Fire Research Report

Assessing the Impact of Vegetation and House Fires on Greenhouse Gas Emissions

Scion & BRANZ

April 2010

This study was conducted for The New Zealand Fire Service Commission (NZFSC), to enable the New Zealand Fire Service (NZFS) to assess the impact of green house gas (GHG) emissions associated with vegetation fires and house fires.

A vegetation fire emissions tool has been developed by Scion, and a house fire emissions tool by BRANZ. The approach, methodology and conclusions are summarised in this report. The specific approaches used for estimating GHG impacts for vegetation fires and for house fires differ; therefore these are presented in two sections in this report for clarity.

New Zealand Fire Service Commission Research Report Number 104
ISBN Number 978-1-877539-19-0 (on-line)
ISBN Number 978-1-877539-18-3 (paperback)
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Final Report

Assessing the impact of vegetation and house fires on Greenhouse Gas emissions

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Report for New Zealand Fire Service Commission

Contestable Research Fund 2009/2010

12.05.2010

Preface

This report forms part of a larger research project conducted for the New Zealand Fire Service Commission into the green house gas emissions associated with house fires (conducted by BRANZ) and vegetation fires (conducted by Scion). The house fire portion of the project was performed by BRANZ under sub-contract to Scion. This report is a summary of both parts of this project.

Acknowledgments

This work was funded by the New Zealand Fire Service Commission through the New Zealand Fire Service Contestable Research Fund.

The authors would also like to acknowledge the following for their invaluable contributions:

- Grant Pearce (Scion) for advice, testing, literature references and fire data
- Stuart Anderson (Scion) for advice, proofing and testing
- Neil Challands (NZ Fire Service) for testing
- Bob King (NRFA) for testing

Note

This report is intended for the New Zealand Fire Service, policy makers and researchers.

Executive Summary

This study was conducted for The New Zealand Fire Service Commission (NZFSC), to enable the New Zealand Fire Service (NZFS) to assess the impact of green house gas (GHG) emissions associated with vegetation fires and house fires. The objectives of the research were to:

1. develop a methodology for the calculation of GHG emissions from vegetation and house fires, and the impact that the New Zealand Fire Service's actions have on the emissions from these fires.
2. create an Excel-based tool that the New Zealand Fire Service can use to estimate the GHG emissions from vegetation and house fires, and the impact that their actions had on the GHG emissions.
3. provide a transparent and useful way of calculating ongoing GHG emissions from fires, and the impact that the NZFS has on these emissions.
4. enable NZFS to assess the most efficient use of resources, through comparison of emissions from fires, with and without suppression action.
5. provide a tool with which NZFS can easily estimate and report on GHG emissions from fire incidents.

A vegetation fire emissions tool has been developed by Scion, and a house fire emissions tool by BRANZ. The approach, methodology and conclusions are summarised in this report. The specific approaches used for estimating GHG impacts for vegetation fires and for house fires differ; therefore these are presented in two sections in this report for clarity.

Vegetation Fires

The fire emissions tool presented here has been created with the goals of having a simple, convenient and user-friendly tool that can give accurate estimations of the GHG emissions from vegetation fires. The tool was also designed to allow estimates of emissions from fires with and without suppression actions. The Microsoft Excel-based tool has been created to allow users to enter data about single or multiple fire incidents, and see the resulting emissions in an easily-readable format.

The tool allows inputs of:

- vegetation type;
- area burned;
- regional, seasonal and climatic influences;
- suppression action (both ground and air); and
- specific detailed fire parameters such as build-up indices and fine fuel moisture codes.

This in turn allows outputs of:

- GHG emissions from vegetation fires;
- GHG emissions from suppression action;
- total GHG emissions with and without suppression action; and
- GHG emissions from worst case scenarios.

The inputs are tied directly to comprehensive New Zealand data, such as the New Zealand Land Cover Database, historical climate & weather records, vehicle types used by the NZFS and New Zealand emission factors for vehicle fuels. This is supported with international data such as emission factors from vegetation burning. The final result is a tool based on robust scientific data that is still simple to understand and use.

This tool provides the NZFS and National Rural Fire Authority (NRFA) with a way of calculating total emissions from fire incidents, which in turn allows more efficient use of resources.

House Fires

The house fire GHG emissions estimation tool presented here is intended to provide comparative results to investigate the potential impact of different strategies or scenarios, e.g. the current situation versus the situation if no Fire Service intervention was available (or the average response time was increased or decreased), versus mandatory home sprinklers systems throughout the nation, and so on.

A house fire GHG emissions estimation tool was successfully developed and results for example scenarios are presented as demonstration of the concept. The metric used for the output of the tool is GHG emissions in metric tonnes of CO_2 equivalent, which is consistent with other GHG emission studies.

The house fire GHG emissions framework described here intentionally does not incorporate the elements covered in the previous home sprinkler cost effectiveness analysis incorporating sustainability impacts (Robbins, Wade et al. 2008), therefore the results from both of these frameworks can be used in combination since no component is counted twice.

The house fire GHG emissions tool is based on a range of input parameters including fire incident statistics, estimated materials and quantities involved in the structure and contents of an exemplar house, and effectiveness of different suppression methods.

An exemplar house was used as an estimate of the most common construction combinations and contents items for houses in New Zealand. Because of the lack of data, species yields were based upon data and information for well-ventilated fires. This was limited to average carbon dioxide (CO_2) yields. To account for the diversity in the NZ housing stock construction and contents and the flame damage for any individual fire event, the context of the national scope was used with an analysis period of 50 years. Results are expressed in terms of per year of this analysis period.

A selection of scenarios was considered so as to provide results to investigate the comparisons between the scenarios using the house fire GHG emissions framework developed here. The scenarios considered were:

1. Total fire loss of an exemplar house structure;
2. Total fire loss of an exemplar house contents;
3. House fires with fire suppression remaining the same as reflected in current fire incident statistics;
4. House fires where home sprinkler systems (according to NZS4817) are present with NZFS intervention using water (if needed in the cases where the home sprinkler system are not effective); and
5. House fires with the equivalent percentage of house area lost to fire increased to 50%.

For the estimations and assumptions used in this framework, the complete fire loss of the exemplar house structure was estimated to account for approximately 82 – 86% of the CO_2 released during a fire, with house contents contributing the balance.

This framework can be used to estimate the impact of changes in fire suppression strategies. For example, comparison of the current fire suppression strategies reflected in recent fire incident strategies (Scenario 3) and implementing a home sprinkler system strategy to protect the NZ housing stock within a 10 year period (Scenario 4) was estimated to provide a 60 – 70% mean reduction of CO_2 equivalent GHG emissions being released during house fires (over the period of analysis) by the introduction of home sprinkler systems. Conversely, a reduction in house fire suppression strategies such that the equivalent percentage of floor area loss per fire increased from 29% (Scenario 3) to

50% (Scenario 5) was associated with an approximately 90% mean increase in CO_2 equivalent emissions.

The most influential input parameters were found to be those related to the estimated number of fires per year and types of material or item that contributed the most CO_2 on average. Sensitivity to these parameters was as expected. For Scenario 4, where home sprinkler systems were introduced to the housing stock, the effectiveness of the system and the maximum limit of flame damage achieved by the system were also influential input parameters.

In summary the framework developed during this study and described in this report is a useful tool for estimating GHG emissions for house fires for NZ and the potential impact of changes in fire suppression strategies.

Figures

Tables

Glossary

BUI	=	Build-up index
CliFlo	=	National Climate Database
EF	=	Emission Factor
FFMC	=	Fine fuel Moisture Code
FWI	=	Fire Weather Index
FWSYS	=	New Zealand Fire Weather Monitoring System
GHG	=	Greenhouse Gas
GWP	=	Global Warming Potential
HCS	=	House Condition Survey
ISI	=	Initial spread Index
IPCC	=	Inter-Governmental Panel on Climate Change
km	=	Kilometre
kg	=	Kilogram
LCA	=	Life Cycle Assessment
LCDB2	=	Land Cover Database Version 2
NIWA	=	National Institute for Water and Atmospheric Research
NZFSC	=	New Zealand Fire Service Commission
NZFS	=	New Zealand Fire Service
NRFA	=	National Rural Fire Authority
PERT	=	Programme Evaluation and Review Technique
t	=	Tonnes

1 Introduction

This study has been conducted for The New Zealand Fire Service Commission (NZFSC), to enable the New Zealand Fire Service (NZFS) to assess the most efficient use of resources through comparison of emissions from fires, with and without suppression action. This report is combined with the report by BRANZ on green house gas (GHG) emissions from house fires in New Zealand, to create a final report that encompasses both vegetation and house fire emissions. This report is also accompanied by a Microsoft Excel-based tool which calculates the emissions from specific vegetation fire incidents.

1.1 Research Objectives

The overall objectives of the research project are to:

1. develop a methodology for the calculation of GHG emissions from vegetation and house fires, and the impact that the NZFS actions have on the emissions from these fires;
2. create an Excel-based tool that the NZFS can use to estimate the GHG emissions from vegetation and house fires, and the impact that their actions had on the GHG emissions;
3. provide a transparent and useful way of calculating ongoing GHG emissions from fires, and the impact that the NZFS has on these emissions;
4. enable NZFS to assess the most efficient use of resources, through comparison of emissions from fires, with and without suppression action; and
5. provide a tool with which NZFS can easily estimate and report on GHG emissions from fire incidents.

1.2 Research Scope

The focus of this study is to develop and demonstrate a methodology to incorporate the impact of GHGs into a cost effectiveness analysis when considering two selected cases of fires: vegetation fires and house fires.

Data and information for estimating parameter values were collected where possible. The impact of voids is discussed and recommendations for future work to improve the confidence in estimated values are included.

1.3 General Research Approach

This research project was divided into two sections: vegetation fires and house fires.

The approach taken to achieve the objectives for the impact of GHG emissions from house and vegetation fires was to:

- review available literature;
- develop a methodology;
- collate data for each of the demonstration cases;
- use the methodology to make an Excel-based tool, and analyse the results; and
- summarise and report the results of the research.

2 Vegetation Fire Emissions Tool

2.1 Literature Review

2.1.1 Overview

An extensive literature review was conducted covering: methods for GHG accounting for forest fires, calculation of emission factors, vegetation classes in New Zealand, types of fire, seasonal and climatic influences, soil carbon, emissions from suppression action and fire behaviour. The methods used in the vegetation fire emissions tool (described in section 2.2 below) are based on the outcomes from this research. More detail is covered in the report, Literature Review – Assessing the impact of vegetation and house fires on Greenhouse Gas emissions (Love & Jaques, 2009).

2.2 Approach

2.2.1 Methodology overview

The methodology for construction of a vegetation fire emissions calculation tool has been described in detail in the methodology report (Love & Jaques, 2009a). The basic calculation equations are based on modified Intergovernmental Panel on Climate Change (IPCC) equations, which take into account extra factors for vegetation classes, seasonality and others.

The variables used in the tool include:

- fire area (area burned);
- vegetation classes (New Zealand relevant);
- seasonal variables (time of year);
- regional variables (region in which fire occurs);
- other influences on burning efficiency;
- number and type of fire appliances in attendance;
- distance from fire station to incident location;
- hours spent fighting the fire; and
- hourly emissions from aerial firefighting units.

These variables affect the parameters in the main equations, as the most important of which is the fuel load. The total emissions for a fire incident are calculated by combining the total fuel load burned with emission factors (EFs) - see 'Vegetation Fire Emissions Calculations' for further information.

In addition, the potential emissions from the fire can be estimated in scenarios where suppression activities were not undertaken, at a range of time periods after the fire begins. Where data gaps exist, default variables are used - calculations for this part of the tool are based on previous Scion work for the NZFSC - the NZ Fire Behaviour Toolkit. (Scion, 2008)

2.2.2 General Approach

This tool has been developed in Microsoft Excel and is designed to be user-friendly and simple, while providing an estimate of greenhouse gas emissions from vegetation fires and suppression activities. In addition, a component has been included for estimating the potential emissions if suppression activities have not been undertaken.

The tool accepts user input variables that will affect the GHG emissions from the fire. For parameters where user-input data is unavailable, default values are available. Conversely, in an instance that a user knows exact fuel load, fine fuel moisture code or build-up index, these can be entered manually.

GHG emissions are reported in tonnes of CO_2 equivalents, a commonly-accepted unit to measure a potential impact on global warming. The global warming potential (GWP)can be calculated with respect to a number of time horizons, the most commonly used time horizon is 100 Years (GWP_{100}). GWP_{100} is a relative scale which compares the gas in question to that of the same mass of CO_2. CO_2 has a GWP_{100} of exactly 1 (since it is the baseline unit to which all other greenhouse gases are compared). Other important gases are methane (CH_4), with a GWP_{100} of 25, and nitrous oxide (N_2O), with a GWP_{100} of 298. (IPCC, 2007). These are the two gases that have been the focus of this report and tool, as a suitable amount of literature exists on emissions from vegetation fires for these gases.

Another important emission from fires is that of nitrogen oxides (NO_x). While the emission of NO_x is widely reported and even relatively well quantified, the impact on global warming remains very uncertain. The most recent IPCC report mentioning nitrogen oxides states that:

"*The short lifetime and complex nonlinear chemistry, which cause two opposing indirect effects through ozone enhancements and CH_4 reductions, make calculations of GWP for NO_x emissions very uncertain…Due to the lack of agreement even on the sign of the global mean GWP for NO_x among the different studies and the omission of the nitrate aerosol effect, a central estimate for the 100-year GWP for NO_x is not presented."(IPCC, 2007)*

For this reason, NO_x has been included as an emission from vegetation fires, but has been assigned a GWP value of zero. In the event that a consensus is reached on the global warming effect of NO_x, a value can easily be added into the tool at a later date.

2.2.3 Vegetation Fire Emissions Calculations

The general method of calculating vegetation emissions was to find a fuel load for a specific vegetation type, multiply this by the area burned, and then use EFs to find the total GHG emissions for the fire incident.

A range of vegetation classes were chosen for use in the emissions tool, and these were based on the Land Cover Database Version 2 (LCDB2) vegetation classes. The LCDB2 is effectively a digital map of the country, which groups different classes of land cover as they are identified from satellite imagery (MfE, 2010). Classes that were not applicable to fire incidents (such as built up areas, rivers and lakes) were excluded from the tool. The vegetation classes used in this project are shown in Table 1.

Table 1: Vegetation classes used in this project

Vegetation Classes				
Native Forest	**Exotic Forest**	**Scrub**	**Grass**	**Other**
Unknown	Unknown	Unknown	Unknown	Unknown
Indigenous Forest	Pine Forest - Open Canopy	Flaxland	High Producing Exotic Grassland	Minor Shelterbelts
Broadleaved Indigenous Hardwoods	Pine Forest - Closed Canopy	Bracken Fern	Low Producing Grassland	Major Shelterbelts
	Other Exotic Forest	Gorse	Tall Tussock Grassland	Afforestation (not imaged)
	Deciduous Hardwoods	Broom	Depleted Tussock Grassland	Afforestation (imaged, post LCDB 1)
		Manuka and or Kanuka	Alpine Grass / Herbfield	Forest - Harvested
		Matagouri	Urban Parkland / Open Space	Short-rotation Cropland - Grain
		Sub Alpine Shrubland		Short-rotation Cropland - Green
		Mixed Exotic Shrubland		Vineyard
		Grey Scrub		Orchard and Other Perennial Crops
				Freshwater Sedgeland / Rushland
				Saltmarsh
				Mangrove
				Dump

The classes are broken down into 5 main categories: Native Forest, Exotic Forest, Scrub, Grass, and Other. Within each main category, there are a range of sub-categories, including the sub-category 'unknown'. This sub-category is an average of the other sub-categories within that category. Thee inclusion of the 'unknown' category allows a user to use the emissions calculation tool even if very little is known about the exact vegetation types involved in the fire.

Where emissions are compared for a fire with and without the effects of fire suppression, fire danger ratings from the Fire Weather Index (FWI) System are required to determine fire characteristics and size. The Initial Spread Index (ISI) component is used to estimate fire rate of spread which, together with fire duration and spread distance, determines the fire area. The ISI is calculated from the Fine Fuel Moisture Code (FFMC) and wind speed (km/h). Forest fuel types also require the Buildup Index (BUI) value to estimate rate of spread, as well as the fuel load available for consumption.

The BUI is defined as "A relative measure of the cumulative effect of daily drying factors and precipitation on fuels with a ten-day time lag", which means that it is a value that takes into account periods of dry weather.[1] The FFMC is a code which conveys "The probable moisture content of fast-drying fuels which have a timelag constant of 1 hour or less; such as, grass, leaves, ferns, tree moss, pine needles, and small twigs (0- 6mm)".[2]

[1] http://www.nwcg.gov/pms/pubs/glossary/b.htm
[2] http://www.nwcg.gov/pms/pubs/glossary/f.htm

Where the FWI System values for a particular fire are unknown, the values required (for FFMC and BUI) are approximated from monthly averages for the region of the country in which the fire occurs. These monthly averages were obtained by averaging the individual monthly averages for the weather stations within each region contained in the fire climatology summaries of Pearce et al. (2003). Due to the statistical distribution of the underlying values, regional monthly average FFMC values were obtained by taking the mean of the monthly median values, whereas average BUI values are the mean of the mean BUI values for each month at each station. The regions used are shown in Table 2.

Table 2: Regions in the emissions tool

Regions in the Emissions Tool
Northland
Auckland
Waikato
Central North Island
Eastern
Taranaki
Wanganui/Manawatu
Wairarapa
Wellington
North Island Average
Nelson
Marlborough
West Coast
Canterbury
South Canterbury
Otago
Southland
South Island Average
National Average

The underlying fire weather data for the Pearce et al. (2003) analyses were in turn obtained from the network of fire weather stations archived by the National Rural Fire Authority (FWSYS), complemented by several NIWA/MetService stations from within the National Climate Database (CliFlo).

Once the vegetation type, FFMC and BUI (and therefore fuel load per hectare) are entered (either directly or using historical data), they can be combined with the total area burned to give a total fuel load. For specific fire incidents, the area burned is entered into the tool as a direct input. Extrapolation of fire area from other data (such as combining wind speed with fire duration) results in an area with high uncertainty. Therefore areas calculated this way are used only for theoretical fire spread predictions.

Emissions of each gas type have been quantified using suitable EFs. These EFs are given in tonnes of gas emitted per tonne of dry fuel burned. Combining these EFs with a total amount of fuel burned gives the total emissions of a fire incident (excluding suppression actions). The EFs are shown below in Table 3.

Table 3: EFs used in this project, from Battye & Battye, 2002.

Vegetation Emission Factors (t gas / t dry fuel)			
	CO_2	CH_4	NO_x
Native Forest	1.521	0.0068	0.0025
Exotic Forest			0.0025
Scrub			0.0065
Grass			0.0035
Other			0.00375

Due to the difficulty in obtaining very specific information such as combustion efficiency of each vegetation type, these average figures have been used. This simplifies inputs to the calculator without unduly compromising the accuracy. More explanation is given in the chapter entitled 'Important Assumptions and Uncertainty Implications'.

2.2.4 Suppression Fire Emissions Calculations

Emissions from vehicles are also calculated using suitable emission factors (EF). Emissions from ancillary items such as foam and extinguishers are excluded, as information on the use and emissions of these items is difficult to source at this time. Emissions from capital goods (such as the production of firefighting equipment) have been excluded because this is commercially sensitive information and production of capital goods is likely to emit negligible quantities of GHGs compared with their use phase. Impacts from the running of fire stations (such as from electricity) are also excluded , as these cannot be allocated to individual fire incidents.

Emissions from vehicles can be taken into account in two ways. If the total fuel use is known, this figure can me multiplied by an EF, as described later in this chapter. For smaller incidents, where fuel use is unlikely to be known, fuel consumption figures can be combined with distances. For fuel consumption figures, European data (GaBi 4.3) for trucks were used. This source was used due to the difficulty of breaking down aggregated New Zealand figures, as well as the variation in specific vehicle makes and models. A generic model for each vehicle type allows a realistic estimation of fuel consumption to be made. The vehicle types were chosen after communication with the NZFS, and are shown below in Table 4.[3] Urban trucks are designed to be a model of the large appliances used in towns and cities, while rural trucks and tankers are designed to be models of the more common appliance types in rural centres. Support vehicles were designed to represent smaller vehicles such as utility vehicles ('utes') and sport utility vehicles.

The fuel use models were based on average transit speeds of 70 km/h, approximating a combination of urban and rural driving. This was combined with the distance from the nearest fire station (which is doubled to account for the return journey) to calculate a total fuel consumption figure for the journey from fire station to fire incident (and back).

The generic GaBi models gave fuel consumption for transit; however for the actual firefighting actions (where the trucks may be stationary or moving very slowly), different consumption factors are used to estimate fuel used per hour (as opposed to per kilometre travelled). These consumption figures are difficult to estimate, as some trucks have separate water pumps, pumps may not be running all the time, and some trucks may have no pumps at all. The 'stationary fuel consumption' estimate for the trucks is based on a pump being driven from the truck's engine, and the engine running at the same rate as driving normally. This also is applied to the support vehicles; while they do not have pumps, they are likely to still be using their engines. These fuel consumption figures are given in litres per hour (Table 4).

[3] Personal communication with John Allardyce, October 2009

Table 4: Vehicle fuel consumption figures used in this project

Vehicle Fuel Consumption		
	Transit (L/km)	**Stationary (L/hour)**
Urban Fire Truck (<25 tonnes)	0.54	37.81
Rural Fire Truck (<6 tonnes)	0.24	17.01
Tanker Truck (<25 tonnes)	0.37	25.98
Diesel Support Vehicle	0.08	5.60
Petrol Support Vehicle	0.08	5.60

Once all fuel consumption figures have been calculated, they are multiplied by an EF. These EFs are taken from the publication 'NZ Fuel and Electricity Life Cycle Emission Factors Total Primary Energy Use, Carbon Dioxide and GHG Emissions based on Life Cycle Assessment (LCA)' (Barber, 2009). Because they are based on LCA, the data are New Zealand-specific, and account for all upstream emissions such as the extraction of oil. The EFs are shown below in Table 5.

