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Integrating life cycle greenhouse gas emissions into the economic valuations of buildings: developing new mechanisms for mitigating greenhouse gas emissions liability

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ABSTRACT

Australia is going through a significant housing boom with 222,000 new homes needed each year to accommodate the estimated additional population of almost 9 million by 2050. With the growing effects of climate change it is critical that greenhouse gas (GHG) emissions implications of this new housing be considered. Mitigation strategies have been predominantly focused on decreasing operational GHG emissions in buildings, leaving embodied GHG emissions largely ignored. In order to achieve national targets, such as zero net emissions by 2050, it has become imperative to address GHG mitigation from a life cycle perspective. It has become necessary to couple this life cycle GHG mitigation with an annualised economic valuation so as to drive better decision-making, and to demonstrate the ecological cost through a much-needed economic mechanism.

Keywords: Greenhouse gas emissions; Life cycle assessment; Buildings; Valuation

INTRODUCTION

Australia's commitment to meet 2030 greenhouse gas (GHG) emission reduction targets is currently tracking well below optimum reduction levels (March, 2019). With atmospheric carbon dioxide at the highest levels ever recorded, the consequences are that a 1.5 degrees of warming is probable, leading to various environmental, social and economic challenges (Climate Council, 2015). Buildings account for 40% of GHG emissions globally, whilst in Australia, 25% of GHG emissions are attributable to buildings. Housing was responsible for 11% of Australia's GHG emissions in 2016 (Department of the Environment and Energy, 2018). Part of our reduction strategy should consider the new housing market, as with each home built, 30 – 50 years' worth of emissions are locked in. The booming Australian population is going to require housing, with an expected population potential of 41.4 million by 2050 if current levels of growth are maintained, thus requiring somewhere in the order of 7,750,000 new homes (HIA Economics, 2018). Consequently, better mechanisms are required to examine how to reduce the overall GHG emission impact of new housing.

The aim of this paper is to demonstrate a new way in which GHG emissions can be considered as an economic incentive or disincentive in the creation of new housing; through creating an economic valuation that integrates life cycle GHG emissions, incorporating embodied and operational GHG emissions. The paper firstly sets out the conceptual framework for the model; followed by a case study example and discussion of the challenges, limitations and practical policy implementation of such an approach, and desired effects this may have on changing consumer behaviour.

DEFINITIONS

Embodied energy: Energy associated with the production and construction of a building; Operational energy: Energy associated with the running of a building (such as heating and cooling); Greenhouse gas emissions: Gases that trap heat in the atmosphere, released predominately from the burning of fossil fuels.

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BACKGROUND

Buildings contribute to GHG emissions through their initial construction (those emissions associated with the extraction, manufacturing and transportation of materials and the construction process), through their ongoing demand for materials (those emissions associated with maintenance, repair, replacement and refurbishment during the building life), and through their operation (as illustrated in Figure 1). At present, efforts to reduce these GHG emissions focus predominately on operational aspects of buildings, with limited if any consideration for embodied GHG emissions. For example, climate change related policies and programs generally do not consider embodied GHG emissions (Zizzo et al., 2017). Further, often to achieve greater operational efficiency, increases in the embodied energy are a result (Crawford, 2013). Also, many of the systems available in the built environment to benchmark, measure and award building performance are focused either on the design potential of the building or the operational performance. Unfortunately, these generally ignore the contribution of embodied GHG emissions.

