessed 15 November 2016).
Ministry for the Environment (NZ), 2009. Life Cycle Assessment of Product Stewardship Options for Mercury-containing Lamps in New Zealand: Final Report. Retrieved from. http://www.mfe.govt.nz/publications. (Accessed 15 November 2016).
Ministry of Business Innovation and Employment, (NZ), 2013. Construction. Retrieved from. http://www.mbie.govt.nz/info-services/business/business-growth-agenda/sectors-reports-series/pdf-image-library/construction-report/construction-report.pdf. (Accessed 20 September 2016).
Ministry of Economic Development, 2011. New Zealand Energy Efficiency and Conservation Strategy 2011–2021. Retrieved from Wellington: www.med.govt.nz/energy-strategy. (Accessed 20 September 2016).
NABERS NZ, 2016. NABERSNZ Ratings a Key Part of Wellington's Smart Plan to Reduce Energy Consumption. Retrieved from. https://www.nzgbc.org.nz/Story?Action=View&Story_id=128. (Accessed 20 September 2016).
Napier, A., 2014. Recycling Buyers Losing Patience. Stuff. Retrieved from. http://www.stuff.co.nz/business/industries/9907512/Recycling-buyers-losing-patience. (Accessed 30 September 2016).
Nebel, B., 2009. Is it Valid to Use International Data in New Zealand LCA Studies. Retrieved from Rotorua, NewZealand: http://www.branz.co.nz/cms_show_download.php?id=0fb692aafd30348c96dbf730a68cac0ccdcfb77e. (Accessed 4 November 2016).
Northey, S., Mohrb, S., Mudd, G.M., Wenga, Z., Giurco, D., 2014. Modelling future copper ore grade decline based on a detailed assessment of copper resources and mining. Resour. Conserv. Recy. 83, 190–201. http://dx.doi.org/10.1016/j.resconrec.2013.10.005.
Nriagu, J.O., 1989. A global assessment of natural sources of atmospheric trace metals. Nature 338 (6210), 47–49. http://dx.doi.org/10.1038/338047a.
Paulik, S., Hertwich, E., 2016. Prospective models of society's future metabolism: what Industrial Ecology has to contribute. In: Clift, R., Druckman, A. (Eds.), Taking Stock of Industrial Ecology. Springer, pp. 21–43.
Peuportier, B., Herfray, G., Malmqvist, T., Zabalza, I., Staller, H.T., Wibke, Hajpál, M., Stoykova, E., 2011. Low Resource Consumption Buildings and Constructions by Use of LCA in Design and Decision Making- Guidelines for LCA. Retrieved from. https://www.sintef.no/globalassets/project/lore-lca/deliverables/lore-lca-wp3-d3.2-armines.pdf. . (Accessed 15 October 2016).
Pizzol, M., Scotti, M., 2016. Identifying marginal supplying countries of wood products via trade network analysis. Int. J. Life Cycle Assess. 1–13. http://dx.doi.org/10.1007/s11367-016-1222-6.
Plastics, N.Z., 2011. NZ Production Statistics. Retrieved from. http://www.plastics.org.nz/factsandresources/statsandsurvey/NZproductionstatistics/. . (Accessed 15 March 2016).
Rigamonti, L., Grosso, M., Sunseri, M.C., 2009. Influence of assumptions about selection and recycling efficiencies on the LCA of integrated waste management systems. Int. J. Life Cycle Assess. 14 (5), 411–419. http://dx.doi.org/10.1007/s11367-009-0095-3.
Rinne, S., Syri, S., 2013. Heat pumps versus combined heat and power production as CO2 reduction measures in Finland. Energy 57 (0), 308–318. http://dx.doi.org/10.1016/j.energy.2013.05.033.

Ruhrberg, M., 2006. Assessing the recycling efficiency of copper from end-of-life products in Western Europe. Resour. Conserv. Recycl 48 (2), 141–165. http://dx.doi.org/10.1016/j.resconrec.2006.01.003.

Sacayon Madrigal, E.E., 2016. Assessment of the Life Cycle-based Environmental Impacts of New Zealand Electricity (Master of Science). Massey University, Palmerston North, New Zealand.

SafeSmart Access NZ, 2015. Growth Forecast in Construction NZ Wide. Industry news. Retrieved from. http://scaffolding.safesmartaccess.co.nz/blog/growth-forecast-in-construction-nz-wide/.

Samarasinghe, D.A.S., 2014. Building Materials Supply Chains: an Evaluative Study of the New Zealand Residential Construction. (Doctor of Philosophy Monograph). Auckland University of Technology, Auckland, New Zealand. Retrieved from. http://aut.researchgateway.ac.nz/handle/10292/7428.

Sandin, G., Peters, G.M., Svanström, M., 2014. Life cycle assessment of construction materials: the influence of assumptions in end-of-life modelling. Int. J. Life Cycle Assess. 19 (4), 723–731. http://dx.doi.org/10.1007/s11367-013-0686-x.

Saner, D., Juraske, R., Kübert, M., Blum, P., Hellweg, S., Bayer, P., 2010. Is it only CO2 that matters? A life cycle perspective on shallow geothermal systems. Renew. Sustain. Energy Rev. 14 (7), 1798–1813. http://dx.doi.org/10.1016/j.rser.2010.04.002.

Sansbury, D. L., & Boyle, C. (2001). The feasibility and practicalities of recycling gypsum plasterboard waste in New Zealand. WasteMinz Conference. Retrieved from http://www.wasteminz.org.nz/pubs (Accessed 21.10.16).

Scanlon, L., 2016. End of an Era for Westport Cement Works. The New Zealand Herald. Retrieved from. http://m.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=11665024. . (Accessed 21 November 2016).