Table 5: Vehicle EFs used in this project (**Barber, 2009)**

Vehicle Emission Factors	
	EF (kg CO_2 equivalents per litre of fuel consumed)
Diesel	3.108
Petrol	2.735
Aviation Gasoline	2.608

Emissions from helicopter and fixed wing aircraft support are included in the tool. The fuel consumption figures are based on information from the NRFA (NRFA, 2009). The NRFA information included a list of all types of aircraft used in fire suppression applications, their fuel use per hour, and fuel type. Fuel use ranged from 105 to 900 litres per hour for helicopters, and 37 to 180 litres per hour for fixed wing aircraft. Average fuel use figures are 308 and 83 litres per hour for helicopters and aircraft, respectively.

The Barber (2009) figures for aviation gasoline match well with international data on emissions from aviation gasoline and kerosene, and so this figure has been used for both fuel types, to aid in simplification of the tool. The US Energy Information Administration report an EF of 2.58 kg of CO_2 per kg of kerosene burnt.[4] It should be noted that this is a figure for carbon dioxide only, and does not appear to include other greenhouse gases.

2.3 Using the Vegetation Fire Emissions Calculation Tool

2.3.1 Vegetation

In the vegetation section of the inputs worksheet, a user can select, from a drop-down list, the vegetation class that corresponds with the fire incident being investigated. The 'simple' vegetation class is required, and the 'detailed' class is optional. If this more detailed class is not known, a user can select 'unknown'.

These vegetation classes allow assignation of fuel load, rate of spread and other calculations. Alternatively, if a fuel load per hectare is known, it can be entered into the tool manually, which overrides calculated fuel loads. This allows theoretical fuel loads to be tested, and calculation of emissions from any type of fire incident that is not in the vegetation classes provided.

[4] http://www.eia.doe.gov/oiaf/1605/coefficients.html

Also included in the 'vegetation' input section is the 'area burned' field. This must be entered, as it (in combination with the fuel load) provides a total amount of fuel burned, which is then tied to EFs to calculate the total emissions from the fire incident. An image of these inputs is shown in Figure 1.

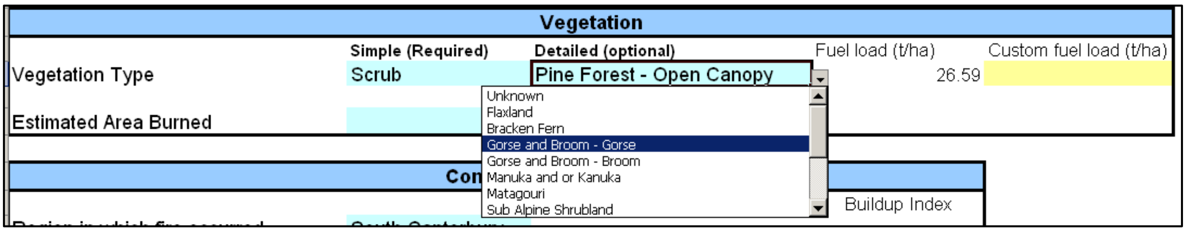


Figure 1: Vegetation inputs in the emissions tool, showing the drop down box to select detailed vegetation type

2.3.2 Conditions

This section of the inputs worksheet contains three input fields:

- Region in which fire occurred
- Month in which fire occurred
- Wind speed (best estimate)

The region in which the fire occurred can be selected from a drop-down list. Additionally, the month in which the fire occurred can be selected. When these two parameters are chosen, the average BUI and FFMC for that region at that time of year will be displayed.

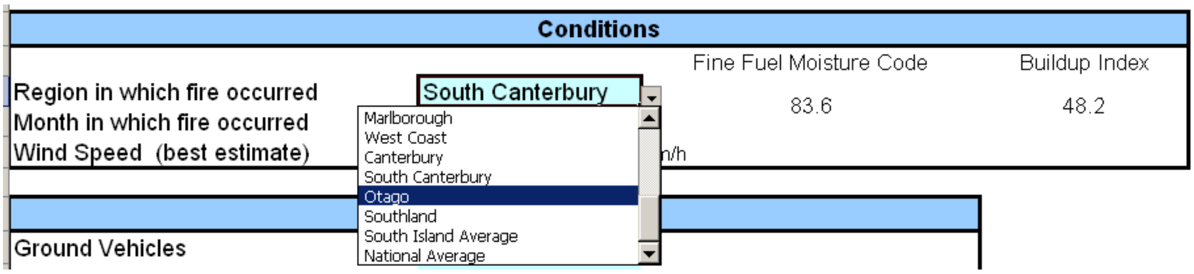


Figure 2: Inputs for conditions in the emissions tool, showing the drop down box to select the region

The wind speed affects the rate of spread, and so affects the total area burned in a worst-case scenario. This must be entered manually; even a rough estimation will provide useful results. All of these inputs can be seen in Figure 2 above.

2.3.3 Suppression Action – Single Fire Incident

Suppression data is able to be entered into one of two categories – 'single fire incident' or 'multiple fire incidents'. This section describes the inputs into the tool when analysing a single fire incident. To estimate emissions from ground vehicles in attendance, the following inputs are offered:

- Number of urban fire trucks in attendance
- Number of rural fire trucks in attendance (<6 tonnes)
- Number of tanker trucks in attendance (<25 tonnes)
- Number of diesel support vehicles in attendance
- Number of petrol support vehicles in attendance
- Distance travelled to fire incident
- Hours spent fighting fire

These inputs are designed to cover most vehicles attending fire incidents, and give a good estimation of the emissions. The 'distance travelled to fire incident' input is important for estimating transit emissions, and the 'hours spent fighting fire' input is important for estimating stationary/slow moving emissions. These inputs, as seen in the tool, can be seen below in the example shown in Figure 3.

Suppression Action			
NB: Enter data into EITHER 'single fire incident' OR 'multiple fire incidents', and leave other blank.			
Single Fire Incident			
Ground Vehicles	Number of Vehicles	Distance Travelled to Fire Incident (one way, approx)	
Urban Fire Trucks (large trucks)			km
Rural Fire Trucks (<6 t)	2	20	km
Tanker Trucks (< 25 t)	1	20	km
Support Vehicles (diesel)			km
Support Vehicles (petrol)	1	30	km
Hours Spent Fighting Fire (approx)	9		
Air Vehicles	Aircraft	Flying Time	
Helicopter type 1	Bell 206	5	hours
Helicopter type 2	AS 350 B3 Squirrel	5	hours
Fixed-wing aircraft type 1	PAC Fletcher	3	hours
Fixed-wing aircraft type 2	Average		hours
Multiple Fire Incidents	(ensure cells below are blank if calculating emissions for a single fire incident)		
Total diesel use		litres	
Total petrol use		litres	
Total helicopter flying time (to nearest hour)		hours	
Total fixed-wing flying time (to nearest hour)		hours	

Figure 3: Inputs (with examples) for suppression action in the emissions tool

For air vehicles, the user can select the type of aircraft (or select 'average' within the helicopter or fixed wing categories if the exact type is unknown), as well as the total flying time. This allows a total emission figure for air vehicles to be calculated. The input fields can be seen in Figure 3.

2.3.4 Suppression Action – Multiple Fire Incidents

For multiple fire incidents, simpler inputs are used. This provides less specific detail (for example specific vehicle type) but allows for calculation of total emissions from large groups of fires in a simple manner. Total fuel use for diesel and petrol vehicles can be entered, as well as total flying time for helicopter and fixed wing aircraft.

2.3.5 Extra Parameters (Optional)

A range of optional parameters can be entered into the tool, for use in situations where good information is available on the fire and the geography of the area (Figure 4).

The Initial Spread Index (ISI), as well as the FFMC and BUI, can be entered into the tool manually, if the data is available from other sources. This may be useful for calculating emissions for historical fires.

In addition, a value for 'Potential area burned in worst-case scenario' can be entered. This is useful for situations where the fire is constrained by natural features, such as rivers or urban areas. If this field is left blank, it is assumed that the fire burns unhindered for 8 hours. This is described in more detail in 'Important Assumptions and Uncertainty Implications'.

Extra Parameters (Optional - enter if known)		
Potential area burned in worst-case scenario		ha
BUI (Buildup Index)		
FFMC (Fine Fuel Moisture Code)		
ISI (Initial spread index)		

Figure 4: Optional parameters in the emissions tool

2.3.6 Inputs Sheet

The inputs sheet in its entirety is shown below, as seen in the tool (Figure 5).

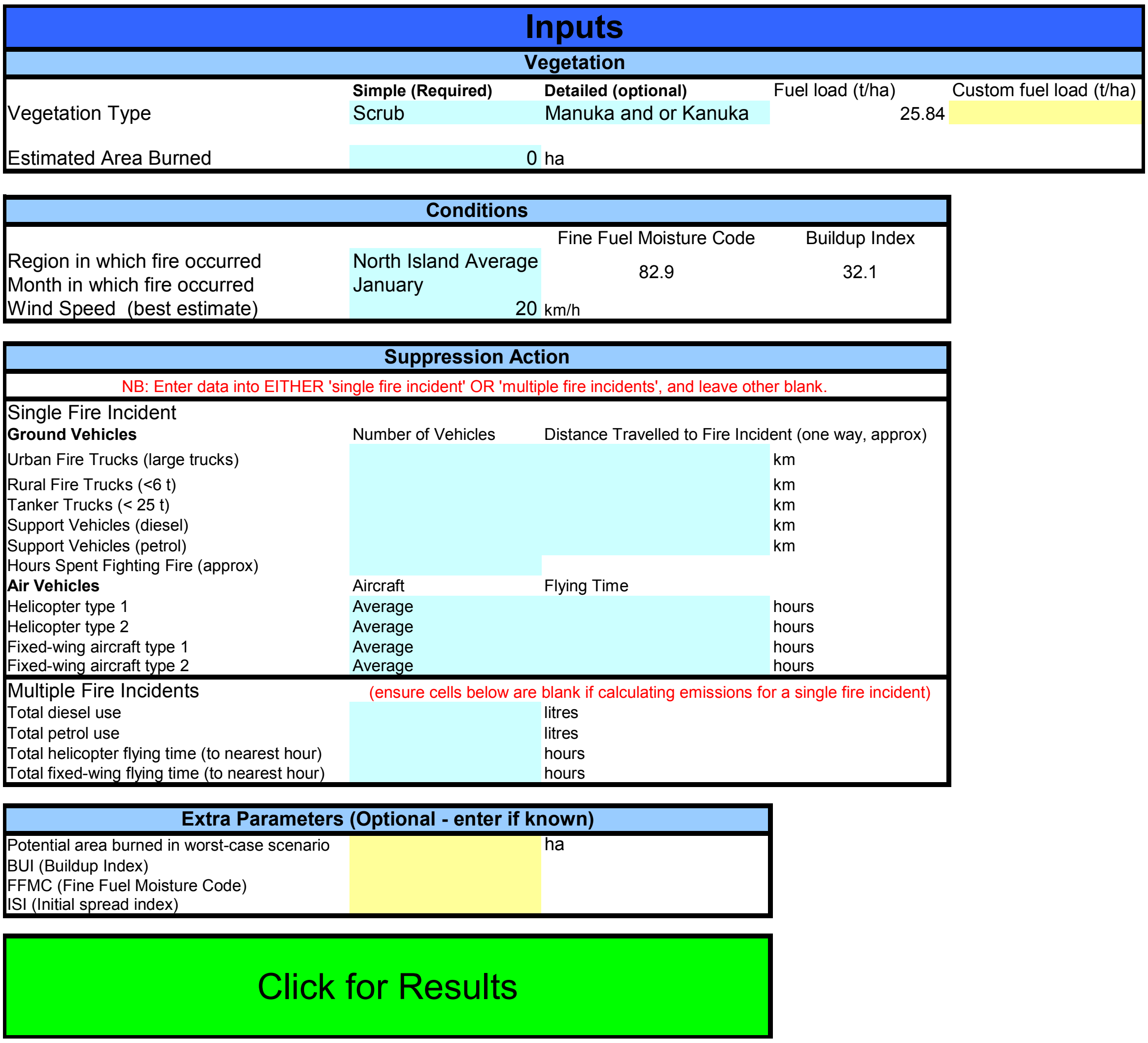


Figure 5: All inputs to the emissions tool

2.3.7 Results – Total

The emissions tool displays all of the results on one worksheet. The parameters entered into the input fields are tied to background data provided within the tool to produce the results.

The results available from the emissions tool are:

- the actual emissions from the vegetation fire incident;
- the emissions from the suppression action:
  - emissions from ground suppression actions;
  - emissions from air suppression actions; and
  - total emissions from suppression actions.
- theoretical emissions from the vegetation fire incident:
  - after 1, 3, 6 and 8 hours; and
  - worst-case scenario (8 hour fire duration, or until maximum potential area is burned, whichever is lower).

An example of the summary box on the results sheet of the tool can be seen in Figure 6 below.

Actual Vegetation Fire Emissions		
Total emissions from vegetation fire	874	t CO_2 equivalents
Total emissions from suppression actions	6	
Total emissions	880	
Potential Emissions (Worst-Case Scenario, no suppression)	13,110	

Figure 6: Example of results summary in the emissions tool

2.3.8 Actual Emissions from Vegetation Fire

The emissions from the vegetation fire are calculated based on the estimate of the total area burned, combined with the fuel load per hectare. The fuel load may also be affected by the BUI and FFMC, if applicable. This figure is the emissions from the fire only, that is, it excludes suppression action emissions.

2.3.9 Emissions from Suppression Action

The emissions from the suppression action, both ground and air, are totalled in the summary box. This figure shows the total emissions, in tonnes of CO_2 equivalents and excludes any emissions from the fire itself. At the bottom of the 'results' worksheet, the suppression emissions are split into those from ground suppression actions and those from air suppression actions (Figure 7).

Emissions from Suppression Actions		
Emissions from ground suppression actions	1.94	t CO_2 equivalents
Emissions from air suppression actions	4.43	
Total emissions from suppression actions	6.37	

Figure 7: Example of suppression action results in the emissions tool

2.3.10 Total Emissons

This figure is a total of the 'actual emissions from the vegetation fire' plus the 'emissions from suppression action'. It represents all greenhouse gas emissions relating to the fire incident.

2.3.11 Theoretical Emissions from Vegetation Fire

Theoretical emissions from other scenarios are presented in a range of ways. Underneath the 'total emissions', the potential emissions from a worst-case scenario are shown. As mentioned above, the worst case scenario is a fire which is assumed to burn for 8 hours, unhindered, with no change in conditions. If the fire is constrained by features such as rivers or urban areas, the worst-case scenario may be a smaller area burned – this parameter will have been defined in the 'inputs' sheet.

Also given on the 'results' worksheet is an indication of the progress of the fire up until the worst-case scenario. Areas burned and total fire emissions are given for a fire, as described in the 'inputs' sheet, burning for 1, 3, 6 and 8 hours (Figure 8). It can be seen that the emissions are constant between 6 and 8 hours – this is due to a 'maximum area burned' being specified on the inputs sheet. As a result, the fire was constrained by natural features, and therefore could not spread any further.

Potential Vegetation Fire Impacts				
	Emissions		Area Burned	
After 1 hour	829	t CO_2 equivalents	19.0	ha
After 3 hours	7,459		170.7	
After 6 hours	13,110		300.0	
After 8 hours	13,110		300.0	

Figure 8: Example of potential impacts in the emissions tool.

2.3.12 Results Sheet

The results sheet in its entirety is shown in Figure 9 on the following page.

Results

Actual Vegetation Fire Emissions		
Total emissions from vegetation fire	**874**	t CO_2 equivalents
Total emissions from suppression actions	**6**	
Total emissions	**880**	
Potential Emissions (Worst-Case Scenario, no suppression)	**13,110**	

Potential Vegetation Fire Impacts				
	Emissions		Area Burned	
After 1 hour	829	t CO_2 equivalents	19.0	ha
After 3 hours	7,459		170.7	
After 6 hours	13,110		300.0	
After 8 hours	13,110		300.0	

Emissions from Suppression Actions		
Emissions from ground suppression actions	1.94	t CO_2 equivalents
Emissions from air suppression actions	4.43	
Total emissions from suppression actions	6.37	

New Calculation

Figure 9: Results page from the emissions tool with example results

2.4 Important Assumptions and Uncertainty Implications

The vegetation emissions tool is based on a number of assumptions, generally for the reason of simplification. With too many variables, results can become meaningless. In this section, each important assumption is explained and justified, and implications on the uncertainty of results noted.

2.4.1 Fuel Consumption and Combustion Efficiency for Vegetation Fires

In this project, emission factors are used to calculate the GHG emissions, as mentioned in section 2.2. These factors take into account the average combustion efficiency. This can vary significantly for different fire types. For example, the average CO_2 emission factor is 1.521 tonnes of CO_2 per tonne of fuel consumed. This is a combination of flaming and smouldering stages, which have emission factors of 1.650 and 1.393 tonnes of CO_2 per tonne of fuel consumed, respectively. This variation is present across all of the gases examined in this project. Table 6 shows the different emission factors for different fire stages, as well as standard deviations. (Battye & Battye, 2002)

Table 6: Emission factors and standard deviations – flaming stage, smouldering stage and overall. Given in kg/tonne for clarity. (Battye & Battye, 2002)

Emission Factors for Different Fire Stages (kg/ tonne)			
Gas	**Flaming**	**Smouldering**	**Overall**
CO_2	1,650	1,393	1,521 ± 5
CH_4	3.8	9.9	6.8
NO_x (forest fuels)	3.1 ± 1.2	1.1 ± 1.3	2.5 ± 0.12
NO_x (grasses)			3.5 ± 0.90
NO_x (scrub)		3.0	6.5 ± 2.7
NO_x (overall)			3.1 ± 2.0

The implications on uncertainty are that the potential variation is relatively high in the emission figures from the emissions tool. In saying this, without constant monitoring of wildfires (which would be impossible), the amount of flaming and smouldering cannot be known for each fire incident, so the overall figure is a best estimate of fire emissions.

2.4.2 Burn Time

A ‘worst-case scenario’ has been included in the emissions tool. In this scenario, a fire burns unhindered for 8 hours before dying out. The figure of 8 hours was chosen after personal communication with the Scion fire team, as a realistic burn time for a vegetation fire. The progress of a wildfire is potentially the most uncertain part of this project, as it will depend strongly on terrain factors, wind speed, fuel types and weather. Terrain is unable to be included in the tool as it is very much fire-specific. The other variables mentioned are included; however a wildfire burning for 8 hours will not necessarily remain burning on one vegetation type, and the wind speed may vary. For this reason, the ‘worst-case scenario’ remains a theoretical scenario using the best available information.

2.4.3 Global Warming Potential

A major component of the gaseous emissions from vegetation fire is NO_x. The GWP for NO_x is not stated by the IPCC, for reasons that the uncertainty of a figure would be too great (IPCC, 2007). For this reason, it has been omitted from the calculations. Though this results in a level of uncertainty, it is still in line with current IPCC guidelines, and inclusion of an EF for NO_x would not improve accuracy of the tool. If a consensus is reached on NO_x global warming potential, the value can be added into the emissions tool with little effort required.

2.4.4 Emission Factors for Vehicles

The EFs used in this project for ground vehicles are based on New Zealand-specific factors that include upstream processes. These EFs are based on LCA principles, and therefore give a robust figure for not only the combustion of the fuel, but also the extraction and transport. No New Zealand-specific figure was found for kerosene; an EF for aviation gasoline was used instead. Though the emission factor appeared very similar to international kerosene values, it should be noted that helicopters have a much higher fuel use figure than ground vehicles, and therefore the kerosene EF has a larger bearing on final suppression emissions than the other EFs used (for incidents where a helicopter is present).

2.5 Results and Discussion

The fire emissions tool has been created with the goals of having a simple, convenient and user-friendly tool that can give accurate estimations of the GHG emissions from vegetation fires. The tool was also designed to allow estimates of emissions from fires with and without suppression actions. Where possible, New Zealand data has been used.

A wide range of NZ-specific vegetation categories have been included, and robust data for all of these categories has been sourced from Scion's fire scientists. The five main categories included are:

- native forest;
- exotic forest;
- scrub;
- grass; and
- other.

Within each of these categories is a range of sub-categories, to accurately define the type of vegetation involved in the fire. Once a category has been chosen, weather and climatic influences are included using historical NZ data. A user can choose the region and month of the fire, and a wind speed. All of this information is combined to automatically calculate total emissions. Potential emissions can also be estimated by assuming an unhindered burn for up to 8 hours.

Emissions from suppression actions are included through using vehicle types based on information directly from the NZFS. These vehicle types are tied to robust international data for fuel use, and New Zealand fuel emission factors. Emissions from air vehicles are included, again using NZ-specific emission factors and also data directly from the NRFA.

This tool provides the NZFS and NRFA with a way of calculating total emissions from fire incidents, which in turn allows more efficient use of resources.

2.6 Future Developments

The completed vegetation emissions tool should be beneficial for the NZFS, for calculation of both single and multiple fire incidents. From a longer-term perspective, the tool could be expanded to include other aspects such as economic parameters associated with fire suppression and fire damage. Other areas of interest include soil nitrogen and carbon, New Zealand-specific vegetation emission factors, and other impact categories such as acidification.

3 House Fire Emissions Tool

3.1 Literature Review

3.1.1 General

At the time this research was carried out, there was no published literature quantifying the impact of GHG emissions from house fires. Furthermore there was limited published literature concerning GHG emissions associated with house fires. Therefore residential fire related information that is useful in estimating the parameter values that effect GHG emissions has been collated here and the information gaps discussed.

Since the impact of GHG emissions associated with a house fire has not been previously quantified, the most influential parameters have not yet been identified. Therefore care is applied when making assumptions about what information is required and where information and data are not currently available.

3.1.2 Fire Statistics

The information available from house fire statistics does not relate directly to GHG emissions, therefore the assumptions associated with the use of this information in the developed methodology must be clearly documented. This will be done in the next stage of this project as the methodology is developed.

Statistical fire information that is available and may be of use includes:

- numbers of house fires;
- approximate percentage of flame damage to the structure (however the method of recording this is crude, and therefore this information needs to be used with caution);
- numbers of fire events where various fire suppression methods were utilised; and
- the most common rooms of fire origin.

The statistics used in the methodology are presented in the following sections discussing the relevant input parameter values.