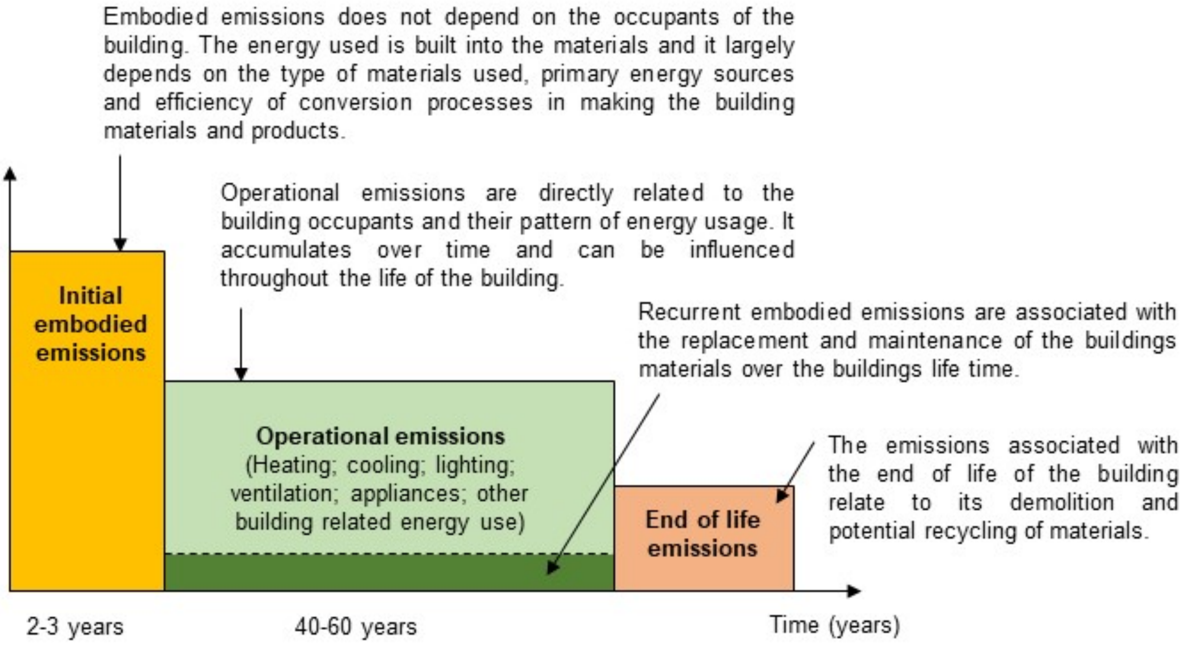

Figure 1 Greenhouse gas emissions by building life cycle stage

Based on Based on Ibn-Mohammed et al. (2013)

The main focus of policy in Australia, and to a broader extent globally, has been on the reduction of GHG emissions during the operational life cycle stage. This is primarily associated with the GHG emissions generated through the operating and running of a building (such as heating, cooling and lighting). At the global level it has been suggested that this life cycle stage accounts for a large proportion (72%) of annual building-related GHG emissions (Architecture 2030, 2019), while in the Australian context this stage has been shown to account for a quarter of building-related GHG emissions (Hosseinie and Martek, 2019).

In Australia, detached dwellings, on average, account for higher emissions than their international counterparts (largely due to the high proportion of coal used in electricity generation) (Jowsey and Kellet, 2012) and are considered some of the least efficient in the developed world (Jowsey, 2012). This, coupled with the significant housing demand, means that it has become imperative to tackle the life cycle GHG emissions of housing in Australia.

While we have some policies in Australia related to operational GHG emissions in residential buildings, this is generally only applied at the new construction end with the requirement for all new homes to achieve a 6 Star NatHERS rating (NatHERS, 2012). This program has a range of issues from modelling, to gaming of the software and the execution of the build; and often does not necessarily result in improved energy efficiency (Kordjamshidi and King, 2009). Whilst the Australian Capital Territory utilise a comparable system they have implemented a mandatory disclosure program to much success, with clear decision-making being demonstrated by both purchasers and occupiers in pricing (Fuerst and Warren-Myers, 2018). Yet, embodied

GHG emissions have been largely ignored even though they can account for between 20% and 28% of annual global building sector GHG emissions (Zizzo et al., 2017) and approximately 11% of Australia's national GHG emissions (Schinabeck and Wiedmann 2015). As operational efficiency increases, the impact of embodied GHG emissions in buildings will become increasingly significant and global and national targets will not be met without approaching building GHG emission reduction from a whole life cycle perspective (Brownbill, 2019). In addition, despite over a decade of energy saving analyses and cost-benefit analyses looking at profits and energy savings, limited consumer engagement has occurred (Yang and Lam, 2019), particularly in the residential sector in Australia (Pitt and Sherry, 2014).