Scheuer, C., Keoleian, G.A., Reppe, P., 2003. Life cycle energy and environmental performance of a new university building: modeling challenges and design implications. Energy Build. 35 (10), 1049–1064. http://dx.doi.org/10.1016/S0378-7788(03)00066-5.

Schmidt, J.H., 2008. System delimitation in agricultural consequential LCA. Int. J. Life Cycle Assess. 13 (4), 350. http://dx.doi.org/10.1007/s11367-008-0016-x.

Schmidt, J., Thrane, M., 2009. Life Cycle Assessment of Aluminium Production in New Alcoa Smelter in Greenland. Retrieved from Aalborg, Denmark: http://lca-net.com/publications/show/life-cycle-assessment-aluminium-production-new-alcoa-smelter-greenland/. (Accessed 21 February 2016).

Schmidt, J.H., Merciai, S., Thrane, M., Dalgaard, R., 2011. Inventory of Country Specific Electricity in LCA – Consequential and Attributional Scenarios. Methodology report v2. Retrieved from Aalborg, Denmark: http://lca-net.com/publications. (Accessed 20 September 2016).

Srinivasan, R.S., Braham, W.W., Campbell, D.E., Curcija, C.D., 2012. Re(De)fining Net Zero Energy: Renewable Emergy Balance in environmental building design. Build. Environ. 47, 300–315. http://dx.doi.org/10.1016/j.buildenv.2011.07.010.

Stacey, M., 2015. Aluminium Recyclability and Recycling-towards Sustainable Cities. Retrieved from. http://www.world-aluminium.org/news/2015/08/25/towards-sustainable-cities-latest-two-studies-available-download/. (Accessed 2 October 2016).

Statistics NZ, 2015a. Building Consents Issued: December 2015. Commentry. Retrieved from. http://m.stats.govt.nz/browse_for_stats/industry_sectors/Construction. (Accessed 30 September 2016).

Statistics NZ, 2015b. Infoshare. Retrieved from. http://www.stats.govt.nz/infoshare/. (Accessed 5 March 2016).

Suh, S., Yang, Y., 2014. On the uncanny capabilities of consequential LCA. Int. J. Life Cycle Assess. 19 (6), 1179–1184. http://dx.doi.org/10.1007/s11367-014-0739-9. . (Accessed 20 September 2016).

Thormark, C., 2001. A low energy building in a life cycle: its embodied energy, energy needed for operation and recycling potential. Build. Environ. 429–435. http://dx.doi.org/10.1016/S0360-1323(01)00033-6.

Treasury, N.Z., 2015. New Zealand economic and Financial Overview- Principal Trading Partners. Retrieved from Wellington: www.treasury.govt.nz/economy/overview/2015/20.htm. (Accessed 20 September 2016).

UN COMTRADE, 2015. Trade of Goods. Retrieved from: http://data.un.org/. (Accessed 6 March 2016).

UNEP, 2011. United Nations Environmental Program- Recycling Rates of Metals. Retrieved from. http://www.unep.org/resourcepanel/Portals/24102/PDFs/Metals_Recycling_Rates_110412-1.pdf. . (Accessed 8 September 2016).

UNEP, 2014. United Nations Environmental Program - Sustainable Buildings and Climate Intiative. Why Buildings? Retrieved from. http://www.unep.org/sbci/AboutSBCI/Background.asp. (Accessed 15 August 2016).

USGS, 2013. U.S Geological Survey - Minerals Yearbook 2013-New Zealand. Retrieved from. https://minerals.usgs.gov/minerals/pubs/country/2013/myb3-2013-nz.pdf. (Accessed 12 September 2016).

Vieira, P.S., Horvath, A., 2008. Assessing the End-of-life impacts of buildings. Environ. Sci. Tech. 42 (13), 4663–4669.

Webb, H., Arnott, J., Crawford, R., Ivanova, E., 2013. Plastic degradation and its environmental implications with special reference to poly(ethylene terephthalate). Polymers 5 (1), 1. http://dx.doi.org/10.3390/polym5010001.

Weidema, B.P., 2003a. Market Information in Life Cycle Assessment. Retrieved from Aalborg: http://mst.dk/service/publikationer/publikationsarkiv/2003/dec/market-information-in-life-cycle-assessment/. (Accessed 12 March 2016).

Weidema, B.P., 2003b. Technical Guidelines for Product Life Cycle Assessment. Retrieved from Aalborg, Denmark: http://lca-center.dk/wp-content/uploads/2015/08/Geographical-technological-and-temporal-delimitation-in-LCA.pdf. (Accessed 12 March 2016).

Weidema, B.P., 2014. Recycling Activities. Retrieved from. www.consequential-lca.org. (Accessed 2 October 2016).

Weidema, B., 2015. By-product, Waste Treatment and Recycling. Consequential-lca. Retrieved from. www.consequential-lca.org. (Accessed 2 October 2016).

Weidema, B., 2016. Memory Lane. Retrieved from. http://lca-net.com/blog/memory-lane/. (Accessed 12 October 2016).

Whats On, R., 2013. NZ Building Consent Information. Retrieved from. http://www.whatson.co.nz/. (Accessed 2 July 2014).

World Steel Association, 2011. Life Cycle Assessment Methodology Report. Retrieved from Brussels: https://www.worldsteel.org/dms. (Accessed 16 March 2016).

World Steel Association, 2015. World Steel in Figures. Retrieved from. https://www.worldsteel.org/statistics. (Accessed 16 March 2016).

Yang, Y., 2016. Two sides of the same coin: consequential life cycle assessment based on the attributional framework. J. Clean. Product. 127, 274–281. http://dx.doi.org/10.1016/j.jclepro.2016.03.089.