3.1.3 House Structure and Contents

Typically, when considering house fire design, the impact of the materials is considered in terms of life safety or structural stability. Therefore, the material parameters influencing life safety and structure stability have the most information, since these have been the focus of previous work. The limits of the applicability of the typical parameters suggested for design fires to the issue of estimating the impact of green house gas emissions is not yet clear.

For example, an average Fire Load of approximately 500 MJ/m^2 (based on data collected in Switzerland) (Fire Engineering Design Guide 2008) is suggested to describe the typical contents of a home. An average value for soot yield and a selection of life safety related gas species (such as CO_2, CO and HCN) may also be estimated. However the parameters that strongly effect the emission of GHGs might be the types and amounts of materials involved and the temperatures reached during the fire. CO_2 yields might be estimated per unit mass of the averaged assumed representative fuel, but CH_4 and NO_x are of little interest when designing for life safety or structural stability.

Information on the types and amounts of materials typically available for burning in the structure and the contents of a house are needed to then estimate the impact. In the future CO_2, CH_4 and NO_x yields may be available for materials burning in incineration conditions, and this information would be useful to contribute to other sources of these yield values.

As an aside, it is important to note that the average values are generally single point values, with no associated distribution.

3.1.3.1 Typical House Contents

Little is published on the numbers of items and amounts of materials in a typical New Zealand home. However a Canadian survey of living room furniture was conducted specifically for use in the estimation of residential design fires (Bwalya 2004; Bwalya et al. 2004). A summary of the average number of each furniture item in a living room is presented in Table 7. The living room and basement were the focus of the survey based on the high numbers of fires starting in these two locations reported in the Canadian statistics. Estimates of the materials and masses composing each of the typical types of furniture were based on information collected from local furniture suppliers.

In fire related assessments, the materials used in typical NZ furniture have been compared to typical construction elsewhere (Enright et al. 2001; Chen 2001; Wade et al. 2003). New Zealand has had fewer restrictions on fire safety features (such as ignitability of fabrics and fire retardant treatments of foams) of upholstered furniture than other countries. The differences in fire safety features may be associated with lower fire loads, higher required ignition temperatures and differences in the species emitted when a fire does occur. Therefore care must be used when adopting estimates of furniture material composition from other countries.

Some parameters to consider that may influence the amount or types of materials present in a house may include:

- occupier type (e.g. owner occupier versus tenant);
- number of occupants (e.g. is a higher number of occupants associated with a larger amount of contents); and
- age of occupants (e.g. are older or younger occupants associated with a larger amount of contents or larger amounts of particularly types of contents)

Alternative ways of possibly collecting information in order to estimate needed parameters may include:

- a home occupier survey to count numbers of furniture items in NZ homes (similar to the Canadian lounge room study by Bwalya, 2004);
- a smaller targeted survey of the amounts of materials associated with each of the typical furniture items, to provide a distribution for the estimate the typical use within a residence (this would include dimensions and materials and masses for furniture items, amounts of materials on bookshelves, amounts of clothing, etc.); and
- collating information from NZ furniture manufacturers and importers on the numbers of items sold per year and distributions for the typical types and amounts of materials contained in the ranges of furniture in each category (e.g. similar to the numbers of furniture items summarised for the United Kingdom in National Statistics (2007) and the strategy used in the study by Bwalya (2004)).

As this study focuses on the demonstration of the methodology, detailed surveys to determine the contents of typical contents of a NZ house is beyond the scope of this study. Therefore a considered approach based on available information will be used in this investigation.

Table 7: Average numbers of items in a living room per household. (Adapted from Bwalya 2004.)

Item of Furniture	Number of items per household
Small Table (e.g. side table, phone stand, etc)	1.45
Upholstered chair (e.g. recliner, covered chair, etc)	1.1
TV	1.0
Sofa	0.92
Entertainment unit	0.78
Coffee table	0.77
Bookcase	0.77
Loveseat	0.55
Magazine rack	0.33
Ottoman	0.20
Desk	0.17
Computer	0.16
Futon	0.13

3.1.4 Fire Suppression

Reported house fire suppression in NZ currently is typically performed by the NZFS by applying water. Alternatives include home sprinkler systems and NZFS intervention where foam additives are used. However recorded fire events in homes with sprinkler systems and the use of foam additives during suppression activities are not statistically significant in NZ. Therefore to include the effect of alternatives to NZFS intervention using water-only suppression, the suppression effectiveness needs to be incorporated into house fire GHG emissions framework when such values become available.

The effectiveness of home sprinkler systems in a NZ context has been considered previously (Duncan et al. 2000; Robbins et al. 2008) and the values for suppression effectiveness used in these previous studies have been based on laboratory test results. The suppression effectiveness of water foam additives have also been tested in laboratory settings (Madrzykowski, 1998). The emissions from the added foams, as these come into contact with flames and hot and burning materials, must also be included in considerations.

3.1.5 Conclusions based on Review of Literature

No published literature quantifying the impact of GHG emissions from house fires currently exists. There is limited published literature concerning GHG emissions associated with house fires. Information that is useful in estimating the parameter values that affect GHG emissions has been collated here. There are many gaps in the available information. Some strategies for dealing with this lack of information have been outlined here. However, the lack of available data is not seen to halt the development of a methodology to quantitatively assess the impact of GHG emissions from fires and the demonstration example of house fires.

Since the impact of GHG emissions associated with a house fire has not been previously quantitatively studied, the most influential parameters have not yet been identified. Therefore care has been applied during this research when making assumptions about what information is required and where information and data are not currently available.

3.2 Approach

3.2.1 General

The methodology for developing a house fire GHG emissions calculation tool is described in this section. The tool uses the metric tonnes of CO_2 equivalent for GHG emissions, to provide consistency with the vegetation fires part of this research project and other GHG emission studies.

The variables used in the tool include:

- numbers of house fire incidents per year;
- areas of flame damage (or conversely areas saved);
- exemplar houses for common construction combinations and contents, identifying materials and quantities per unit of floor area;
- distributions of house floor area; and
- material GHG potential yields.

A full list of the framework input parameters are presented in Table 9 and the assumptions for the estimated values are discussed in Section 1.

The GHG emissions that were considered within this framework are only associated with those emitted during a house fire by the burning structure materials and contents items. GHG emissions associated with suppression activities or replacement of structure or contents was not included in this framework, since these aspects have been considered in previous studies (e.g. Robbins, Wade et al. (2008) or PriceWaterhouseCoopers (2008)) that may be used in conjunction with the results from this tool without the overlap of specific content.

To reduce the impact of specific assumptions, the framework is designed utilising an analysis period that can be specified by the user. This analysis period starts with the current year and then estimates the impact forward, for future years, up to the analysis period specified by the user. The results are then reported in terms of CO_2 equivalents per year.

It was expected that not all values for the input parameters would be available during the timeframe of this study. However the framework was intentionally developed to be inclusive. Therefore updated values can be added to the framework as they become available.

A few scenarios for different potential suppression methods were investigated and compared to provide comparison of the results based on the available data for tool input parameters. These are summarised in Section 3.2.3.1 and the results are presented in Section 3.4.

A sensitivity analysis was also performed to identify important parameters and assess the influence of estimated parameter values and distributions. The analysis is discussed in Section 3.2.3.2 and the results are presented following the results of the relevant Scenario.

3.2.2 Emissions Calculations & Metrics

To be in alignment with the vegetation fire part of this project as well as previous studies, such as the PriceWaterhouseCoopers study that calculated the total GHG emissions for the NZFS (PriceWaterhouseCoopers, 2008), the estimates for GHG emissions from house fires will also utilise the metric of CO_2 equivalents. This will allow indicative comparisons with the results from other studies. However, the numerical values will not be comparable because of the assumptions needed to be made for the input parameter values, as discussed in the following section.

CO_2 equivalent is the estimate of the quantity that describes the amount of carbon dioxide that would have the same the Global Warming Potential (GWP), when measured over a timescale of 100 years, for a mix of greenhouse gases (as described in section 2.2.1 of this report). Table 8 presents the Global Warming Potential of a selection of gases.

Table 8: Examples of Global Warming Potential of selected gases. (IPCC, 2007)

Gas	Carbon Dioxide (CO_2)	Methane (CH_4)	Nitrous Oxide (N_2O)
Global Warming Potential	1	25	298

GHG emissions from the production, transport, etc. (cradle to gate) of the materials involved with the replacement 'cost' of materials as installed in the house construction and contents are not included in this framework. These aspects have been included in the previous study for a home sprinkler system cost effectiveness analysis incorporating sustainability issues (Robbins, Wade et al. 2008). The framework developed here is intentionally designed not to incorporate aspects of this previous framework, thus the results from both of these studies can be combined without counting any contribution twice.

3.2.2.1 GHG Emission Potential of the Materials Involved

In terms of material-related GHG emissions of house fires, it was initially assumed likely that CO_2, CH_4 and NO_x yields would be available for materials burning in incineration conditions; however these values were unavailable within the timeframe required for this project. If these values become available in the future, some assumptions will have to be made in the use of incineration figures for a lower temperature house fire event.

Therefore it was expected that yields for CO_2, CH_4 and NO_x would not be available for all types of materials included in this demonstration of concept. Subsequently the framework developed and described here has the capacity to include these additional yields as more appropriate values become available.

Values for CO_2 yields were estimated from limited experimental results and handbook values, where available. With this limitation the GHG emissions estimates are limited to CO_2 yields for the majority of materials that will are included in this demonstration of concept. A summary of the species yield values used in this study are presented in Sections 3.3.4.9.1 and 3.3.5.

3.2.3 Emissions Calculation Tool

The tool developed to calculate CO_2 equivalency was implemented using Microsoft® Excel and Palisade Corp. @RISK. MS Excel was chosen because of the common usage of this product and therefore provides future proofing of the tool for revisions as more data becomes available. The @RISK software (a commercial MS Excel add-in) was chosen because it offers one approach to input parameters as distributions instead of single values. This software also facilitates a systematic way of performing a sensitivity analysis.

The output of the tool is an estimate of GHG emissions in metric tonnes of CO_2 equivalents. The results were presented in terms of CO_2 equivalents per year, per NZ household, and per fire for comparison.

GHG emissions were only considered in terms of gaseous species release. That is, the total amount of carbon was not used in the calculations, only the estimated yield of CO_2.

3.2.3.1 Scenarios

Scenarios were selected for consideration to provide a comparison for the results of the estimated GHG emissions using the framework described here. Because of the assumptions involved in the estimation of the parameters influencing GHG emissions made in this study, it is recommended that the results from this model be used to compare different scenarios instead of direct comparison with numerical results from other models.

The scenarios that were considered are:

1. total fire loss of an exemplar house structure;
2. total fire loss of an exemplar house contents;
3. house fires with fire suppression remaining the same as reflected in current fire incident statistics;
4. home fires where home sprinkler systems (according to NZS4517) are present with NZFS intervention using water (if needed)[5]; and
5. an increase in house fire losses to an equivalent percentage of floor area loss per fire of 50%.

Scenarios 1 and 2 provide baselines for the maximum GHG emissions per house fire.

3.2.3.2 Sensitivity Analysis

A sensitivity analysis was performed to identify the most influential parameters and the impact of distributions of the input parameters. The results of this analysis are presented in Section 3.4 for each Scenario.

3.3 Methodology

Since the type and amount of materials involved in the construction and contents of a New Zealand house vary so much throughout the current housing stock, the approach was taken to consider the impact as a nation over a specified number of years. This approach evens out the assumptions of the specific types and amounts of materials involved in each specific house fire to provide an indication of the magnitude of the overall impact.

The house fire GHG emissions framework input parameters are listed with a brief description in Table 9. A list of the house fire GHG emissions framework output variables is presented in Table 11 and the calculation methods employed are presented in Table 12.

Where input distributions were estimated, a Program Evaluation and Review Technique (PERT) distribution (identifying the best, maximum and minimum values to form a triangular distribution) was used, unless a more appropriate (such as a normal or uniform) distribution was identified.The framework was run for 10,000 iterations, using Latin Hypercube sampling with a random seed generator.

3.3.1 House Fire GHG Emissions Framework Input Parameters

The house fire GHG emissions framework input parameters are listed with a brief description in Table 9. The framework input parameters associated with the potential impact of home sprinkler systems (as considered in Scenario 4) are listed with a brief description in Table 10.

[5] This scenario assumes the mandatory installation of home sprinklers in every new house built and a rate of retrofit such that the current building stock has NZS4517 system in 10 years.

Table 9: List of house fire GHG emissions framework input parameters.

Name	Symbol	Brief Description
Initial number of house structure fires per year	F_0	The current number of house fires per year. The number of house fires each year is assumed to be proportional to the number of houses, $F_t = \frac{H_{t,all}}{H_{0,all}} F_0$
Floor area of house lost to fire	$A_{\%lost}$	The percentage of floor area lost to fire of the exemplar house.
Current number of households	$H_{0,all}$	The current number of houses. The number of houses is assumed to increase at a uniform rate, $H_t = H_{0,all} t r_{house}$
Increase in households per year	r_{house}	An estimate of the average percentage increase of the number of house per year over the chosen analysis period.
Discount rate	$r_{discount}$	Estimated discount rate. Similar as typically used for money. A value is not included in this study, but this parameter is included in the framework, so that if an effective value is recommended for the use of CO_2 equivalents then it can be utilised within this framework.
Inflation rate	$r_{inflation}$	Estimated inflation rate. Similar as typically used for money. A value is not included in this study, but this parameter is included in the framework, so that if at an effective value is recommended for the use of CO_2 equivalents then it can be utilised within this framework.
Analysis period	$Y_{analysis}$	Number of years considered for this analysis.
GWP of Species	G_{gas}	The GWP of the gas (gas), as listed in Table 8.
Species yield	$Y_{gas,x}$	Mass yield of a gas species (gas , e.g. CO_2, etc.) per unit of mass of fuel for each material or item (x).
Mass of house structural component	$m_{i,j}$	Estimated mass of each structural component (j) for each combination (i) of foundation, wall and roof cladding exemplar house. The structural components are listed in Table 18 and Table 19.
Number of house contents item	n_k	Estimated number of each item of house contents (k) in the exemplar house. The estimated numbers of items of house contents are listed in Table 21.
Mass of house contents item	m_k	Estimated mass of each contents item (k) for the exemplar house. The items of house contents and the associated estimated mass distribution are listed in Table 26 of Robbins, Page & Jaques (2010).
Proportion of material burnt	$p_{A\%lost,x}$	Estimated proportion of each material, proxy material, item or proxy item (x) burnt for a particular amount of house floorarea burnt ($A_{\%,lost}$).
Proportion of fires with specific proportion of floor area burnt	$p_{A\%lost,fires}$	Estimated proportion of fires with a particular amount of house floor area burnt ($A_{\%,lost}$).
Maximum number of gas species	gas_{max}	The maximum number for the counter used for the gas species (gas).
Maximum number of materials considered	j_{max}	The maximum number for the counter used for the materials, proxy materials, items or proxy items for structural components (j).
Maximum number of items considered	k_{max}	The maximum number for the counter used for the materials, proxy materials, items or proxy items for structural components (k).

Table 10: List of house fire GHG emissions framework input parameters associated with the scenario considering the potential impact of home sprinkler systems (Scenario 4).

Name	Symbol	Brief Description
Sprinkler effectiveness	η_{sprink}	A measure, based on statistics, for a sprinkler system to activate and control a fire according to the design of the system, assuming the fire is large enough to activate the sprinkler system.
Limit of flame damage for effective sprinkler system	L_{sprink}	An assumed percentage of the total structure to which an effective sprinkler system would control the fire from spreading beyond.
Initial number of sprinklered households	$H_{0,sprink}$	The current number of NZS4517 sprinklered households. The number of sprinklered houses each year is both retrofitted and new sprinkler systems, $H_{t,sprink} = r_{retrofit}\left(H_{t-1,all} - H_{t-1,sprink}\right) + p_{new\_sprink}\left(H_{t,all} - H_{t-1,all}\right)$
Proportion of new households sprinklered	$p_{new,sprink}$	The proportion of new households built with a NZS4517 fire sprinkler system.
Rate of retrofit of sprinkler in households	$r_{retrofit}$	An estimate of the average rate of retrofit of systems in households with no fire sprinkler system currently present.
Sprinkler system life	Y_{sprink}	Number of years for the design life of the sprinkler system.
Discount rate	$r_{discount}$	Estimated discount rate
Room of fire origin – distribution of fire incident	$p_{fire,ROO}$	Proportions of fire incidents according to statistics for room of fire origin.
Proportion of fire incidents covered by an NZS4517 system	$p_{fire,NZS4517}$	A proportion of the total incidents, to take into account that a NZS4517 system does not necessarily cover every room.

3.3.2 House Fire GHG Emissions Framework Output Variables

A list of the house fire GHG emissions framework output variables is presented in Table 11.

Table 11: List of house fire GHG emissions framework output variables.

Name	Symbol	Brief Description
GHG emissions from total loss of the structure of an exemplar house	$E_{exe\_struct,i}$	CO_2 equivalent release for the total loss of the structure of the exemplar house for each combination (i) of foundation, wall and roof cladding.
GHG emissions from total loss of the contents of an exemplar house	E_{exe_cont}	CO_2 equivalent release for the total loss of the contents of the exemplar house.
GHG emissions released by house fires	$E_{house,total}$	CO_2 equivalent release due to house fires. The results are presented in terms of three units: 1. Equivalent CO_2 per household per year 2. Equivalent CO_2 per fire per year 3. Equivalent CO_2 per year
GHG emissions saved from being released by house fires where home sprinkler systems are effective	S_{sprink}	CO_2 Equivalent saved from being released due to house fires by an effective home sprinkler system. The results are presented in terms of three units: 1. CO_2 equivalent per household per year 2. CO_2 equivalent per fire per year 3. CO_2 equivalent per year

3.3.3 House Fire GHG Emissions Framework Equations

The house fire GHG emissions framework calculation methods employed are presented in Table 12.

Table 12: List of house fire GHG emissions framework calculation methods.

Name	Calculation Method
GHG emissions from total loss of the structure of an exemplar house	$E_{exe\_struct,i} = \sum_{j=1}^{j_{\max}} \sum_{gas=1}^{gas_{\max}} \left(m_{i,j} p_{100\%,j} Y_{gas,j} G_{gas} \right) \quad [\mathrm{kg_{CO2}}]$
GHG emissions from total loss of the contents of an exemplar house	$E_{exe\_cont} = \sum_{k=1}^{k_{\max}} \sum_{gas=1}^{gas_{\max}} \left(n_k m_k p_{100\%,k} Y_{gas,k} G_{gas} \right) \quad [\mathrm{kg_{CO2}}]$
GHG emissions released by house fires	$E_{house,total} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{1}{H_{all,t}} \left(\frac{F_t \sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j} p_{A\%lost,j} p_{A\%lost,fires} Y_{gas,j} G_{gas} \right) \right)}{H_{all,t}} + F_t \sum_{k=1}^{k_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k p_{100\%lost,k} A_{\%lost} p_{A\%lost,fires} Y_{gas,k} G_{gas} \right) \right) \right) \quad [\mathrm{kg_{CO2}}/\mathrm{household/year}]$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\left(\frac{\sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j} p_{A\%lost,j} p_{A\%lost,fires} Y_{gas,j} G_{gas} \right) \right)}{H_{all,t}} + \sum_{k=1}^{k_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k p_{100\%lost,k} A_{\%lost} p_{A\%lost,fires} Y_{gas,k} G_{gas} \right) \right) \right) \quad [\mathrm{kg_{CO2}}/\mathrm{fire/year}]$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\left(\frac{F_t \sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j} p_{A\%lost,j} p_{A\%lost,fires} Y_{gas,j} G_{gas} \right) \right)}{H_{all,t}} + F_t \sum_{k=1}^{k_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k p_{100\%lost,k} A_{\%lost} p_{A\%lost,fires} Y_{gas,k} G_{gas} \right) \right) \right) \quad [\mathrm{kg_{CO2}}/\mathrm{year}]$

GHG emissions saved from being released by house fires where home sprinkler systems are effective	$S_{sprink,total} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\frac{1}{H_{all,t}} \left(\frac{F_t \sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j}\, p_{A\%lost,j}\, p_{A\%lost,fire} \left(\eta_{sprink} + p_{fire,NZS4517} - 1\right) Y_{gas,j} G_{gas} \right)\right)}{H_{all,t}} + F_t \sum_{k=1}^{k_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k p_{100\%,k} A_{\%lost,fires}\, p_{A\%lost,fires} \left(\eta_{sprink} + p_{fire,NZS4515} - 1\right) Y_{gas,k} G_{gas} \right)\right)\right)$ $[\mathrm{kg_{CO2}/household/year}]$ $= \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\left(\frac{\sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j}\, p_{A\%lost,j}\, p_{A\%lost,fire} \left(\eta_{sprink} + p_{fire,NZS4517} - 1\right) Y_{gas,j} G_{gas} \right)\right)}{H_{all,t}} + \sum_{k=1}^{k_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k p_{100\%,k} A_{\%lost,fires}\, p_{A\%lost,fires} \left(\eta_{sprink} + p_{fire,NZS4515} - 1\right) Y_{gas,k} G_{gas} \right)\right)\right)$ $[\mathrm{kg_{CO2}/fire/year}]$ $S_{sprink,total} = \frac{1}{Y_{analysis}} \sum_{t=1}^{Y_{analysis}} \left(\left(\frac{F_t \sum_{type=A}^{F} \left(H_{type,t} \sum_{j=1}^{j_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(m_{type,j}\, p_{A\%lost,j}\, p_{A\%lost,fire} \left(\eta_{sprink} + p_{fire,NZS4517} - 1\right) Y_{gas,j} G_{gas} \right)\right)}{H_{all,t}} + F_t \sum_{k=1}^{k_{\max}} \sum_{gas=1}^{gas_{\max}} \sum_{A\%lost=0}^{100\%} \left(n_k m_k p_{100\%,k} A_{\%lost,fires}\, p_{A\%lost,fires} \left(\eta_{sprink} + p_{fire,NZS4515} - 1\right) Y_{gas,k} G_{gas} \right)\right)\right)$ $[\mathrm{kg_{CO2}/year}]$

3.3.4 House Fire GHG Emission Framework Input Parameters

The background and subsequent choice of values used for the input parameters of the framework to estimate GHG emissions from house fires, as described in Table 9, are discussed here. The input parameter values involve the amount of materials burned which will be estimated from the number of fire incidents, the amount of flame damage, proportions of types of construction and the materials used in the current New Zealand building stock.