Further, current approaches fail to proactively engage consumers to make better decisions, particularly in the choice of materials that would potentially reduce embodied GHG emissions, in addition to operational GHG emissions reductions and actions in the use of buildings. With embodied GHG emissions representing such a significant proportion of a household's GHG emissions, it is critical that this aspect is considered in conjunction with the operational energy across a building's life cycle. There is an urgent need to consider embodied GHG emissions and to capture both embodied and operational emissions together in creating an assessment scheme that can aid decision-making while also having an influence on consumer behaviour during the lifetime of the building.

A regulatory approach needs to be taken in order to generate a better system that considers both the embodied and operational GHG emissions across the life cycle of a building. One way in which this can be done, is to create a mechanism or lever that is understandable and has an immediate effect on purchasers and occupiers of property. Understanding the value argument has had much discussion in practice, in markets and in academia; particularly in the role of sustainability and other levers used in order to change consumer behaviour (Spangenberg and Lorek, 2019). There has been much discussion about mandatory versus voluntary approaches, particularly in the context related to energy efficiency (Säynäjoki et al., 2017, ASBP, 2014, Dixit et al., 2012). However, mandatory reporting programs have demonstrated the greatest effect and also demonstrable changes in consumer behaviour in the buying or renting of property (Brounen and Kok, 2011, Hyland et al., 2013, Fuerst et al., 2015, Kahn and Kok, 2014, Stanley et al., 2016)). Certainly, over the past decade clearer relationships have identified the capitalisation of energy efficiency in building values, rents and sale prices across the world in both commercial and residential markets. Learning from the past two decades of policy and rating tools, this paper suggests a more holistic approach to incorporating all GHG emissions across the life cycle, and contrived in such a way that consumers can readily understand the impact and financial implications of their choices in the purchasing of a new home, or in future decision related to existing buildings.

Whilst Carbon Rights attached to land was established in 2003 under the *Carbon Rights Act 2003,* which enables a Carbon Right to be registered to the certificate of title of land. A carbon right is defined as being 'the right to the benefits and risks arising from carbon sequestration and release on a specified parcel of land' (Landgate, 2017).Whilst its' registration and identity are in existence, and the rights guaranteed, the value is subject to market dynamics and ultimately market value. Further, once a Carbon Right is registered, there are also Carbon Covenants, that can be applied positively and negatively. The Carbon Right and Covenant is related to the sequestration and release comprised in vegetation and soil absorption of carbon dioxide. As yet, there is no built environment equivalent in Australia; but anticipate that in the future as GHG emissions and their measurement, quantification and value become prevalent in society; mechanisms and legal entity will be developed. Learning from the past two decades of policy and rating tools; this papers suggests a more holistic approach to incorporated all GHG emissions across the lifecycle be considered including embodied and operational energy; and contrived in such a way that consumers can readily understand the impact and financial implications of their choices in the purchasing of a new home; or in the future of any home or building (this is future research). Further, this research may present a possible methodology and the initial development of Carbon Rights for the built environment.

METHOD

Conceptual Model

From a valuation perspective, there is the implicit assumption of *in perpetuity*, yet by ignoring the GHG emissions associated with buildings over their entire life, the contribution of buildings to meeting GHG emissions targets is lost. Further, environmental economics would suggest that incentive structures can be used to alter decision-making (Tietenberg and Lewis, 2016); if reductions and better consideration of the GHG emissions of new buildings was considered at the outset of a building design then greater reductions could be achieved. Therefore, there is growing importance in assessing and capturing GHG emissions of buildings in order to create appropriate reduction schemes, reduce GHG emissions across the life cycle, and to calculate offsets, sequestration and penalties for the emission of GHGs.

The conceptual model is shown in Figure 2, which attempts to incorporate the initial embodied GHG emissions, recurrent embodied GHG emissions, end of life embodied GHG emissions and the operational GHG emissions over the life of a building. These are combined to comprise a total life cycle GHG (LCGHG) emissions liability. These can then be offset by sequestered GHG emissions, or generation of energy or other offsets for GHG emissions that might be undertaken. This provides the asset side of the equation. The asset side provides a modelled total life cycle GHG emissions for a building. For the development of new housing, a current market carbon price would be utilised to demonstrate the effective cost of the building's life cycle GHG emissions. This could then be annualised to provide an understanding of the recurrent probability of the ongoing GHG liability for the building. Key limitations and areas for future research are around estimating effective building life and the implications this has on the modelling, the estimation of carbon prices into the future and whether carbon prices will astronomically increase as carbon-pricing policies are determined at a national and globally level (Aldy and Stavins, 2012, Stavins, 2019), and identifying the most effective mechanisms for reducing GHG emissions associated with the various stages of a building's life.