3.3.4.1 Number of House Fires per Year

The numbers of house fires with structure damage in New Zealand based on the past fire incident statistics, as made available by the New Zealand Fire Service via the Fire Incident Reporting System (Challands 2009), are summarised in Figure 10.

The number of house fires per year used as a model input parameter value is conservatively based on the statistics for incidents with structure damage (i.e. incidents without structure damage are not included in this estimate) and 1997 to 2008 data is used. This approach is assumed to be conservative because fire incidents without structure damage would involve the burning of home contents. Therefore the contribution of CO_2 equivalents of these incidents is not included, subsequently underestimating the amount of CO_2 equivalents released by NZ house fires.

The estimate of the number of fires for the first year considered was a best value of 1600 fires per year, maximum value of 1800 fires per year and minimum value of 1400 fires per year.

The number of fires per year for subsequent years was assumed to be proportional to the total number of houses that year. This assumes the fire initiating propensity of the occupants, contents and structure remain the same throughout the analysis period considered.

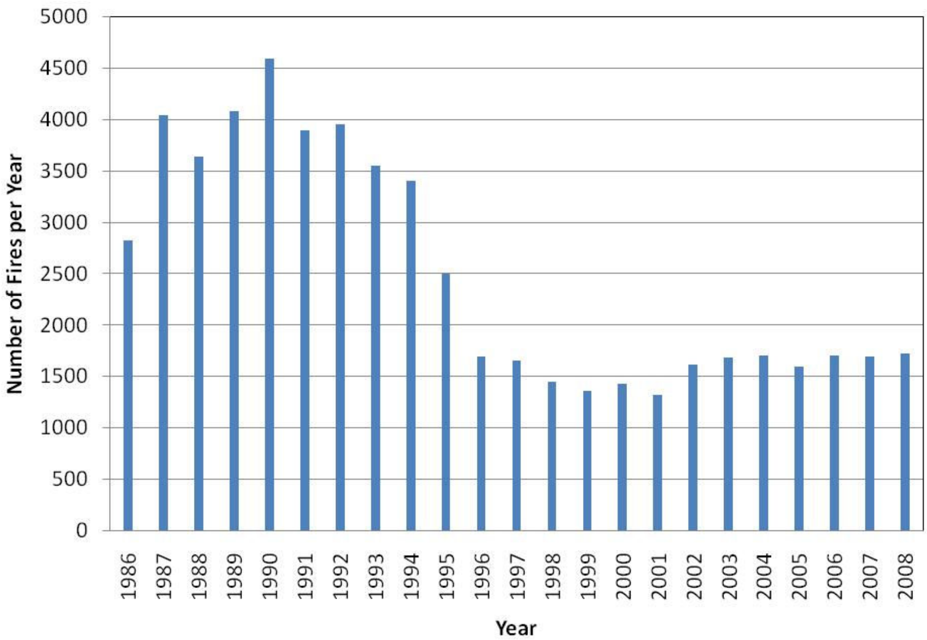


Figure 10: Number of house fire incidents with structure damage reported to the NZFS per year (1986 – 2009)

3.3.4.2 Analysis Period

The analysis period considered for this study was 50 years.

3.3.4.3 Discount Rate & Inflation Rate

Calculation of GHG emissions as estimated using the metric of CO_2 equivalents incorporate discount rates and inflation rates. These rates were included to allow the value (or impact) of CO_2 equivalents release, or averted release, at an earlier period in time to be of more value (or impact) compare to this happening at a later time, similar to the handling of financial models.

The values for these rates were set to zero for the purposes of this study because of the lack of data on the perceived value over time of CO_2 equivalent release or averted release. When estimates become available for a discount rate and inflation rate (or real discount rate) of CO_2 equivalents, the values can be entered into the current tool.

3.3.4.4 Floor area Lost to Fire

The extent of damage per house fires is based on statistics for the estimates for the floor area of flame damage (or the percentage of the structure saved) that are also available. An example of the summarised statistical results in Table 14 and for the period of 2005/2006 to 2007/2008 is presented in Table 15 (Challands 2009). These results are for all residential fire incidents.

These statistical values were used within the framework of the house fire GHG emissions only as an indication of the general trend in the overall statistics per year, since the uncertainty associated with the values is not quantified. (Challands 2009)

If a proportion of house contents were estimated for the extent of damage associated with the fire incidents with no structure damage, then this could be added to the framework.

The input parameter values used in the framework are those shown in Table 14. These proportions were assumed to be constant over the analysis period considered.

3.3.4.4.1 Equivalent Proportion of House Floor area Lost to Fire

An equivalent percentage of house floor area lost to fire can be calculated from the percentage of floor area lost and the proportion of total fires that had the category of percentage floor area lost. This provides an equivalent percentage of house floor area lost to fire per fire.

Using the statistical data presented in Table 14, an example of the equivalent percentage of house floor area lost to fire per fire is shown in Table 13. Based on the statistics for fire incidents with structure damage from the 2002 to 2006 corporate years, the equivalent percentage of house floor area lost to fire is 29% of the housing stock that had fire events.

This approach provides one means of comparing current house fire suppression strategies (as reflected in fire incident statistics) to either general improvements in suppression strategies or reductions in suppression activities.

Table 13: Summary of the numbers of fire incidents associated with estimated areas of household property lost. Values based on statistics presented in Table 14.

Average Percentage Household Area Lost	Total Number of Fire Incidents	Percentage of The Total Number of Fires	Cumulative Area Lost
100%	921	13%	13%
85%	132	1.9%	2%
75%	98	1.4%	1%
65%	169	2.4%	2%
55%	338	4.9%	3%
45%	173	2.5%	1%
35%	276	4.0%	1%
25%	410	6.0%	1%
15%	699	10%	2%
5%	3625	53%	3%
Total fires	**6941**	**100%**	**29%**

3.3.4.5 Types of Equipment Involved in Suppression

The equipment involved in suppression of the fires are also recorded in the statistics, as indicated in the example summary presented in Table 15. This summary indicates that the majority of the incidents reported here involved suppression using fire appliances, hose reels or monitors. The use of foams and sprinkler systems in these residential incidents is negligible.

Therefore it is assumed that framework input parameter values based on the current fire incident statistics provides a reasonable estimate of residential fire suppression for incidents without the use of foams or sprinkler systems (i.e. fire personnel using building facilities, portable equipment, or fire appliances, hose reels or monitors). Therefore the available fire incident statistics form the basis of the input values for Scenario 3 (Section 3.2.3.1). Scenario 4 is the estimate of the amount of CO_2 that would be saved due to the mandatory introduction of home sprinkler systems. The details of the framework assumptions related to home sprinkler system is discussed in Section 3.3.5.1. Similarly, as information becomes available on the use of foams in house fires, this information can be incorporated into the framework as an additional scenario for comparison.

Table 14: Summary of the numbers of fire incidents associated with estimated areas of household property lost

Average Percentage Household Area Lost	Range of Property Saved	Numbers of Fire Incidents						Percentage of The Total Number of Fires
		2002/03	2003/04	2004/05	2005/06	2006/07	Total	
100%	0-10%	179	220	193	154	175	921	7%
85%	11-20%	29	22	27	32	22	132	1%
75%	21-30%	18	16	20	25	19	98	1%
65%	31-40%	43	30	28	29	39	169	1%
55%	41-50%	60	76	59	62	81	338	3%
45%	51-60%	38	41	27	37	30	173	1%
35%	61-70%	54	55	60	61	46	276	2%
25%	70-80%	83	95	82	78	72	410	3%
15%	81-90%	132	134	143	135	155	699	5%
5%	91-100%	685	732	725	721	762	3625	28%
0%	No structural damage	1415	1283	1231	1087	1105	6121	47%
	Total fires	2736	2704	2595	2421	2506	12962	100

Table 15: Example of the statistical results available for the percentage of property saved and the equipment used in suppression activities for residential fire incidents (05/06 - 07/08) (Challands 2009)

Description of Category of Suppression	Equipment Used	Percentage of Property Saved										Total No. Fires
		0-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	81-90%	91-100%	
Contained by Occupant or Passer-By		19	1	2	2	8	2	4	17	42	1,138	1,236
Controlled by an In-Built Extinguishing System.	Sprinkler system	0	0	0	0	0	0	0	0	0	11	11
Fire Personnel Using Building Facility	Garden hose	2	1	0	0	1	0	1	3	6	89	103
	Extinguisher portable	0	0	0	0	0	0	0	0	0	3	3
	Hose reel fixed	0	0	0	0	0	0	0	0	1	18	19
	Power source isolated	0	0	0	0	0	0	0	0	0	96	96
	Fuel supply isolated	0	0	0	0	0	0	0	1	0	18	19
	Removal from building	0	0	0	0	0	0	0	1	0	56	57
	Bucket pump or buckets of water	1	0	0	0	0	0	1	1	1	76	80
	Fixed installations for NZFS use	0	0	0	0	0	0	0	0	0	2	2
	Fire personnel using building facility - not classified above	0	0	0	0	0	0	0	0	0	21	21
Fire Appliance Portable Extinguishers and Pumps.	CO_2 extinguisher	4	0	0	0	0	0	2	1	5	298	310
	Dry powder extinguisher	1	0	0	0	0	0	2	0	1	74	78
	Using portable water pump	9	1	0	1	2	0	1	0	0	18	32
Fire Appliance Hose Reels, Deliveries, Monitors.	Hose reel, high pressure delivery	254	45	37	63	147	92	118	190	376	1,598	2,920
	Low pressure delivery	164	36	20	25	59	17	29	33	46	92	521
Foam	Foam	7	0	2	1	5	3	2	3	4	11	38
No fire control needed	No fire control needed	73	8	8	13	25	5	14	22	53	3,274	3,495
	All Equipment Used	**534**	**92**	**69**	**105**	**247**	**119**	**174**	**272**	**535**	**6,893**	**9,041**

3.3.4.6 Numbers of New Zealand Housing Stock

The number of detached dwellings in 2006 by the decade in which they were built is shown in Figure 11. The total number of detached dwellings was 1.34 million in 2006.

In a previous study involving home sprinkler system (Robbins, Wade et al. 2008), an average increase in the total NZ building stock of 0.5% per annum was assumed. This was also assumed for the current framework.

The initial number of houses used in the framework was 1.4 million.

In the cost effectiveness study for home sprinkler systems in NZ a range of occupier categories was considered (e.g. owner occupier, rentals, state owned). This was not included in this current study, however the framework was developed to enable this at a future time if it is identified as of interest.

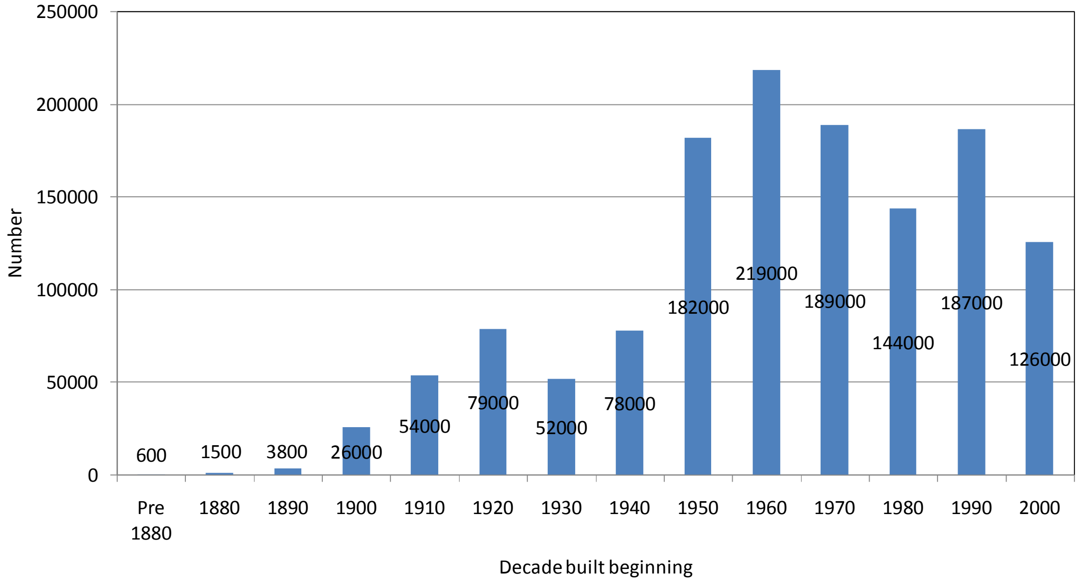


Figure 11: Number of detached residential dwellings in New Zealand by decade in which built as at 2006 (QVNZ, Census 2006, BRANZ)

3.3.4.7 Floor areas of New Zealand Housing Stock

A summary of the average floor area according to the decade of construction for detached dwellings in 2006 is shown in Figure 12. The category denoted as mixed indicates cases where the original building had undergone renovations or extensions at a later date. The floor area of the exemplar house used for the frame work was 195 m^2. The exemplar house is described in more detail in the following sections.

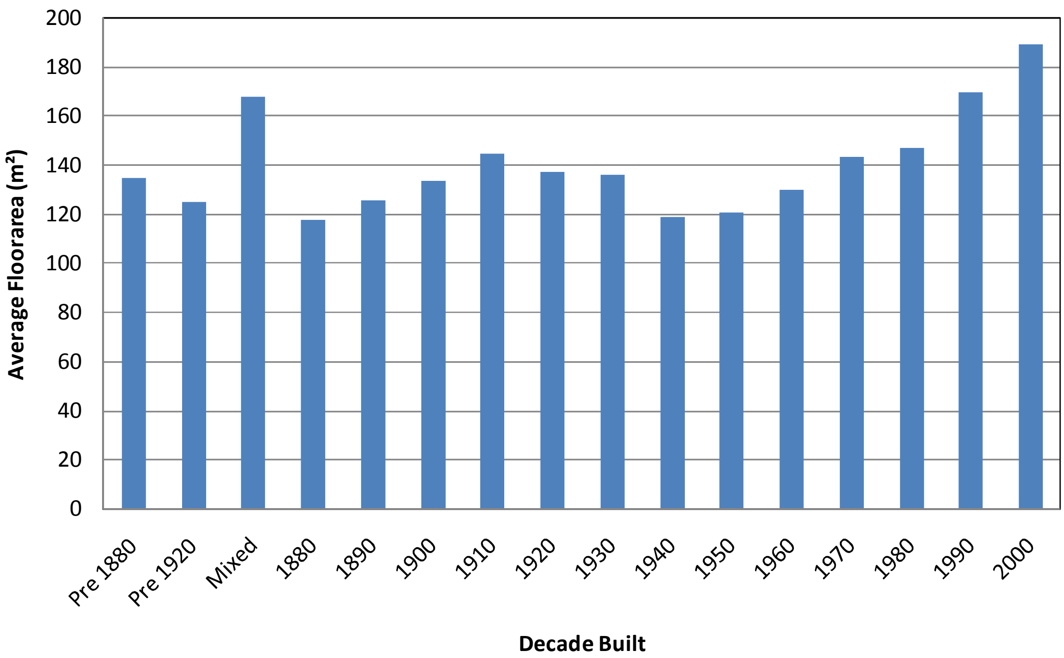


Figure 12: Average floor area by decade in which built as at 2006 (QVNZ, Building Consents)

3.3.4.8 Construction Types of New Zealand Housing Stock

Examples of the information available on the types of wall claddings (Figure 13), flooring (Figure 14), roof claddings (Figure 15) and combinations of wall and roof claddings (Figure 16) by the year the structure was built are included to demonstrate that there are common construction components throughout the building stock. The source for this data was the BRANZ House Condition Survey (HCS) (Clark et al, 2005). This lends to the usage of an exemplar house for a select range of combinations of wall cladding, roof cladding and foundations. This is utilized in the following section for types and amounts of materials.

When considering future housing construction, the estimate for this framework is based on the most recent newly build housing, e.g. roof and wall cladding combinations for houses built in 2008, as presented in Table 16. From this information the top four combinations of roof cladding and wall claddings were estimated to represent approximately 55% of recently build houses.

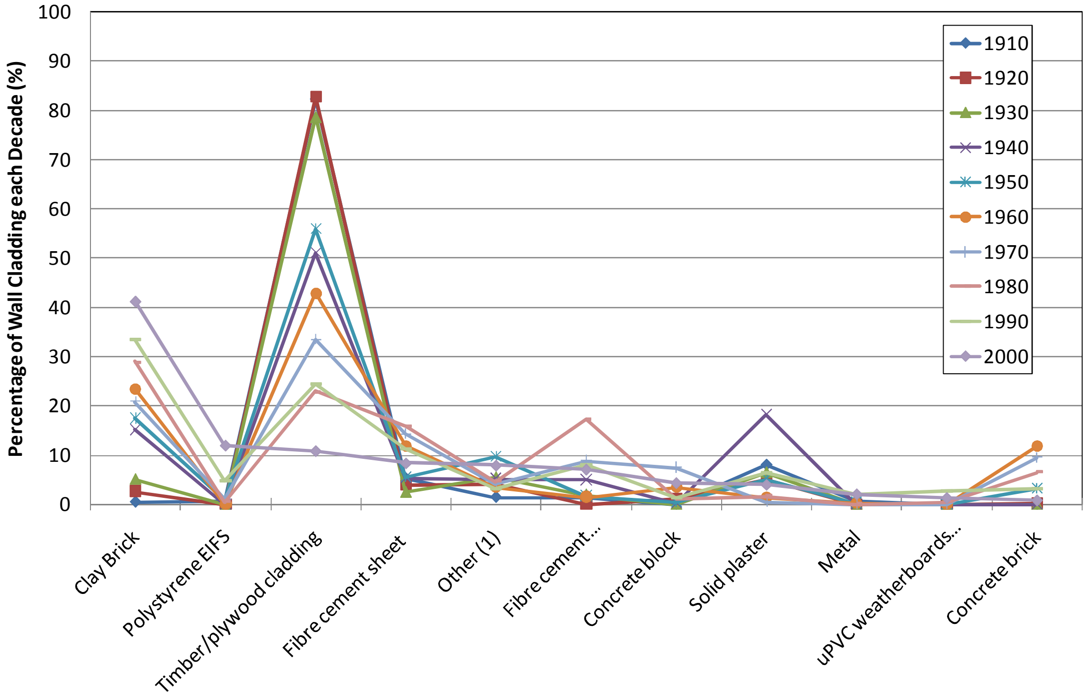


Figure 13: Percentages of each type of wall cladding used each decade (BRANZ HCS Survey)

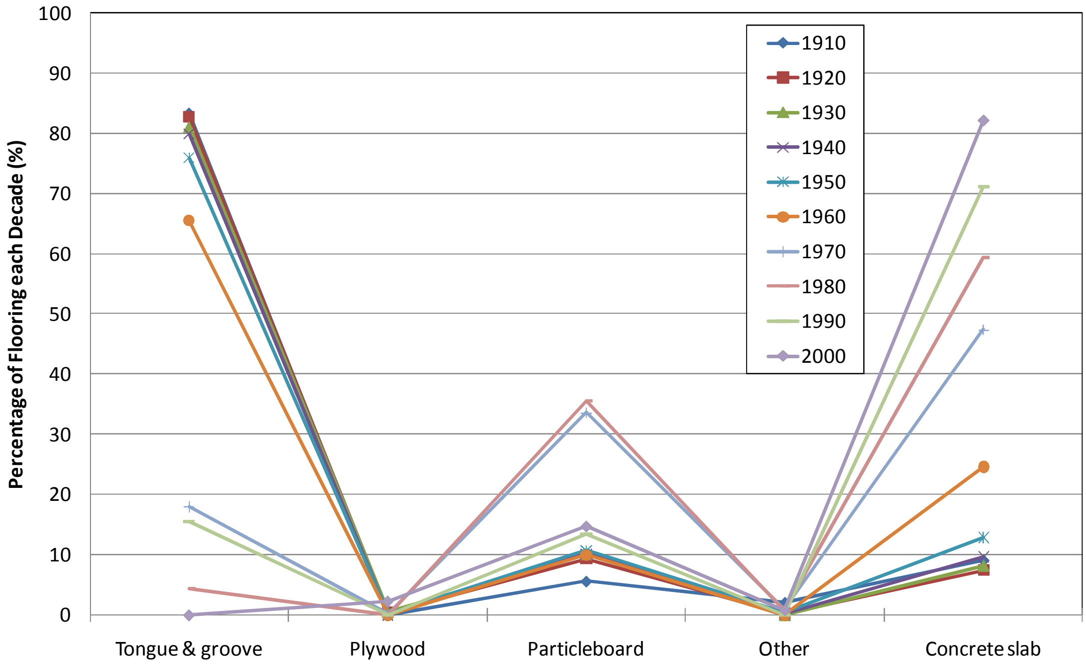


Figure 14: Percentages of each type of flooring used each decade (BRANZ HCS Survey)

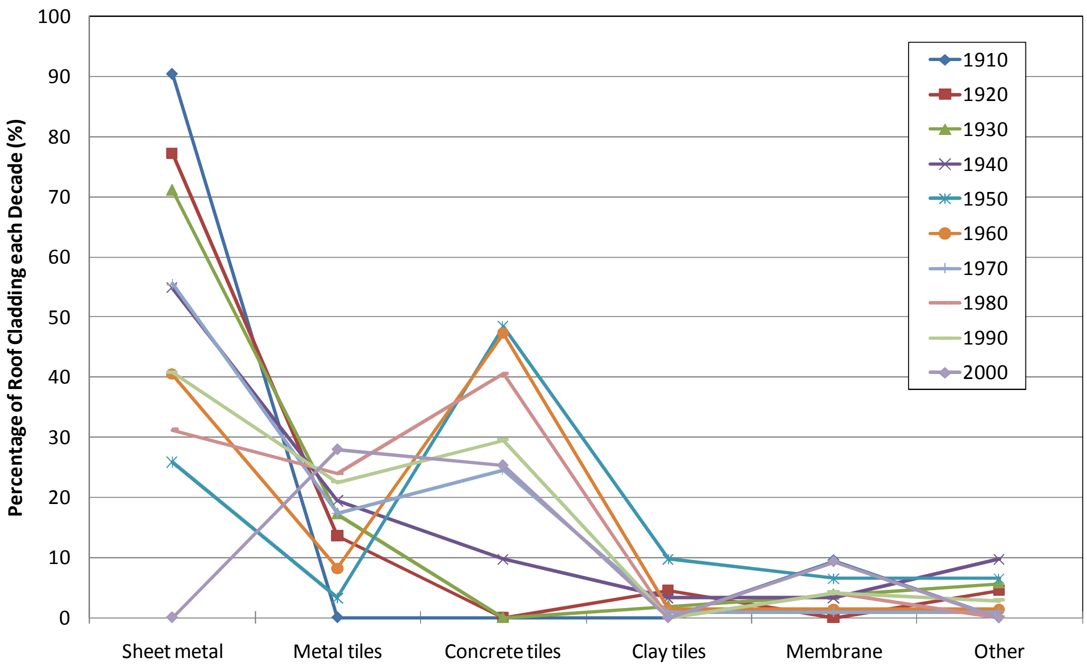


Figure 15: Percentages of each type of roof cladding used each decade (BRANZ HCS Survey)

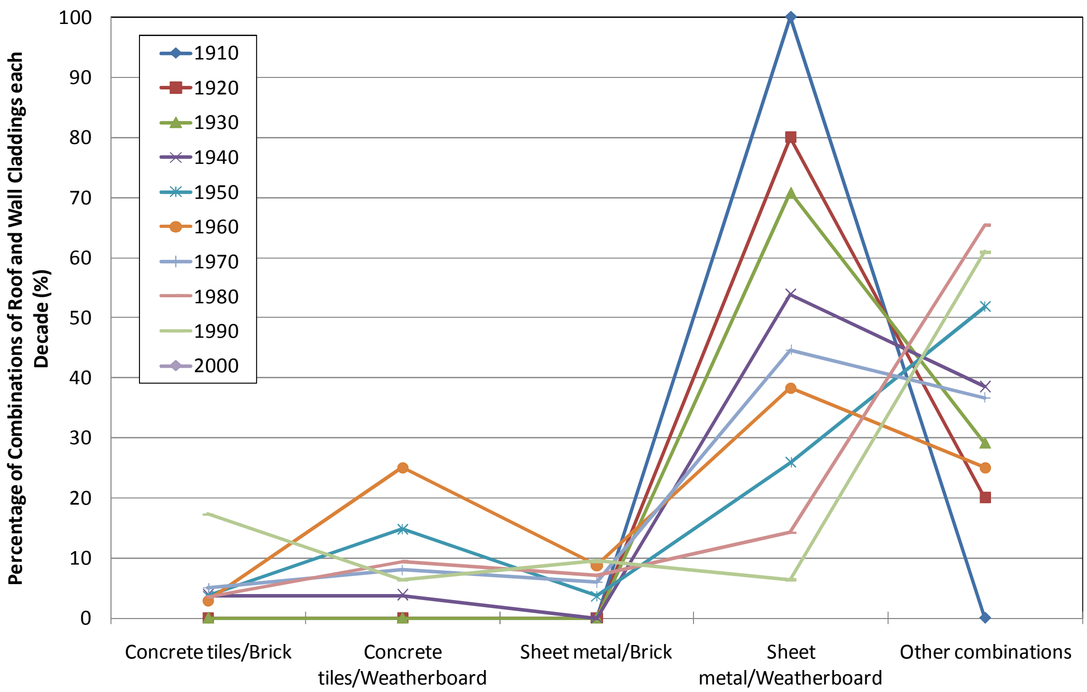


Figure 16: Percentages of selected combinations of roof and wall claddings used each decade (Page 2005)

Table 16: Roof and wall cladding combinations for houses built in 2008, based on survey results described in Page (2005).

Roof/Wall Cladding Combinations	Number	Percentage (%)
Sheet metal/brick	177	15.1
Concrete tile/brick	171	14.5
Metal tile/brick	158	13.4
Sheet metal/fibre cement weatherboard	136	11.6
Sheet metal/timber weatherboard	41	3.5
Sheet metal/EIFS	28	2.4
Metal tile/EIFS	18	1.5
Sheet metal/concrete block & panel	15	1.3
Concrete tile/EIFS	7	0.6
Concrete tile/Concrete block & panel	6	0.5
Metal tile/fibre cement weatherboard	6	0.5
Concrete tile/timber weatherboard	5	0.4
Concrete tile/fibre cement weatherboard	3	0.3
Metal tile/timber weatherboard	3	0.3
Metal tile/Concrete block & panel	3	0.3
Other combinations	399	33.9

3.3.4.9 Material Quantities of New Zealand Housing Stock

An exemplar house of 195 m^2 with six combinations of potential foundation, wall cladding and roof cladding combinations (as summarised in Table 17) was used as the basis for materials and quantities involved in the structure of a house that is representative of the New Zealand housing stock. The six combinations correspond to the most common combinations in the current building stock (Figure 13 to Figure 16 and Table 16), as discussed in the previous section.

The materials utilised in each of the combinations of foundation, wall and roof cladding are listed in Table 18. The common materials involved in each of the combinations considered are summarised in Table 19.

The masses of the materials used for each of the combinations considered are presented in Robbins, Page & Jaques (2010) Tables 23 and 24.

Table 17: Combinations of foundation, wall cladding and roof cladding types considered for the exemplar house

Combination	A	B	C	D	E	F
Foundation	Slab	Slab	Slab	Timber	Slab	Timber
Wall Cladding	FC plank	Brick	Brick	FC plank	Timber weatherboard	Timber weatherboard
Roof Cladding	Sheet steel	Concrete tile	Sheet steel	Sheet steel	Sheet steel	Sheet steel

Table 18: Summary list of structural materials that were involved in foundations, external wall cladding or roofing for the exemplar house

House Component	Material Involved
Foundation	Sand blinding
	Re-steel
	Concrete blocks
	Concrete readymix
	Steel bolts/plates/straps
	PVC
	Fibre cement baseboard & soffits
	Timber piles H5
	Sawn timber H3.2 (deck)
	Framing timber H1.2
	Framing timber UT
	Deck planks H3.2
	Exterior H3.1 finish/battens
	Particle Board sheets
	Polythene DPC
	Foil insulation (floors)
External Wall Cladding	Fibre cement plank
	Brick
	Timber weatherboard
Roofing	Sheet Steel
	Concrete tile

Table 19: Summary list of structural materials involved in the internal lining and components and landscaping, etc. common to all of the six combinations of foundation, wall cladding and roof cladding for the exemplar house

House Component	Material Involved
Landscaping, etc.	Retain wall/fence timber H4
	Half round retain wall H4
	Sawn timber H3.2 (fences etc)
Internal linings	Interior UT mould, jamb, liner
	Fibre cement baseboard & soffits
	Building paper
	Windows glass
	Windows aluminium
	Insulation Fibreglass
	Plasterboard
	Wet wall lining(coated HB)
	Paint
	Wallpaper
	Carpet (pile & backing)
	Vinyl
	Nails
Other internal components	Doors

3.3.4.9.1 Structure Materials Species Yield Values

A summary of the values used for the distributions estimated for the CO_2 yield for each material involved in the structure of the exemplar house is presented in Table 20.

Table 20: Summary of the carbon dioxide yield for structure materials.

Structure Component	Material	Assumed to be Combustible	CO_2 Yield Distribution		
			Minimum Value	Best Value	Maximum Value
Foundation	Hardfill	n		-	
	Sand blinding	n		-	
	Re-steel	n		-	
	Concrete blocks	n		-	
	Concrete readymix	n		-	
	Steel bolts/plates/straps	n		-	
	PVC	y	0.3	0.46 [b]	1.1
	Fibre cement baseboard & soffits	y	1.2	1.4 [c]	1.6
	Timber piles H5	y	1.2	1.3 [a]	1.8
	Sawn timber H3.2 (deck)	y	1.2	1.3 [a]	1.8
	Framing timber H1.2	y	1.2	1.3 [a]	1.8
	Framing timber UT	y	1.2	1.3 [a]	1.8
	Deck planks H3.2	y	1.2	1.3 [a]	1.8
	Exterior H3.1 finish/battens	y	1.2	1.3 [a]	1.8
	Particle Board sheets	y	1.1	1.2 [d]	1.3
	Polythene Damp Proof Course	y	0.59 [e]		1.71
	Foil insulation (floors)	n		-	
Wall Cladding	Fibre cement Plank	n		1.4 [f]	
	Brick	n		-	
	Timber Weatherboard	n	1.2	1.3 [a]	1.8
Roofing	Sheet Steel	n		-	
	Concrete tile	n		-	
Common Materials	Paint	y	0.35	0.4 [g]	0.45
	Retain wall/fence timber H4	y	1.2	1.3 [a]	1.8
	Half round retain wall H4	y	1.2	1.3 [a]	1.8
	Sawn timber H3.2 (fences etc)	y	1.2	1.3 [a]	1.8
	Interior UT mould, jamb, liner	y	1.1 [h]		1.6
	Fibre cement baseboard & soffits	n		1.4 [f]	
	Building paper	n	1.2 [i]		1.3
	Windows glass	n		-	
	Windows aluminium	n		-	
	Insulation Fibreglass	n		-	
	Plasterboard	y	0.25	0.3 [j]	0.35
	Wet wall lining (coated Hardboard)	y		1.4 [f]	
	Doors	y	1.2 [i]		1.3
	Wallpaper	y	1.2 [i]		1.3
	Carpet pile	y	0.8 [k]		3.4
	Carpet backing	y	0.8 [k]		3.4
	Vinyl	y	0.59 [e,m]		1.71
	Nails	n		-	
	Electrical wiring	y	1.29 [n]		2.08

For Table notes see next page.

Notes (Table 20):

a Assumed to be an average of wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg from Table 3-4.14 from SFPE Handbook (2008)) for the best value and the range of values (1.2 – 1.8 kg/kg) based on real-scale in exhaust stack values (Gann et al. 2003).

b The best value (0.46 kg/kg) based on values published in Table 3-4.14 (SFPE 2008), and the range (0.3 – 1.1 kg/kg) from real-scale in exhaust stack measurements (Babrauskas et al. 1988).

c Assumed as the value for fiberboard listed in Table 3-4.14 of the SFPE Handbook (2008), then assuming ±10%.

d Taken as the value for particle board (1.2 kg/kg) listed in Table 3-4.14 of the SFPE Handbook (2008), then assuming ±10%.

e Assumed to be a uniform distribution based on the values listed in of Table 3-4.14 of the SFPE Handbook (2008) for polythene (25% chlorine 1.71 kg/kg, 36% chlorine 0.83 kg/kg, 48% chlorine 0.59 kg/kg)

f Assumed as the value for fiberboard listed in Table 3-4.14 of the SFPE Handbook (2008).

g Assumed to be similar to plastic on gypsumboard (0.4 kg/kg, (SFPE 2008)), then assuming ±10%.

h Uniform distribution assumed with values based on the values listed in the SFPE Handbook (2008) for rigid polyurethane building product (1.1 kg/kg) and polyurethane rigid foams (1.1 –1.6 kg/kg).

i Assumed to be a uniform distribution, with the values based on a combination of SFPE Handbook (2008) values for wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg), wood panel (1.2 kg/kg), and particle board (1.2 kg/kg).

j Assumed to be gypsumboard (0.3 kg/kg, (SFPE 2008)), assuming ±10%.

k A uniform distribution was assumed based on values from cone calorimeter data for non-fire retardant filament olefin carpet (3.36 kg/kg, 3.13 kg/kg, 2.6 kg/kg, (Grosshandler et al. 2005)), and wool (estimated to be approximately 0.8 kg/kg). The carpet value was also used for the carpet backing.

m Vinyl was assumed to have a similar value to polythene e.

n A uniform distribution was assumed, with values based on polyethylene (1.29 – 2.08 kg/kg, (SFPE 2008)).

3.3.4.10 Material Quantities of New Zealand House Contents

There are no controls on the contents of a residence. Therefore an exemplar for residential contents was assembled from what data was available at the time of this study. Initially the materials involved in home contents for an exemplar house was approached in terms of individual component materials (e.g. cellulosic materials, cork, cotton, nylon, polyester, polyurethane, timber - pine, wool, etc.), similar to the approach used in listing the materials involved in the structural components of the exemplar house. However the data available for the amount of furniture sold in New Zealand is not useful since it is either reported in terms of total dollar amounts, such as statistics associated with the Statistics New Zealand Retail Trade Survey (SNZ 2009), Furniture Association of NZ (Dunnett 2009), Nielsen Media Research National Readership Survey (NMR 2009).

Implementation and execution of a survey of the contents of New Zealand residential spaces was beyond the initial scope of this project.

Therefore the data for the numbers (as summarised in Table 21), masses (as summarised in Robbins, Page & Jaques (2010) Table 26) and materials for this study is estimated to allow demonstration of concept of the methodology. The values used have been estimated based on results from the living room survey for Canadian homes (Bwalya 2004; Bwalya, Sultan and Benichou 2004), reported details of items of home contents used in fire experiments (e.g. Babrauskas (1980), Hietaniemi et al. (2001)), a limited survey of local New Zealand residential spaces and small samples of available local manufacturer's and supplier's information. Since the majority of fire incidents originate in kitchens, bedrooms or living rooms (as indicated in the statistics summarised in Table 23), the focus of exemplar home contents was based around these rooms. It is emphasised here that the values used are loosely indicative and have been estimated for the use within the house fire GHG emissions framework for demonstration of concept. As data becomes available, these numbers are to be updated.

The sensitivity analysis investigated the influence of the estimated parameter values and distributions associated with mass and CO_2 yield.

Table 21: Average numbers of items in the most common rooms of fire origin per household

Item Description	Estimates of the Average Number of Items in Each Room		
	Living Room	Bedroom [d]	Kitchen
Small Table (e.g. side table, phone stand, bedside table, etc)	1.45 [a]	0.6 [b]	
Upholstered chair (e.g. recliner, covered chair, etc)	1.1 [a]	0.2 [b]	
Television	1 [a]	0.75 [b]	
Sofa	0.92 [a]		
Entertainment unit	0.78 [a]		
Coffee table	0.77 [a]		
Bookcase	0.77 [a]	0.4 [b]	
Loveseat	0.55 [a]		
Magazine rack	0.33 [a]		
Ottoman	0.2 [a]		
Desk	0.17 [a]	0.7 [b]	
Computer	0.16 [a]	0.6 [b]	
Futon	0.13 [a]	0.1 [b]	
King, Queen or Double bed		0.5 [b]	
Single bed		0.6 [b]	
Drawers		1 [b]	
Built-in wardrobe		0.7 [b]	
Stand-alone wardrobe		0.3 [b]	
Clothes		1 [c]	
Manchester		1 [c]	
Toys		1 [c]	
Books/Magazines		1 [c]	
Fridge (separate or combined refrigerator-freezer, mini-bar, etc.)			1.5 [b]
Dishwasher			1 [b]
Microwave			1 [b]
Gas Stove			0.3 [b]
Electric Stove			0.7 [b]
Rangehood			0.8 [b]
Cabinet - wood finish			8 [b]
Cabinet - laminate finish			8 [b]
Table		0.5 [b]	1 [b]
Chairs		0.5 [b]	6 [b]
Washing machine			1 [b]
Dryer			1 [b]
Electrical cable (extension cords, multiboxes)	2 [b]	1 [b]	

Notes:
a Estimate based on a small sample of New Zealand households and the Canadian study by Bwalya (2004).
b Estimate based on a small sample of New Zealand households.
c These items are estimated to be 1 unit per bedroom.
d The number of items listed here estimated is per bedroom. The average number of bedrooms per house was estimated as 3.4.

3.3.5 House Contents Species Yield Values

A summary of the values used for the distributions estimated for the CO_2 yield and estimated proportion of combustible mass for each item involved in the contents of the exemplar house is presented in Table 22.

Table 22: Summary of the carbon dioxide yield for home contents items.

Item Description	Estimated Proportion of Mass of Combustibles	Average Carbon Dioxide Yield (kg/kg)			
		Minimum Value	Best/ Average Value	Maximum Value	Sample Standard Deviation
Small table	1 [a]	0.8 [d]		1.33	
Upholstered chair	0.8 [b]		1.6 [e]		0.35
TV	0.9 [a]		1.8 [g]		0.4
Sofa	0.8 [b]		1.6 [f]		0.35
Entertainment unit	0.9 [a]		2.5 [k]		0.2
Coffee table	1 [a]	1.27 [m]		1.33	
Bookcase	1 [a]		0.29 [n]		0.14
Loveseat	0.8 [b]		1.6 [e]		0.35
Magazine rack	1 [a]		0.29 [p]		0.14
Ottoman	0.8 [b]		1.6 [e]		0.35
Desk	1 [a]	0.8 [d]		1.33	
Computer	0.9 [a]		2.5 [k]		0.2
Futon	0.8 [b]		1.6 [e]		0.35
King, Queen or Double bed	0.8 [b]		1.6 [e]		0.35
Single bed	0.8 [c]		1.6 [e]		0.35
Drawers	1 [a]	0.8 [d]		1.33	
Stand-alone wardrobe	0.8 [a]	0.8 [d]		1.33	
Clothes	1 [a]	1.5 [q]		2.2	
Manchester	1 [a]	1.5 [r]		1.6	
Toys	1 [a]	1.5 [r]		2.2	
Books/Magazines	1 [a]	1.27 [s]		1.33	
Fridge	0.5 [a]		2.22 [j]		0.07
Dishwasher	0.5 [a]		1.62 [i]		0.02
Microwave	0.3 [a]		2.5 [k]		0.2
Gas Stove	0.2 [a]		2.5 [k]		0.2
Electric Stove	0.2 [a]		2.5 [k]		0.2
Rangehood	0.3 [a]		2.5 [k]		0.2
Cabinet - wood finish	1 [a]	1.27 [s]		1.33	
Cabinet - laminate finish	1 [a]	0.8 [t]		1.2	
Table	1 [a]	0.8 [d]		1.33	
Chairs	1 [a]	1.2 [u]		1.9	
Washing machine	0.3 [a]		2.43 [h]		0.34
Dryer	0.3 [a]		2.5 [k]		0.2
Electrical cable	0.8 [a]		0.12 [v]		0.05

For Table notes see next page.

Notes (Table 22):
a No published data available, therefore values were estimated.
b Values assumed to be similar to bed values, therefore used bed values from experiments by Babrauskas (1980).
c Single mattress values were based on the values published for experiments performed by Babrauskas (1980).
d Assumed to be a uniform distribution based on values listed in Table 3-4.14 (SFEP 2008) for melamine-faced particle board (0.8 kg/kg), wood panel (1.2 kg/kg), and wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg).
e Assuming a sofa as a proxy furniture item.
f A normal distribution was assumed based on published sofa values: pre-flashover 0.8 kg/kg ±0.17 and post-flashover 0.57 kg/kg ±0.12 (Gann et al. 2003); and upholstered cushions values in a steel frame: pre-flashover 1.59 kg/kg ±25% and post-flashover 1.13 kg/kg ±25% (Gann et al. 2007).
g Assumed to be a normal distribution based on the average and standard deviations of free-burning televisions: television sets (average 2.560 kg/kg, standard deviation 0.110kg/kg) (Hietaniemi et al. 2001), and for non-fire retardant specimens (1.39 kg/kg) and fire retardant specimens (0.74 kg/kg) (Babrauskas et al. 1988).
h Assumed to be a normal distribution based on the average and standard deviations of free-burning washing machines: 2.43 kg/kg, 0.34 kg/kg (Hietaniemi et al. 2001).
i Assumed to be a normal distribution based on the average and standard deviations of dishwashers burning in a cupboard: 1.62 kg/kg, 0.02 kg/kg (Hietaniemi et al. 2001).
j Assumed to be a normal distribution based on the average and standard deviations of free-burning refigerator-freezers: 2.22 kg/kg, 0.07 kg/kg (Hietaniemi et al. 2001).
k Assumed to be similar to the average and standard deviation of free-burning appliances (television sets g: 2.56 kg/kg, 0.11 kg/kg; washing machines h: 2.43 kg/kg, 0.34 kg/kg; dishwashers: 2.81 kg/kg, 0.27 kg/kg (Hietaniemi et al. 2001); refrigerator-freezers j: 2.22 kg/kg, 0.07 kg/kg)
m Assumed to be a uniform distribution, with values based on those listed in Table 3-4.14 (SFPE 2008) for (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg), and real-scale wood crib values measured in the exhaust stage (1.2 – 1.8 kg/kg) (Babrauskas et al. 1988).
n Assumed to be a normal distribution, with values based on average and standard deviation values from experimental measurements for a particle board bookcase: pre-flashover 0.29 kg/kg ±0.4, post-flashover 1.10 kg/kg ±0.80 (Gann et al. 2003), wood: red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg from Table 3-4.14 of (SFPE 2008), and room-scale fire tests of particle board with laminated PVC: pre-flashover 0.5+/-50%, post-flashover 0.12+/- 45% (Gann et al. 2007).
p Assuming similar values to a bookcase (see note n).
q Assuming a uniform distribution, with values based on Nylon (2.06 kg/kg), Polyester (polyester-1: 1.65 kg/kg and polyester-2: 1.56 kg/kg) from Table 3-4.14 in SFPE Handbook (2008).
r Values were assumed to be similar to clothes.
s Assumed to be a uniform distribution, with values assumed to be similar to wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg) (Table 3-4.14 of SFPE 2008)
t Assumed to be a uniform distribution, with values based on melamine-faced particle board (0.8 kg/kg) and wood panel (1.2 kg/kg) from Table 3-4.14 of SFPE Handbook (2008).
u Assuming a uniform distribution, with values based on furniture calorimeter data (1.89 kg/kg) and cone calorimeter data (1.62 kg/kg) for mock chairs with a small nylon fabric covered polyurethane foam cushion (Babrauskas et al. 1988), and wood (red oak 1.27 kg/kg, Douglas fir 1.31 kg/kg, pine 1.33 kg/kg) from Table 3-4.14 of SFPE Handbook (2008).
v Assuming a normal distribution, with values based on cable experiments with measurements reported for pre-flashover (0.057 kg/kg ±0.024), post-flashover (0.65 kg/kg ±0.10) (Gann et al. 2003), and pre-flashover(0.12 kg/kg ±45%) and post-flashover (1.38 kg/kg ±15%) (Gann et al. 2007).