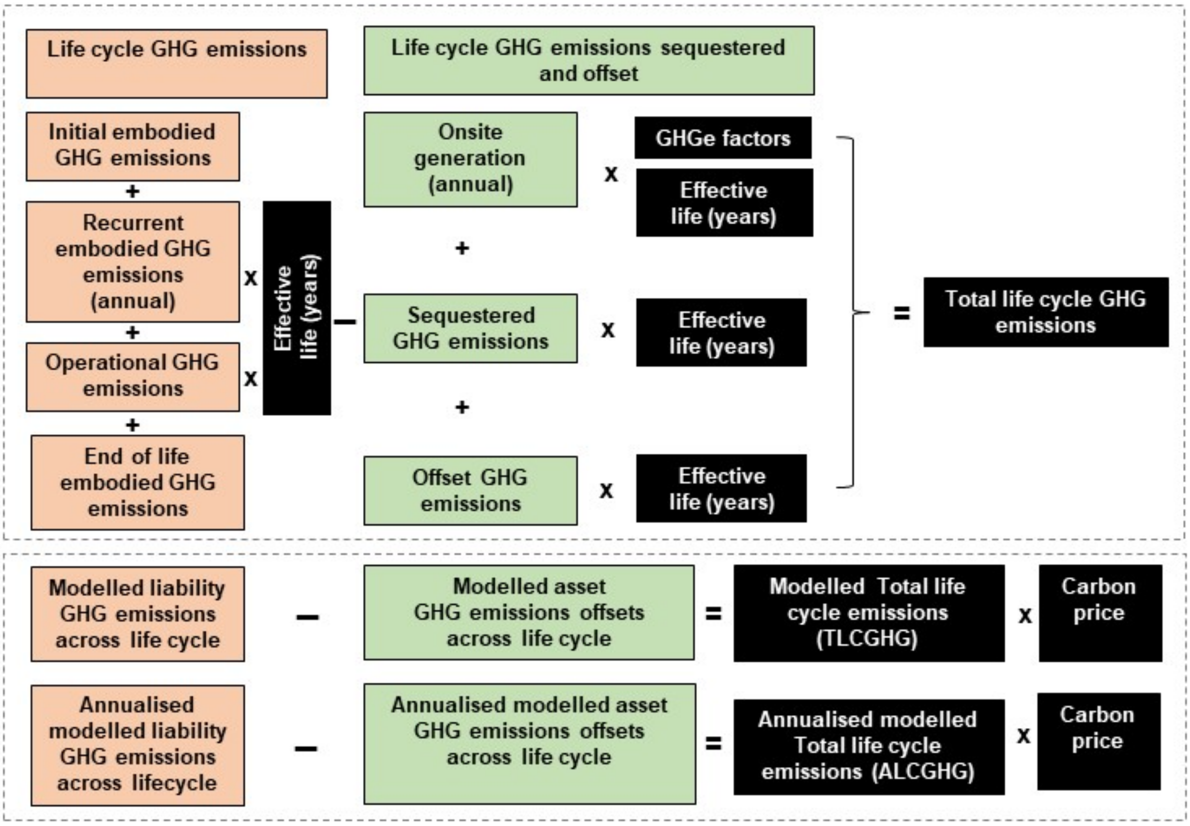

Figure 2 Conceptual Model Stage 1 – Modelling life cycle greenhouse gas emissions of new housing

The modelled total life cycle GHG (LCGHG) emissions would provide the initial basis on which potential developers, new home builders and prospective owners could consider the liability and potential financial implications of their choices. To move beyond just yet another modelled concept; and to engage decision-makers and actual occupiers in changing their behaviour, this modelled approach then needs to be engaged with an annualised engagement program. The embodied aspects would be annualised as shown in Figure 3, while the actual operational aspects and onsite generation are taken from actual annual data, then processed to provide the net annual operational GHG emissions of the asset. This then provides an annual life cycle GHG emissions figure which can then be valued to extrapolate and demonstrate understanding of the ongoing financial liability.