3.3.5.1 Home Sprinkler Systems

Home sprinkler systems were considered in a New Zealand context in previous studies by Wade and Duncan (2000) and Robbins, Wade, et al. (2008). Therefore information available from these studies was used where appropriate. The following is a summary of the assumptions and input parameter values used in the framework for CO_2 Equivalent estimates within the context of Scenario 4 (Section 3.2.3.1).

3.3.5.1.1 Sprinkler Effectiveness

A summary of the information available on sprinkler system effectiveness is presented in Robbins, Page & Jaques (2010) Table 27. For this study an estimate of the overall effectiveness was used, combining suppression effectiveness when a system activates and the operational reliability of the system. The following is a summary of relevant published literature on sprinkler system effectiveness and reliability.

The estimate of the overall effectiveness of a home sprinkler was a best value of 95% with a maximum value of 99% and a minimum value of 90%, in alignment with the previous study by Robbins, Wade et al. (2008).

3.3.5.1.2 Limit of Flame Damage for Effective Sprinkler Operation

A maximum limit for flame damage of a residential structure was estimated, assuming effective operation of a home sprinkler system. There is currently no published literature that specifically relates to such a limit, therefore a conservative estimate was made of a mean damage limit of 5% of a structure, with a minimum of 2% and a maximum of 7%. These estimates are expected to be conservative, i.e. greater than would be expected for an effective home sprinkler system, and are in alignment with values used in a previous study related to home sprinkler systems (Robbins, Wade et al. 2008).

3.3.5.1.3 Distribution of Rooms of Fire Origin

The percentage distributions of the room of fire origin for residential fire incidents based on recorded statistics are presented in Table 23 for a range of countries. A comparison of the percentage distributions for fire incidents for various countries is shown in Figure 17. Note that the line connecting the average values is only for ease of identification, and no trend or connection is implied between the considered categories. A summary of the values assumed for the current framework is presented in Table 23. These values were primarily based on the New Zealand statistics.

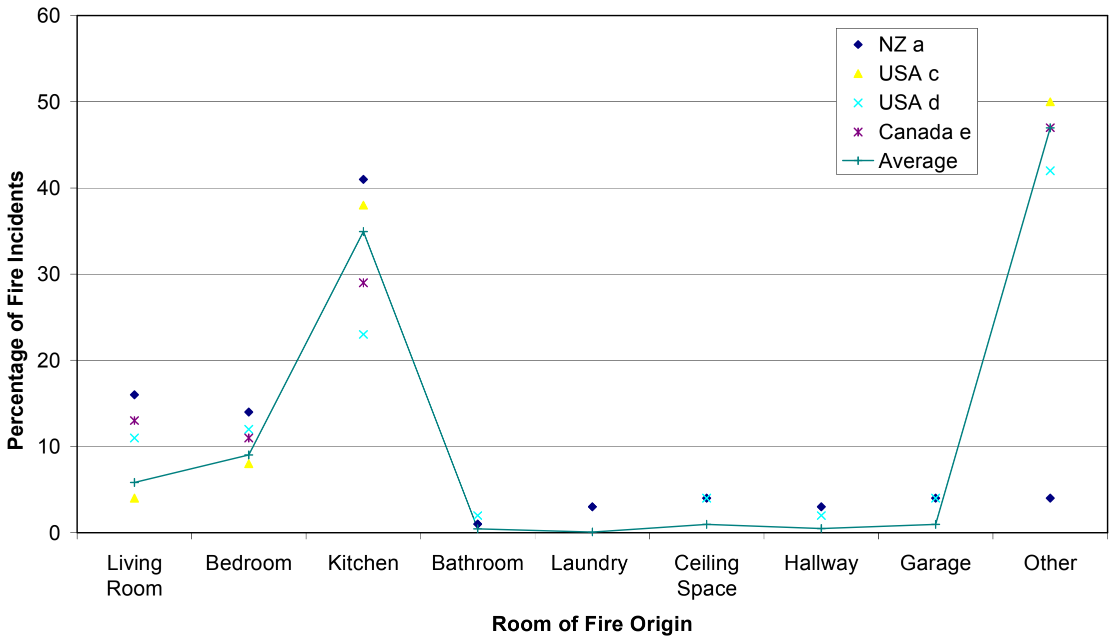


Figure 17: Percentages of residential structure fire incidents for various countries over various periods. (Extracted from Robbins, Wade et al. (2008). Details are presented in Table 23.)

Table 23: Summary of the distribution of fire incidents by room of fire origin used in the current framework

Room of Fire Origin	Percentage of Fire Incidents
Living Room	16
Bedroom	14
Kitchen	41
Bathroom	1
Laundry	3
Ceiling Space	4
Hallway	3
Garage	4
Other	14

3.3.5.1.4 Proportion of Structure Covered by NZS 4517

Since NZS 4517 does not require full coverage of all areas of a structure for which it is designed, a conservative approach was taken by including a coverage parameter. That is the coverage parameter for averting potential fire incidents is related to the proportion of the rooms covered by NZS 4517. For example, bathrooms and ceiling spaces do not have mandatory sprinkler coverage according to NZS 4517. Therefore when considering the coverage of home sprinklers, these spaces are excluded. As a conservative approach the ‘other’ category, as shown in Table 23, was also not included in the coverage of a NZS 4517 system.

The estimated values of coverage of a NZS 4517 system used for room of fire origin for fire incidents was 81% ± 5%.

3.3.5.1.4.1 Sprinkler System Life

The home sprinkler system life was assumed to be the same as that of domestic plumbing. This was assumed to be 50 years.

3.4 Examples of Use of the House Fire Emissions Calculation Tool

The house fire GHG emissions estimation tool presented here is intended to provide comparative results to investigate the potential impact of different strategies or scenarios, e.g. the current situation versus the situation if no NZFS intervention was available (or the average response time was increased or decreased), versus mandatory home sprinklers systems throughout the nation, and so on. Therefore the results for five example scenarios are presented here as a demonstration of concept.

The scenarios that were considered are:

1. total fire loss of an exemplar house structure;
2. total fire loss of an exemplar house contents;
3. house fires with fire suppression remaining the same as reflected in current fire incident statistics;
4. house fires where home sprinkler systems (according to NZS4817) are present with NZFS intervention using water (if needed); and
5. an increase of equivalent percentage of floor area loss per fire to 50%.

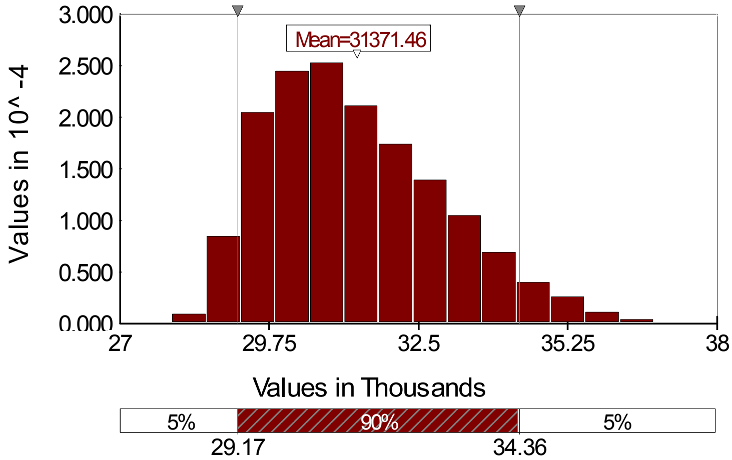
The results for each of these scenarios are presented in the following Sections.

3.4.1 Scenario 1: Total fire loss of an exemplar house structure

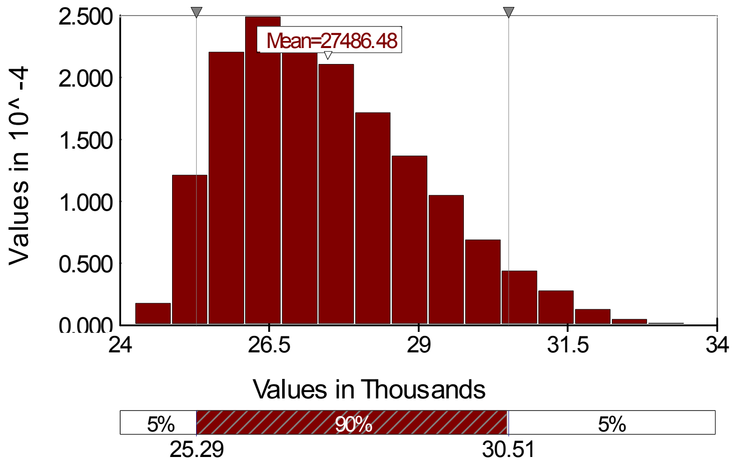
The results for Scenario 1 are summarised in Table 24 and Figure 18.

Table 24: Summary of the results for Scenario 1.

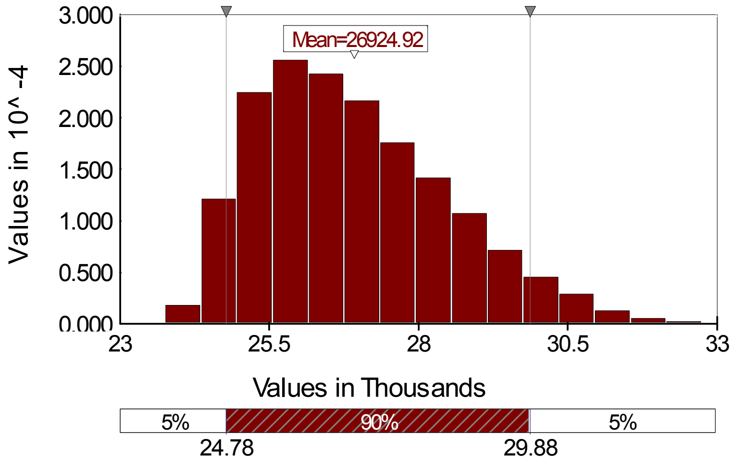
	Total CO_2 Equivalent Released by the Total Fire Loss of each Combination of 195 m² Exemplar House (kg CO_2)					
	A	B	C	D	E	F
Minimum	28,000	24,000	24,000	34,000	27,000	33,000
Maximum	37,000	33,000	33,000	46,000	38,000	46,000
Mean	31,000	27,000	27,000	38,000	31,000	37,000
Standard Deviation	1,600	1,600	1,600	2,000	1,900	2,300



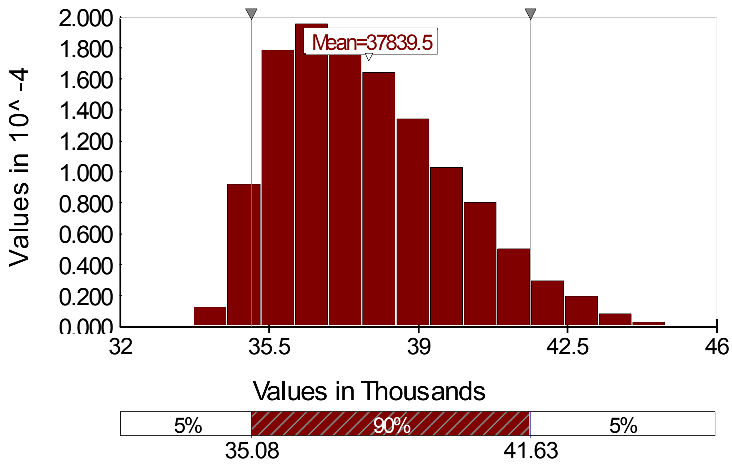
(a)


Mean=27486.48
Values in 10^ -4
2.500
2.000
1.500
1.000
0.500
0.000
24
26.5
29
31.5
34
Values in Thousands
5%
90%
5%
25.29
30.51

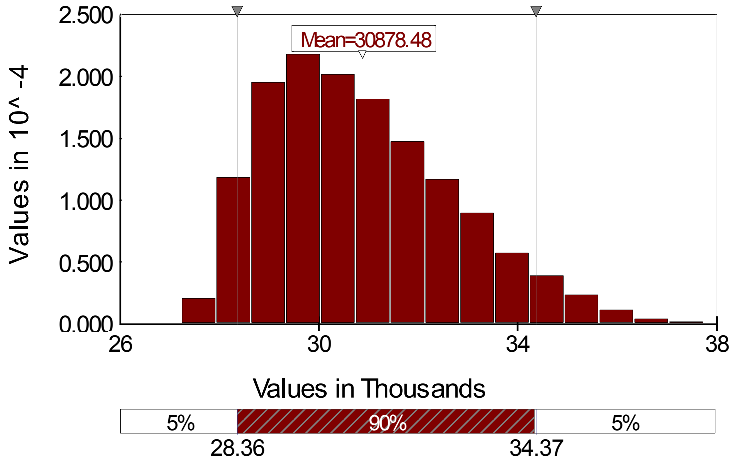
(b)


Mean=26924.92
Values in 10^ -4
3.000
2.500
2.000
1.500
1.000
0.500
0.000
23
25.5
28
30.5
33
Values in Thousands
5%
90%
5%
24.78
29.88

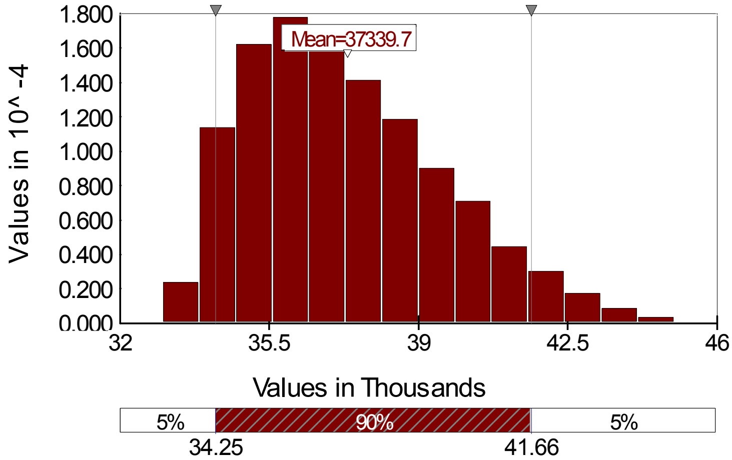
(c)


Mean=37839.5
Values in 10^ -4
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
32
35.5
39
42.5
46
Values in Thousands
5%
90%
5%
35.08
41.63

(d)



(e)

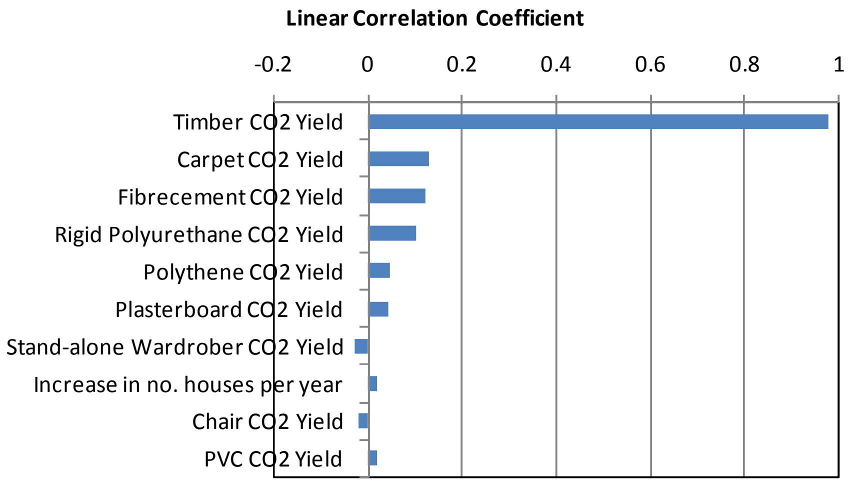


(f)

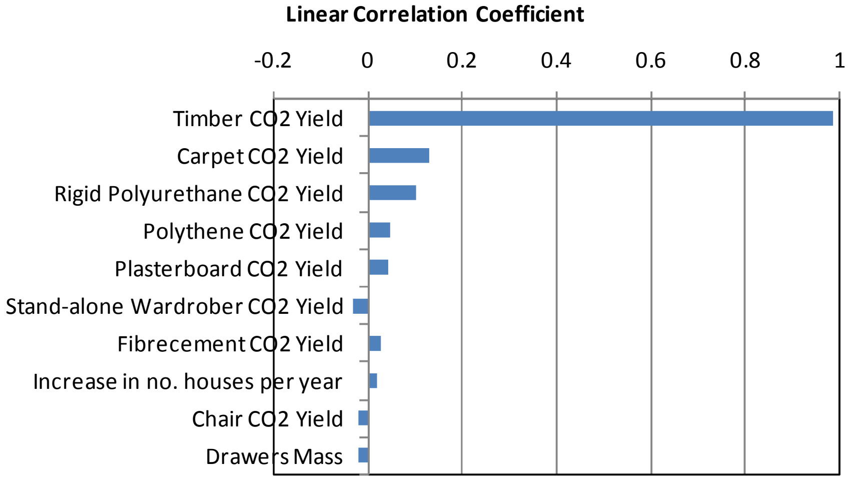
Figure 18: Summary of the results for Scenario 1 for each of the Exemplar house combinations considered: (a) Type A (b) Type B, (c) Type C, (d) Type D, (e) Type E and (f) Type F.

3.4.1.1 Sensitivity Analysis

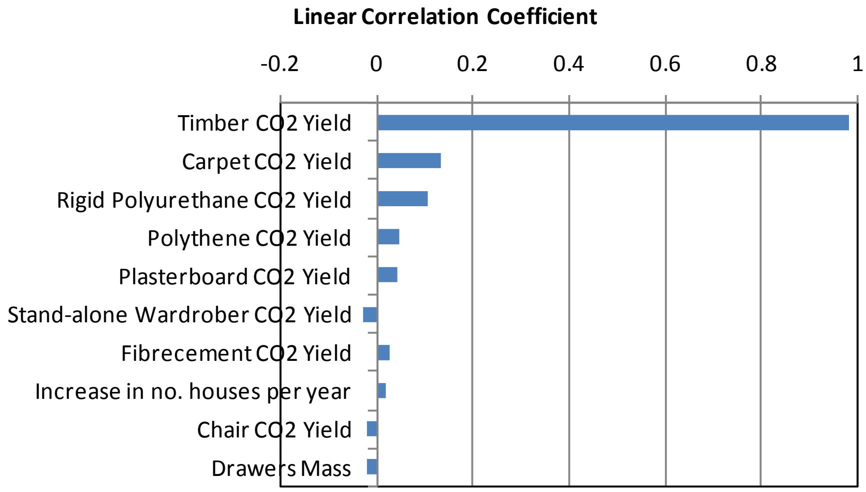
The results for the Scenario 1 sensitivity analysis are summarised in Figure 19.



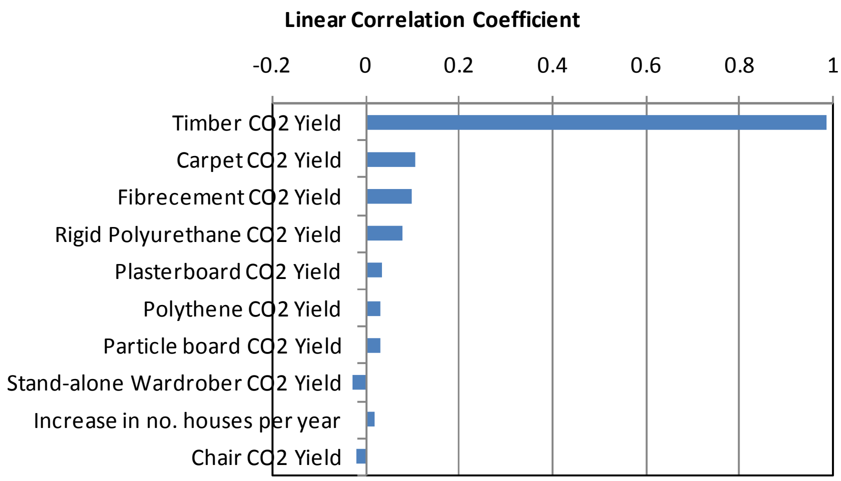
(a)


Linear Correlation Coefficient
-0.2
0
0.2
0.4
0.6
0.8
1
Timber CO2 Yield
Carpet CO2 Yield
Rigid Polyurethane CO2 Yield
Polythene CO2 Yield
Plasterboard CO2 Yield
Stand-alone Wardrober CO2 Yield
Fibrecement CO2 Yield
Increase in no. houses per year
Chair CO2 Yield
Drawers Mass

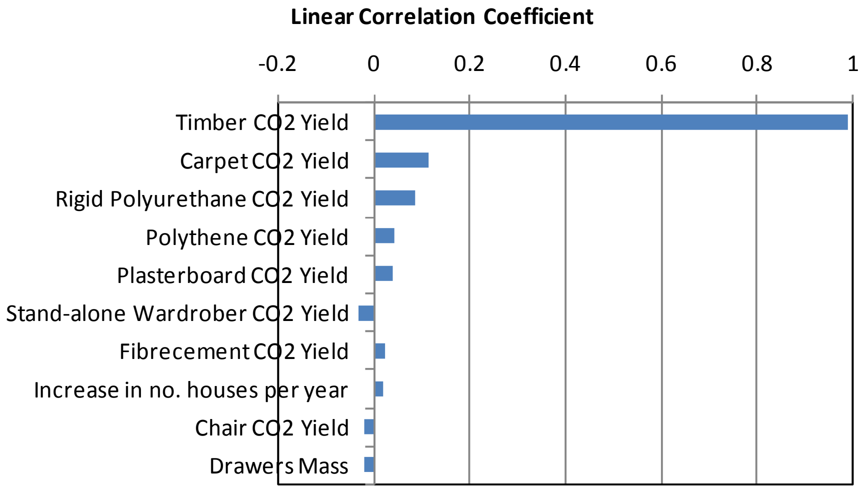
(b)


Linear Correlation Coefficient
-0.2
0
0.2
0.4
0.6
0.8
1
Timber CO2 Yield
Carpet CO2 Yield
Rigid Polyurethane CO2 Yield
Polythene CO2 Yield
Plasterboard CO2 Yield
Stand-alone Wardrober CO2 Yield
Fibrecement CO2 Yield
Increase in no. houses per year
Chair CO2 Yield
Drawers Mass

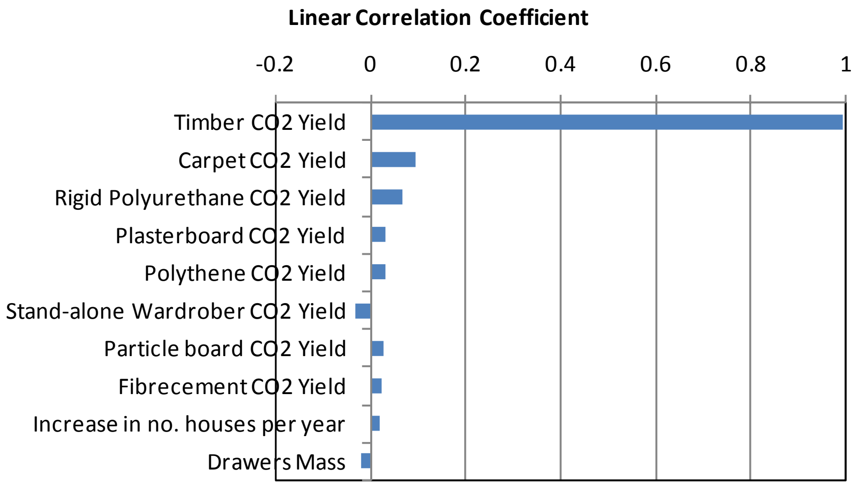
(c)


Linear Correlation Coefficient
-0.2
0
0.2
0.4
0.6
0.8
1
Timber CO2 Yield
Carpet CO2 Yield
Fibrecement CO2 Yield
Rigid Polyurethane CO2 Yield
Plasterboard CO2 Yield
Polythene CO2 Yield
Particle board CO2 Yield
Stand-alone Wardrober CO2 Yield
Increase in no. houses per year
Chair CO2 Yield

(d)



(e)



(f)

Figure 19: Summary of the top ten influential input parameters, based on fibre cement weatherboard correlation coefficients, for Scenario 1 for each of the Exemplar house combinations considered: (a) Type A (b) Type B, (c) Type C, (d) Type D, (e) Type E and (f) Type F.

3.4.2 Scenario 2: Total fire loss of an exemplar house contents

The results for Scenario 2 are summarised in Table 25 and Figure 20.

Table 25: Summary of the results for Scenario 2 for the CO2 Equivalent released due to the total fire loss of the exemplar home contents.

	Total CO_2 Equivalent Released by the Total Fire Loss of the Contents of the 195 m² Exemplar House (kg CO_2)
Minimum	4,700
Maximum	7,500
Mean	6,000
Standard Deviation	400

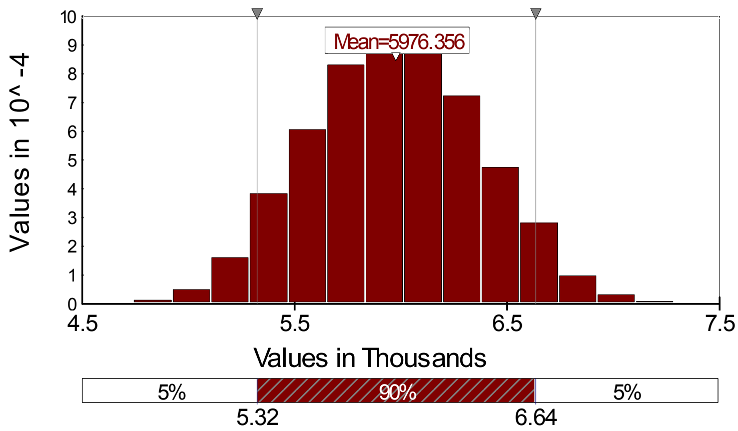


Figure 20: Summary of the results for Scenario 2 for the CO_2 Equivalent released due to the total fire loss of the exemplar home contents.

3.4.2.1 Sensitivity Analysis

The results for the Scenario 2 sensitivity analysis are summarised in Figure 21.

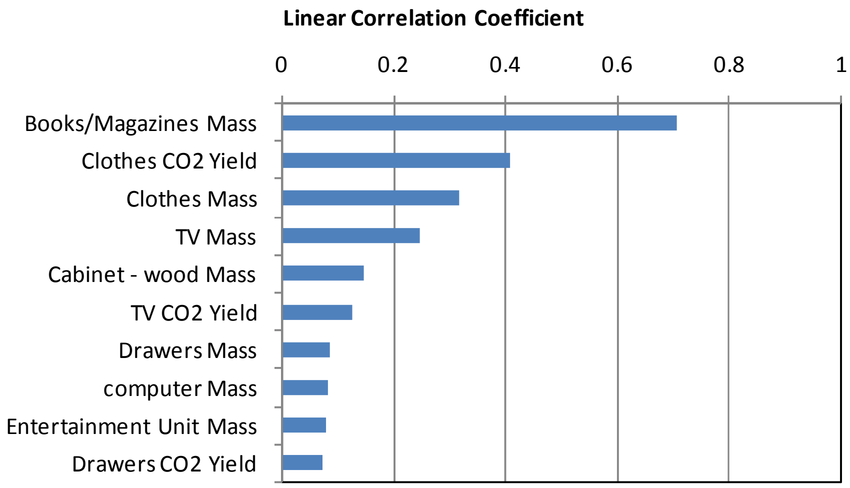


Figure 21: Summary of the top ten influential parameters for the CO_2 Equivalent released due to the total fire loss of the exemplar home contents, based on fibre cement weatherboard correlation coefficients.

3.4.3 Scenario 3: House fires with continuing current suppression strategies

The results for Scenario 3 are summarised in Table 26 and Figure 22.

Table 26: Summary of the results for Scenario 3.

	Total CO_2 Equivalent Released by House Fires with fire suppression continuing as reflected in the current fire incident statistics		
	kg(CO_2)/ household/ year	kg(CO_2)/ fire/ year	t(CO_2)/ year
Minimum	8	7,700	14,000
Maximum	13	11,000	21,000
Mean	10	9,000	16,000
Standard Deviation	1	460	1,100

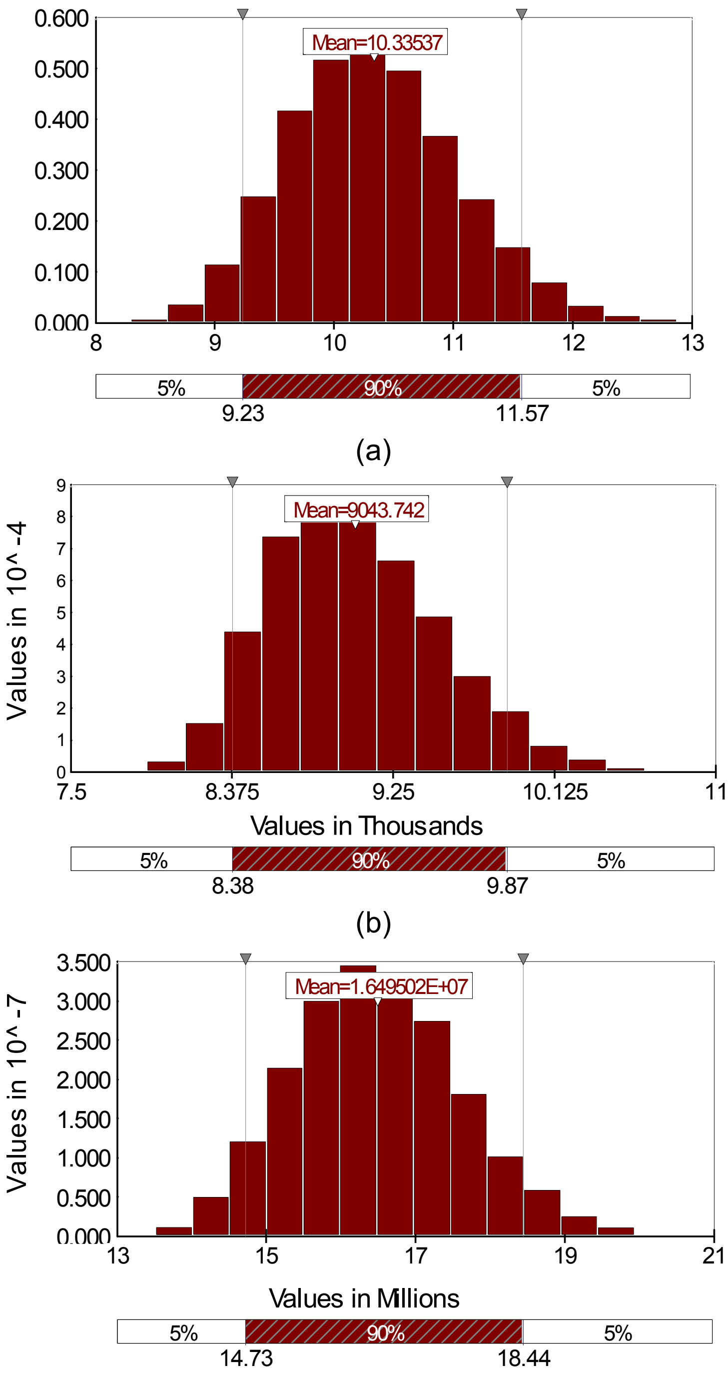
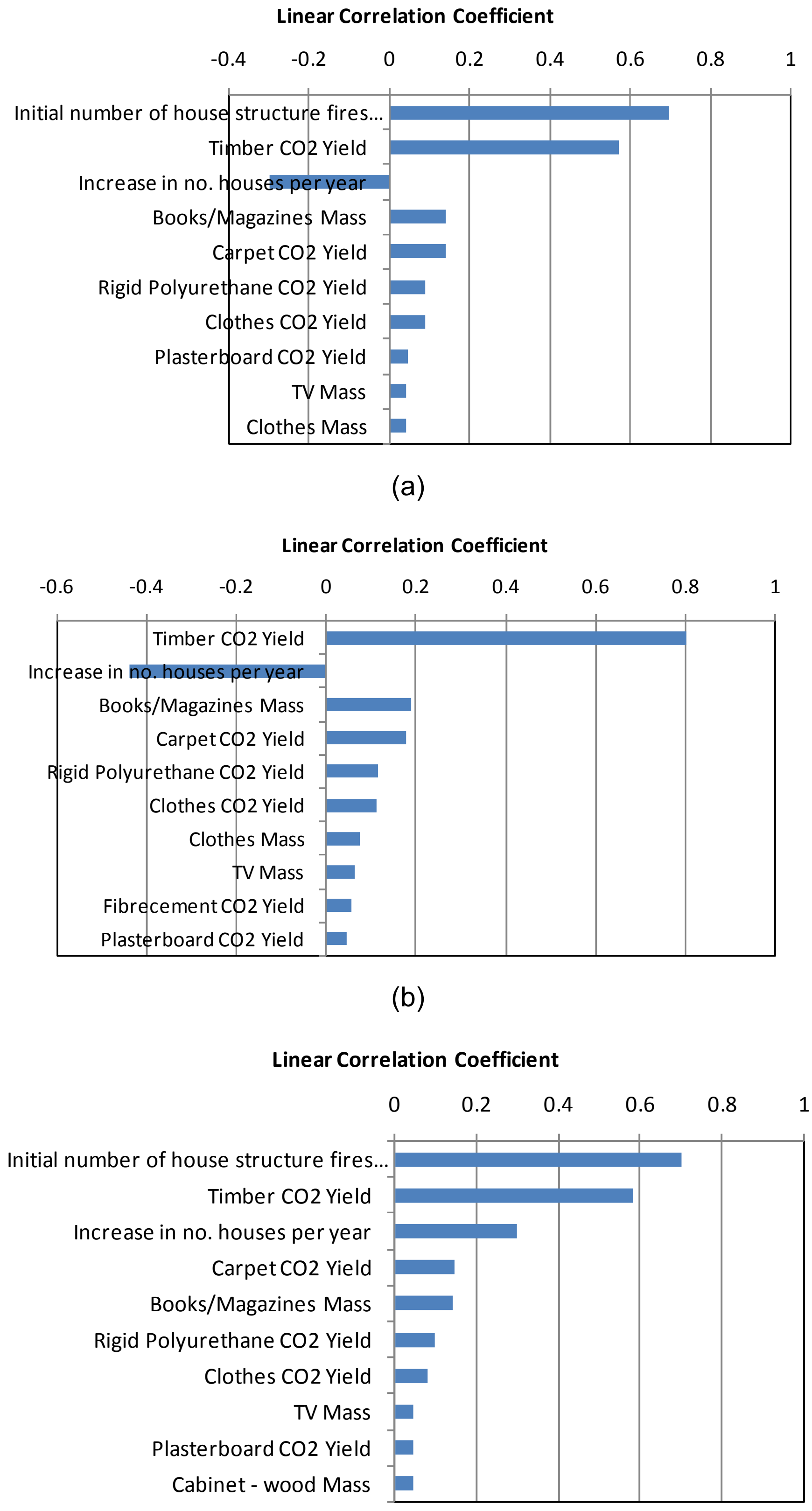


Figure 22: Summary of the results for Scenario 3 for the total CO_2 Equivalent released by NZ house fires with fire suppression continuing as reflected in the current fire incident statistics in (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

3.4.3.1 Sensitivity Analysis

The results for the Scenario 3 sensitivity analysis are summarised in Figure 23.



(c)

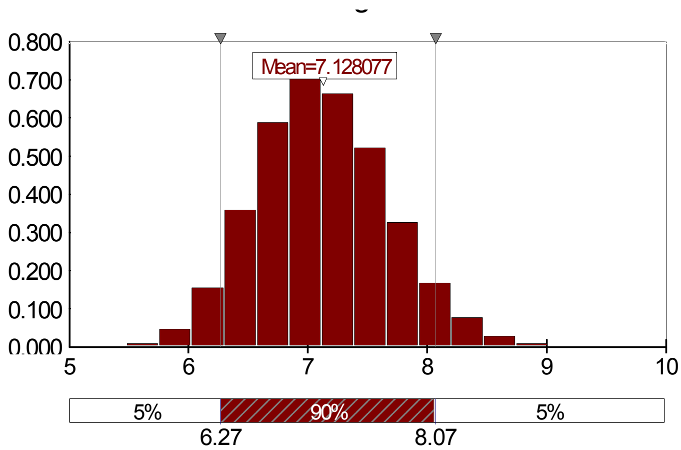
Figure 23: Summary of the top ten influential input parameters for the total CO_2 Equivalent released by NZ house fires with fire suppression continuing as reflected in the current fire incident statistics, based on fibre cement weatherboard correlation coefficients, for (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

3.4.4 Scenario 4: House fires where home sprinkler systems are present

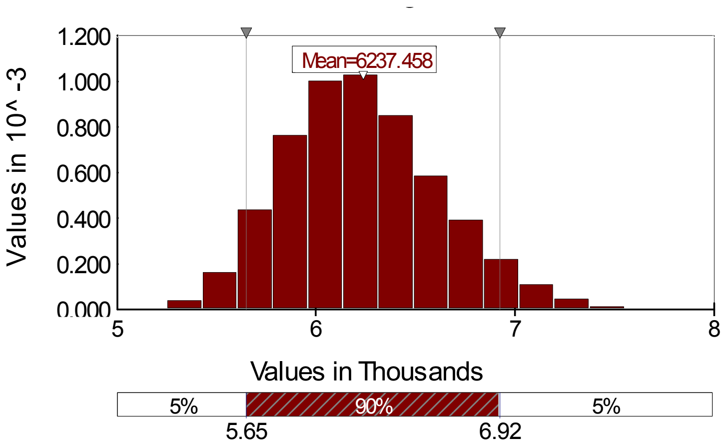
The results for Scenario 4 are summarised in Table 27 and Figure 24.

Table 27: Summary of the results for Scenario 4.

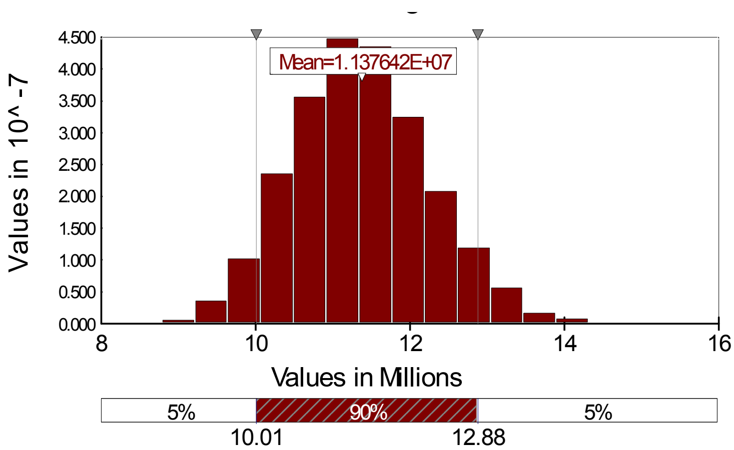
	Total CO_2 Equivalent Saved from being Released by House Fires with Home Sprinklers Present Compared to Scenario 3		
	kg(CO_2)/ household/ year	kg(CO_2)/ fire/ year	t(CO_2)/ year
Minimum	5	5,100	8,800
Maximum	10	7,700	15,000
Mean	7	6,200	11,000
Standard Deviation	0.5	390	880



(a)



(b)

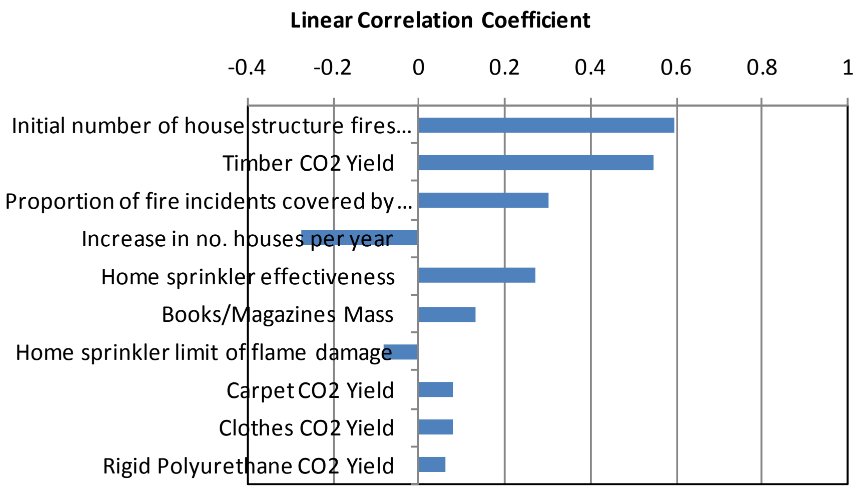


(c)

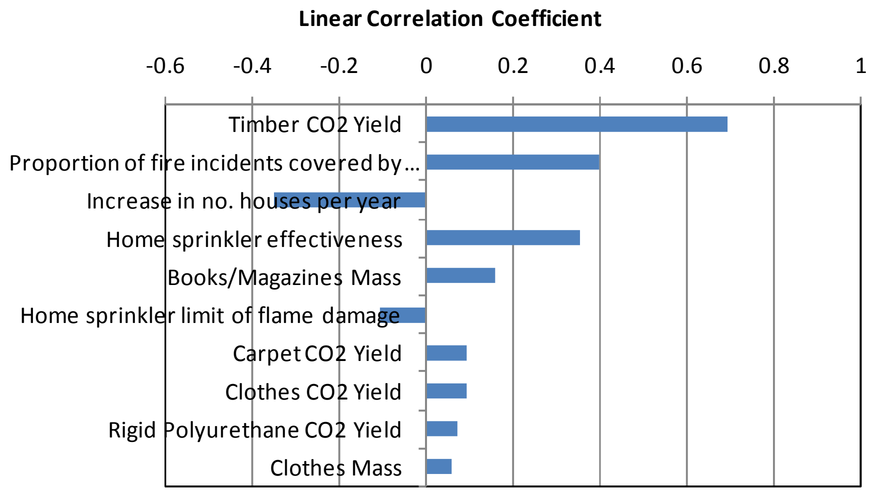
Figure 24: Summary of the results for Scenario 4 for the total CO_2 Equivalent saved from being released by NZ house fires with home sprinklers systems present in (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

3.4.4.1 Sensitivity Analysis

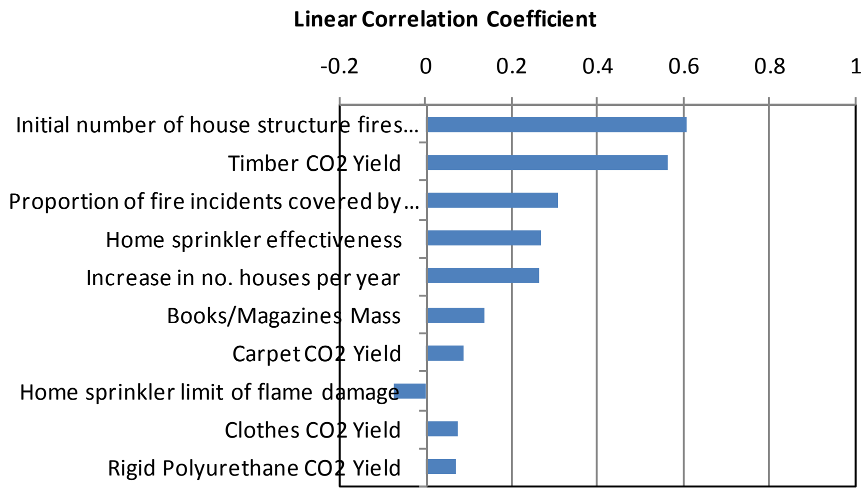
The results for the Scenario 4 sensitivity analysis are summarised in Figure 25.



(a)



(b)



(c)

Figure 25: Summary of the top ten influential input parameters for the total CO_2 Equivalent saved from being released by NZ house fires by home sprinklers systems present, based on fibre cement weatherboard correlation coefficients, for (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

3.4.5 Scenario 5: Increased equivalent floor area loss% per fire to 50%

The results for Scenario 5 are summarised in Table 28 and Figure 26.

Table 28: Summary of the results for Scenario 5.