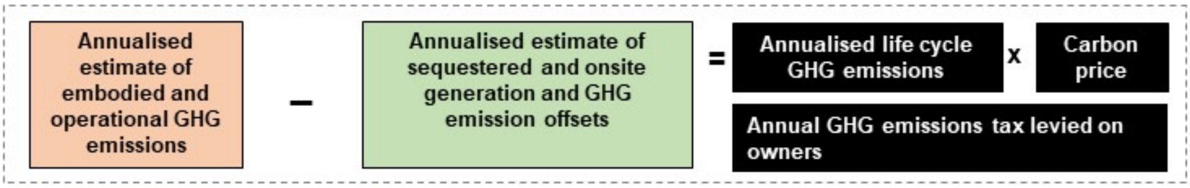

Figure 3 Conceptual Model Stage 2 – Valuation and estimate of annual life cycle greenhouse gas emissions liability

Capturing and valuing environmental implications, in this case the GHG emissions related to buildings, is encroaching on the decade long debate in economics regarding the valuing of environmental concerns which is split into two key areas: ecological economics and environmental economics (Tietenberg and Lewis, 2016). Environmental economics focuses on the neoclassical approach whereby economic incentives (or disincentives) are used to shape human behaviour to achieve enhanced human welfare. It is with this approach in mind that the valuation of GHG emissions associated with buildings and examining mechanisms to create and generate responsibility, through financial levers, is considered, in order to drive better decision-making at the outset.

Valuation of GHG emissions has been attempted using various approaches, namely the *damage cost avoided approach, the abatement cost estimate, willingness-to-pay estimates* and *market pricing of carbon (*Dobes et al., 2016*).* The variability and uncertainty in the first three approaches can often generate unrealistic figures and the implications for how this should then be interpreted for housing is complex and likely confusing. Thus, the approach to utilise the market price of carbon, at the date of assessment, should be utilised at least in the first instance, lending itself towards current valuation practice of real estate in the assessment of market value, the utilisation of market evidence to ascertain current consideration; further, as this would then also reflect current pricing (which will likely vary depending on future political and economic approaches to tackling climate change); thus having the ability for this to be a considered 'market' rate for carbon or a 'defined' rate generated by government. Other approaches also include the econometric approaches to valuing environmental and natural resources from a non-market perspective (Haab and McConnell, 2002). These approaches are established in welfare economics; and comprise parametric models and distribution-free models for contingent valuation, in addition to several approaches to willingness-to-pay and its use as a contingent valuation approach. Table 1 depicts current practice for valuing carbon dioxide equivalent emissions, although none consider the built environment explicitly.

Table 1 Current international practice for valuing carbon dioxide equivalent emissions

Jurisdiction	Department	Method	Mid-range value per tonne of CO_2e	PPP USD 2013	Remarks
Australia	Transport	Abatement cost	A$34.75	22.8	Source: Austroads (2014)
New Zealand	Transport	Damage cost	NZ$40	27.2	
	Health and Environment	Carbon prices	NZ$6.5 (March 2015)	4.4	For cost effectiveness analysis
France	Transport	Abatement cost	€42.05(2010 € for 2015)	51.1	Source: OECD (2015)
Germany		Damage and abatement cost	€80 (2010 € for years to 2030)	105.6	
Japan		Damage cost	US$25.70 (2013 $)	25.7	
The Netherlands		Abatement cost	€78 (2010 € for 2015)	96.5	
Norway		Abatement cost	NOK210 (2013 NOK for 2014)	22.8	
Sweden		Fuel tax and CO_2	SEL1.08 per kg (2010 SEK for 2015)	126.6	

UK	All departments	Abatement cost	£61 (non-traded) (2013 £ for 2015)	92.2	
US	All departments	Damage cost	US$11 (2007 $ in 2015)	12.1	

Note: CO_2e values for Australia and New Zealand were first inflated to 2013 process in domestic currency using GDP deflators and then converted to USD using PPP conversion factors. GDP deflators and PPP data are sourced from The World Bank. Other CO_2e estimates were sourced from OECD (2015).
Source: Dobes et al. (2016, Table A5.1)