	Total CO_2 Equivalent Released by House Fires with the Equivalent Floor area Loss Percentage Increased to 50%		
	kg(CO_2)/ household/ year	kg(CO_2)/ fire/ year	t(CO_2)/ year
Minimum	15	14,000	25,000
Maximum	25	20,000	38,000
Mean	19	17,000	30,000
Standard Deviation	1	800	2,000

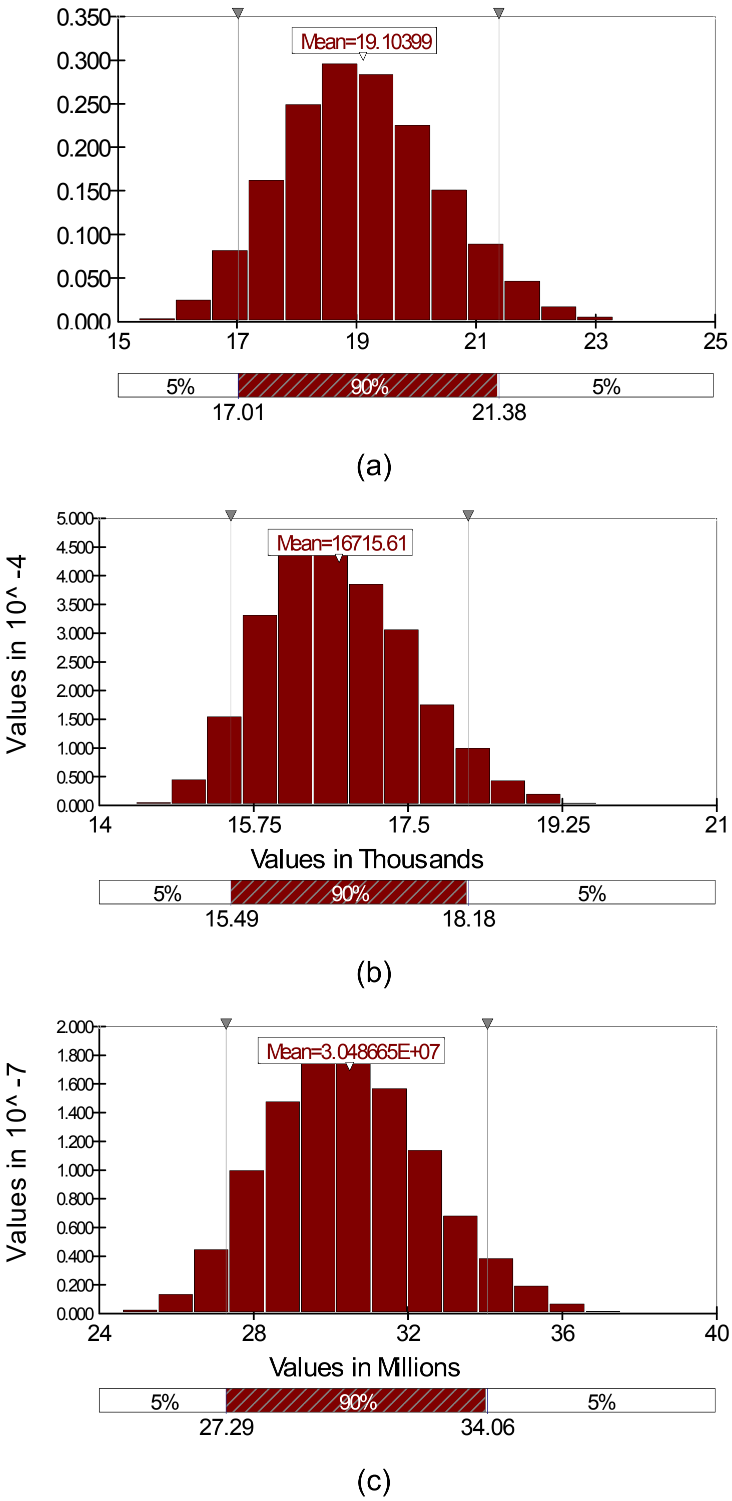
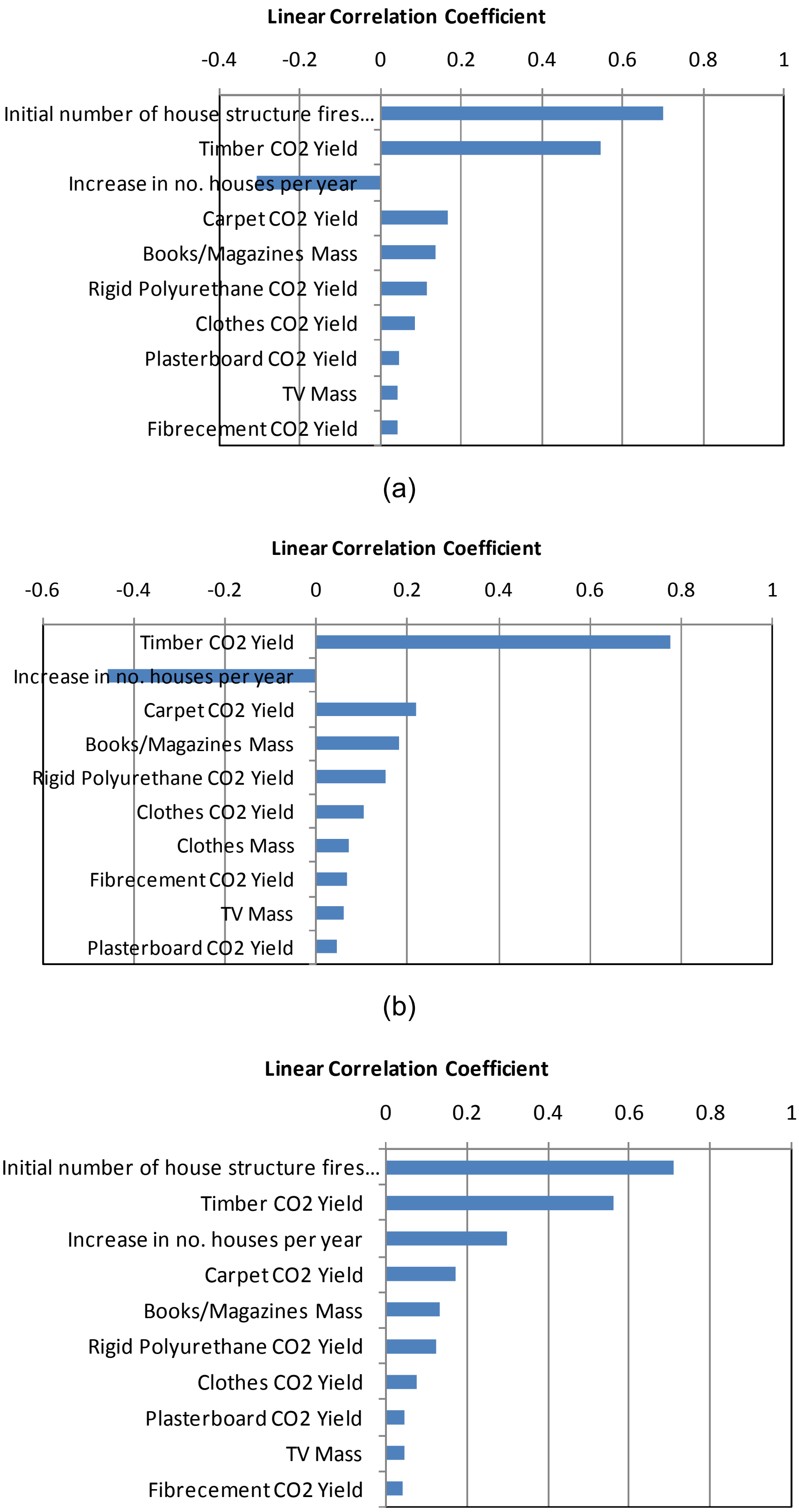


Figure 26: Summary of the results for Scenario 5 for total CO_2 Equivalent released by NZ house fires with the equivalent floor area loss increased to 50% in (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

3.4.5.1 Sensitivity Analysis

The results for the Scenario 5 sensitivity analysis are summarised in Figure 27.



(c)

Figure 27: Summary of the top ten influential input parameters for the total CO_2 Equivalent released by NZ house fires with the equivalent floor area loss increased to 50%, based on fibre cement weatherboard correlation coefficients, for (a) kg(CO_2)/household/year, (b) kg(CO_2)/fire/year, and (c) kg(CO_2)/year.

3.4.6 Discussion of Scenario Results and Analysis

The mean values for the CO_2 equivalents released from the complete fire loss of the structure of an exemplar house is approximately 27 to 38 t(CO_2), as shown in the results of Scenario 1 summarised in Section 3.4.1. The most influential input parameters for the estimates of CO_2 equivalency associated with the exemplar house structure were consistently associated with estimations of the amount of CO_2 yielded for timber, carpet, rigid polyurethane, fibreboard, plasterboard, polythene, doors, particle board and PVC. That is, the estimated values for CO_2 yield, extent of material burnt and mass for each of the components. These parameters were expected to have the most influence as they are the basis of the calculation for estimating CO_2 equivalents. Timber was expected to be highly influential component, because of the large amounts of timber involved with each of the exemplar house combinations considered (Table 20 and Table 23 and 25 of Robbins, Page & Jaques (2010)).

The mean values for the CO_2 equivalents released from the complete fire loss of the contents of an exemplar house is approximately 6 t(CO_2), as shown in the results of Scenario 2 summarised in Section 3.4.2. This represents approximately 16 – 22% of the CO_2 equivalents released from the complete fire loss of the structure of an exemplar house, for the assumptions used in this study. Therefore when exemplar structure and contents are combined, the structure contributes approximately 82 – 86% of the total CO_2 equivalents released during an exemplar house fire. The most influential input parameters for the estimates of CO_2 equivalents for the total loss of exemplar house contents were associated with books and magazines, clothes, television, cabinets, drawers and beds. Parameters associated with these items were expected to have a significant influence on results, since they are related to contents items of large collective mass and CO_2 yield.

Considering the house fires throughout New Zealand and the suppression strategies reflected in the fire incident statistics of the past five years continue for the next 50 years, the CO_2 equivalents released to the atmosphere was estimated at a mean value of 10 kg(CO_2)/NZ household/year or 9,000 kg(CO_2)/house fire/year, which is a mean total of approximately 16,000,000 kg(CO_2)/year (as summarised for Scenario 3 in Section 3.4.3). The most influential parameters are associated with the number of structure fires (relating to the specific parameters of the initial number of house structure fires that is used to set the proportion of houses that have a structure fire each year, and the increase in the number of houses per year), and the CO_2 equivalents associated with timber, carpet, books and magazines, rigid polyurethane and clothes.

Considering the house fires throughout New Zealand with the same proportion of houses have fire incidents based on the statistics of the past five years and the mandatory inclusion of home sprinkler systems in newly constructed houses and retrofit of existing houses (such that the entire building stock is retrofitted in 10 years), then from analysing the next 50 years the CO_2 equivalents released to the atmosphere was estimated at a mean value of 3 kg(CO_2)/NZ household/year or 4,000 kg(CO_2)/house fire/year, which is a mean total of approximately 5,000,000 kg(CO_2)/year. This is a reduction in the CO_2 equivalents released into the atmosphere compared to continuing the house fire suppression strategies currently reflected in the fire incident statistics (Scenario 3). The estimated mean amount of CO_2 equivalents saved from being released into the atmosphere was approximately 7 kg(CO_2)/NZ household/year or 6,000 kg(CO_2)/house fire/year, which is a mean total of approximately 11,000,000 kg(CO_2)/year (as summarised for Scenario 4 in Section 3.4.4). Considering the mean values of estimated CO_2 equivalents, for the scenario for the mandatory introduction of home sprinkler systems throughout New Zealand, approximately 60 – 70% of CO_2 equivalents could be saved from being released during house fires compared to the current situation of house fire suppression represented by the last five years of New Zealand fire incident statistics for structure fires (i.e. predominantly by NZFS personnel with portable suppression or appliances, etc).

The most influential parameters in the results of Scenario 4 were the same as Scenario 3 in addition to the effectiveness of a home sprinkler system and the maximum percentage of floor area that a home sprinkler system would limit flame damage to.

Considering the house fires throughout New Zealand assuming a effective decrease in the suppression strategies that are reflected in the fire incident statistics of the past five such that the equivalent floor area lost to flame damage is increased to 50% per house fire and this continues for the next 50 years, the CO_2 equivalents released to the atmosphere was estimated at a mean value of 19 kg(CO_2)/NZ household/year or 17,000 kg(CO_2)/house fire/year, which is a mean total of approximately 30,000,000 kg(CO_2)/year (as summarised for Scenario 5 in Section 3.4.5). This represents a mean increase of approximately 90% from Scenario 3 that assumes house fire suppression strategies remain similar to those reflected in the fire incident statistics of the last five years. The most influential parameters in the results of Scenario 5 were the same as Scenario 3.

3.5 Summary & Conclusions

Summary and important conclusions of this study include:

- A House Fire GHG Emissions estimate tool was developed.
- The House Fire GHG Emissions estimate tool is based on input parameters for:
    - Numbers of house structure fires per year,
    - Current numbers of housing stock,
    - Rate of increase of housing stock numbers,
    - Percentages of house floorareas lost to fire,
    - Types and amounts of materials involved in house structures,
    - Numbers and masses of items included in house contents,
    - CO_2 yields for materials and items included in the framework,
    - Effectiveness of suppression strategies considered, and
    - Extent and rate of installation of these suppression strategies in houses.
- The results of the House Fire GHG Emissions estimate tool are reported in CO_2 equivalents.
- The House Fire GHG Emissions estimate tool only considers the GHG emissions related to the fire loss of the house structure and contents.
    - Cradle-to-gate GHG emissions related to the replacement of house structure after a fire was included in a previous study by Robbins, Wade et al. (2007). The framework developed in this study was designed to be used in parallel with the previous study, with no double counting of impacts between studies.
- Construction of the NZ housing stock is diverse; therefore use of an exemplar house was used. Types and amounts of materials were estimated for exemplar houses representing the top six combinations of foundation, wall and roof claddings (Table 17). Similarly, numbers of items and masses of contents were estimated for an exemplar house.
- Because of the estimation of the housing stock using an exemplar house approach, the results are most relevant in terms of a national average.
    - The scenarios considered in this study for comparison use an analysis period of 50 years.

- Five scenarios were considered to demonstrate the concept of the potential usages for the estimation tool:
  - Scenario 1: Total fire loss of an exemplar house structure.
    - This scenario provided a baseline for the maximum GHG emissions per type of exemplar house structure.
    - The complete fire loss of the exemplar house structure releases approximately 27 to 38 t CO_2 Equivalent.
  - Scenario 2: Total fire loss of an exemplar house contents.
    - This scenario provided a baseline for the maximum GHG emissions for total house contents.
    - The complete fire loss of the exemplar house contents releases approximately 6 t CO_2 Equivalent.
    - Assuming a homogeneous fire loss of structure and contents based on floor area, house contents are associated with approximately 14 – 18% of the GHG emissions in this study.
  - Scenario 3: House fires with fire suppression remaining the same as reflected in current fire incident statistics.
    - This scenario estimated the GHG emissions from house fires assuming the fire suppression strategies remain similar to current strategies for the next 50 years.
    - The CO_2 Equivalent released to the atmosphere was estimated at an approximate mean value of 10 kg(CO_2)/NZ household/year or 9 t(CO_2)/house fire/year, which is a mean total of approximately 16,000 t(CO_2)/year for the house fires across the nation.
  - Scenario 4: Home fires where home sprinkler systems (according to NZS4517) are present with NZFS intervention using water (if needed),
    - This scenario estimated the savings in GHG emissions results assuming the mandatory installation of home sprinklers in every new house built and a rate of retrofit such that the current building stock has NZS4517 protection within 10 years compared to the results of Scenario 3 (i.e. an estimate of the savings of GHG emissions).
    - Implementing a home sprinkler strategy to protect the NZ housing stock (according to the assumptions of Scenario 4 was estimated to save approximately a mean value of 7 kg(CO_2)/NZ household/year or 6 t(CO_2)/house fire/year, which is a mean total of approximately 11,000 t(CO_2)/year compared to current suppression strategies reflected in the recent fire incident statistics (as used in Scenario 3).
    - This indicates a 60-70% (based on mean values) reduction of CO_2 equivalent GHG emissions could be saved from being released during house fires by the introduction of home sprinkler systems compared to the current suppression strategies represented by the recent NZ fire incident statistics.
  - Scenario 5: An increase in house fire losses to an equivalent percentage of floor area loss per fire of 50%.
    - This scenario estimated the fire suppression strategies used over the next 50 years were decreased from the current strategies (producing an equivalent percentage of floor area

fire loss per fire of approximately 29% per house fire, based on statistics) to 50%. This would be the equivalent of less NZFS intervention. This equivalent percentage of floor area loss per fire is a user input parameter.

  - The reduction in suppression strategies from those reflected in recent fire incident statistics (as used in Scenario 3, with an equivalent percentage of floor area fire loss of 29% per house fire) to a strategy that produces an equivalent percentage of floor area fire loss of 50% per house fire (Scenario 4) was estimated to increase the GHG emissions by 9 kg(CO_2)/NZ household/year or 8 t(CO_2)/house fire/year, which is a mean total of approximately 14,000 t(CO_2)/year
  - An increase in the loss of equivalent percentage of floor area fire loss per house fire from 29% to 50% (representing a 72% increase in fire damage during house fires), was associated with a 90% increase in GHG emissions.
  - The approach used in this Scenario may be used to explore the GHG emissions saving impact of the current NZFS house fire suppression strategies compared to generic conditions with less fire intervention (e.g. if the Fire Service didn't attend, etc.).
  - Similarly, the approach of this Scenario could also be used to assess the impact of potential new strategies for house fire intervention in terms of the GHG emissions impact saved for an increase in effectiveness (i.e. a reduction in house floor area fire loss).

- The most influential input parameters were found to be parameters related to the estimated number of fires per year (i.e. the initial number of structure fires per year, the initial number of housing stock and the rate of increase of housing stock) and types of material or item that contributed the most CO_2 (i.e. the mass or number of items per exemplar house for timber, carpeting, rigid polyurethane, books and magazines, clothes, etc). Sensitivity to these parameters is as expected, because of the assumption that house construction materials and contents were evenly distributed over the house floor area (i.e. location of individual fire starts were not included in the approach). For Scenario 4, where home sprinkler systems were introduced to the housing stock, the effectiveness of the system and the maximum limit of flame damage achieved by the system were also influential input parameters.

3.5.1 Future Developments

Recommended future work includes:

- Collection and collation of species yields associated with GHG emissions during material and item fire testing in addition to the current species yields associated with life safety.
- Development of a survey and database for estimates of residential contents, in terms of types of items, materials, masses and proportion of item mass of combustible material that would contribute to the fire load. If such details were available, then this would be useful for a range of studies including GHG emissions from house fires, as investigated here, as well as item-to-item fire spread and the impact of the change of amounts and types of home contents on the fire load and fire hazard, etc.
- As more detailed information becomes available and is collated, the framework developed here can be adapted to consider the GHG emissions impact of house fires based on proportions of fire events for different rooms of fire origin. This may be a useful contribution to other residential fire studies, enabling GHG emissions impacts to be incorporated into a broader study of impacts.
- The House Fire GHG Emissions tool can be used to assess the impact of a wider range of fire suppression strategies, where information on the effectiveness and potential GHG emissions associated with the strategy can be quantitatively estimated. Further research is required before other types of suppression strategies can be assessed using this framework.

4 Overall Conclusions

The NZFS began quantification work for their GHG emissions in 2008 with a report investigating their operational emissions. The current study was undertaken for the NZFSC to investigate emissions from both vegetation and house fires, and suppression actions associated with each. The vegetation part of this study was completed by Scion, and the house fire part by BRANZ. Two separate calculation tools were developed, with the intention that they be used by NZFS staff in each category.

In both tools, GHG emission outputs are calculated, and results presented in GHG equivalents, based on GWP_{100} values defined by the IPCC. These values allow a standard comparison of the anticipated potential effect that single or multiple fire incidents may have.

For the vegetation part of the study, a Microsoft Excel-based tool has been created to allow users to enter data about single or multiple fire incidents, and see the resulting emissions in an easily-readable format.

The tool allows inputs of:

- vegetation type;
- area burned;
- regional, seasonal and climatic influences;
- suppression action (both ground and air); and
- specific detailed fire parameters such as build-up indexes and fine fuel moisture codes.

This in turn allows outputs of:

- GHG emissions from vegetation fires;
- GHG emissions from suppression action;
- total GHG emissions with and without suppression action; and
- GHG emissions from Worst case scenarios.

The inputs are tied directly to comprehensive New Zealand data, such as the New Zealand Land Cover Database, historical climate & weather records, and New Zealand emission factors for vehicle fuels. This is supported with international data such as emission factors from vegetation burning. The final result is a tool based on robust scientific data that is still simple to use and understand.

The house fire GHG emissions estimation tool was created by BRANZ, and is intended to provide comparative results to investigate the potential impact of different fire intervention strategies. The tool is based on a range of input parameters including fire incident statistics, estimated materials and quantities involved in the structure and contents of an exemplar house, and effectiveness of different suppression methods.

An exemplar house was used as an estimate of the most common construction combinations and contents items for houses in New Zealand. Because of the lack of data, species yields were based upon data and information for well-ventilated fires. This was limited to average carbon dioxide (CO_2) yields. To account for the diversity in the NZ housing stock construction and contents and the flame damage for any individual fire event, the context of the national scope was used with an analysis period of 50 years. Results are expressed in terms of per year of this analysis period.

A selection of scenarios was considered so as to provide results to investigate the comparisons between the scenarios using the house fire GHG emissions framework developed here. The scenarios considered were:

1. total fire loss of an exemplar house structure;
2. total fire loss of an exemplar house contents;
3. house fires with fire suppression remaining the same as reflected in current fire incident statistics;
4. house fires where home sprinkler systems (according to NZS4817) are present with NZFS intervention using water (if needed in the cases where the home sprinkler system are not effective); and
5. house fires with the equivalent percentage of house area lost to fire increased to 50%.

The most influential input parameters were found to be parameters related to the estimated number of fires per year and types of material or item that contributed the most CO_2 on average. Sensitivity to these parameters was as expected. For Scenario 4, where home sprinkler systems were introduced to the housing stock, the effectiveness of the system and the maximum limit of flame damage achieved by the system were also influential input parameters.

In summary the framework developed during this study and described in this report is a useful tool for estimating GHG emissions for house fires for NZ and the potential impact of changes in fire suppression strategies.

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