As with any approach that attempts to generate greater efficiencies and reduction in GHG emissions, this often comes at a cost; and with affordability being a composite concern of governments, there is likely a need to create benchmarks reflecting a level achievable and for everything that is greater; otherwise there might be a greater affordability issue when people are reluctant to build new homes, and with the growing population there is going to be extant need to develop more housing into the future. However, how does the communication of the cost of GHG emissions be portrayed to consumers, in a format that they can effectively understand. Further, not just looking at the energy bills expected into the future, of which there is still scant information about this; but consider the whole of life GHG emission implications. By creating an economic value of the GHG emissions, this can be communicated in monetary terms. This could then be considered side-by-side with cost-benefit options of how one could improve the initial embodied energy GHG emission contribution, whilst balancing long term operational GHG emissions. This would also generate a focus on the initial design decisions made at the outset, but also consideration for ongoing occupant behaviour. By using annual consumption data this may further encourage greater efficiencies, but would require some level of normalisation and testing of benchmarks so as not to overtly disadvantage. Once benchmarked, validated and normalised, this approach could be utilised as a policy lever to drive better behaviour in not only initial decision-making of the design and construction, but ongoing utilisation of the asset over time through the application of a tax.

Given the uncertainty of climate change and the implications of its effects, the possibility of determining the carbon price earlier in the equation is not realistic and consequently needs to be a live consideration; in such that the model then becomes dynamic when utilised as an annual measure from a policy context and capturing of GHG emissions through creation of a building related tax utilising this formula. The effective and perceived value would also be uncertain and subject to change; which by demonstrating an annual form of tax liability means that the potential of this to be considered in a similar manner by prospective purchasers, owners and occupiers would be in the nature of current council rates, land tax and other operational expenses considered in the owning of property (Oates, 1969, Palmon and Smith, 1998). Thus, those properties with high LCGHG liability, would likely have a higher annual liability which could be partially offset by occupier behaviour; but would still act as an indicator of future costs for prospective purchasers of the asset. Therefore, from an economic theory perspective, it would suggest that one would choose a property with a lower LCGHG liability and/or accordingly factor into the price offered the economic impact of the LCGHG liability. This would then be reflected in the market prices and subsequently market values of properties.

Methodology and Data

The process for calculation of the GHG emissions across the life cycle of the building (LCGHG) takes a staged approach; similar to that depicted in Figure 2 of the conceptual model. The initial calculation would be completed by adding together the initial embodied GHG emissions (*IEGHG*) of a house (h), the annual operational GHG emissions (*OGHG*) multiplied by the service life of the house (SL_h), and the recurrent embodied GHG emissions (*REGHG*). The annual GHG emissions offset by the onsite generation of the house (OG_h) and the annual sequestered GHG emissions ($SGHG_h$) are then subtracted to complete the calculation. This paper uses a case study house to demonstrate how this is performed.

The IEGHG emissions were calculated using the Path Exchange (PXC) hybrid approach which has been shown to provide the most comprehensive analysis of embodied emissions compared to other approaches (Crawford, 2011). The IEGHG of the main materials that make up the fabric of the house (such as the ground floor; external walls; internal walls; roof and internal finishes) is calculated by multiplying specific material quantities by an embodied GHG emissions coefficient for each material.

The OGHG emissions have been estimated using a dynamic simulation approach, which has been shown to provide reliable results (Reeves et al., 2012, Wang and Zhai, 2016). The simulation software package Green Building Studio was used and has been shown to be a suitable software tool for decision-making at an early design stage (Stumpf et al., 2011). The recurrent embodied GHG emissions were calculated using the PXC hybrid approach and material service life values for materials, for the period of analysis considered (i.e. 12 years). See Equation 1.

$$LCGHG_{hYx} = IEGHG_h + REGHG_h + (OGHG_h \text{ x } SL_h) + (OG_h \text{ x } SL_h) + (SGHG_h \text{ x } SL_h) \qquad (1)$$

Case Study

The case study used here is a detached brick veneer house located in Victoria, Australia. The rationale for selecting a detached house is that at present 69% of housing activity is attributed to detached dwellings, with the rest comprising of 8% semi-detached and 23% multi-units (HIA, 2018). Approximately 90% of these dwellings have 3 or 4 bedrooms (Robb and Lucas, 2016), with 3-bedroom dwellings being the most common (CommSec, 2017). For this case study, one of the most popular floor plans was selected from the largest house builder in Australia, Metricon (Metricon, 2019), as shown in Figure 4. The house comprises four bedrooms, separate sitting entry area, open plan kitchen family and dining, master with ensuite, family bathroom with separate toilet, laundry and a double car garage, of 230 square metres. The key characteristics of the house are detailed in Table 2. The house has a concrete waffle pod ground slab and concrete roof tiles with timber trusses, brick veneer external walls, single glazed windows with aluminium framing. Insulation used for the home comprises R2 glasswool batts in the walls and (denoted by the red line in Figure 4) and R4 glasswool batts in the ceiling. The house does not have any provisions for onsite generation and carbon sequestration has not been included.

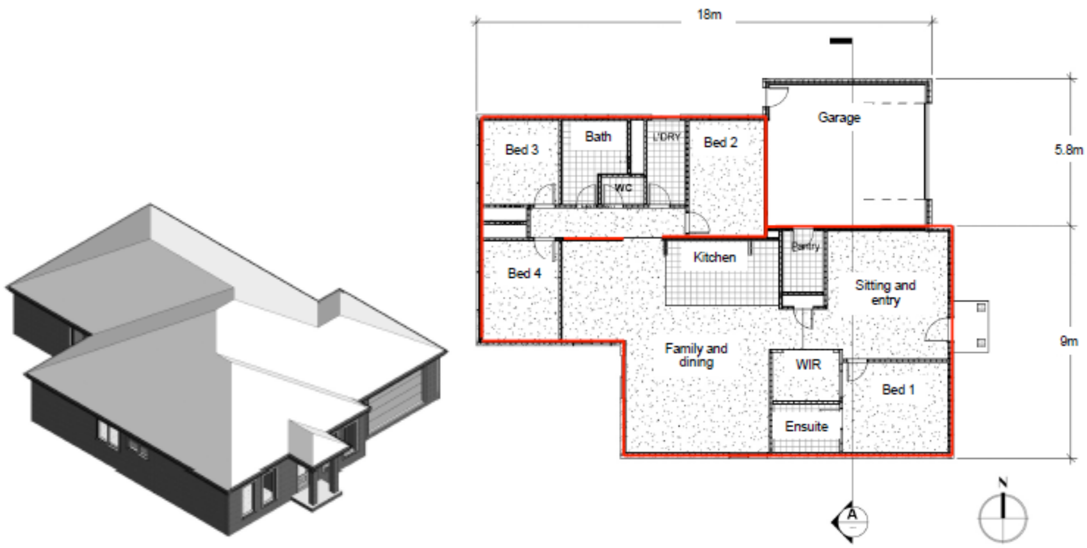

Figure 4 Floor plan and view of the case study house

Table 2 Characteristics of case study house

Building item	Detail	Building item	Detail
Areas and dimensions		**Materials and finishes**	
Area	230 m²	External wall	Brick veneer with 90mm timber frame
Number of bedrooms	4	Roof	Concrete tile with timber truss
Ceiling height	2400 mm	Windows	Clear single glazed with aluminum frame
Length and width	19.7m / 14.8m	Floor	Concrete waffle pod slab
Heating		**Insulation**	

Heating	Gas ducted 3 star heating unit	External wall	R2 Glasswool batts
Water heater	Solar hot water heater 200 litre	Ceiling	R4 Glasswool batts

RESULTS

Stage 1 results of the case study house are detailed in Table 3. The IEGHG of the case study house is 167.9 tCO_2e (0.72 tCO_2e/m^2). The OGHG emissions of the house is 8.5 tCO_2e per annum. The service life of the house considered for the purpose of this paper is 12 years (including Year 1) so as to determine the LCGHG emissions until the year 2030. The analysis at this stage has not included sequestration or onsite generation, as these are an area for future research.

Table 3 Life cycle greenhouse gas emissions for the case study house

Type	**Description**	**Total** (tCO_2e)
$IEGHG_h$	Initial embodied GHG emissions	167.9
$OGHG_h$	Annual operational GHG emissions	8.5
$REGHG_h$	Recurrent embodied GHG emissions (at 2030)	34.5
$LCGHG_{hY2030}$	Life cycle GHG emissions (at 2030)	304
$SeGHG_h$	Sequestration	NA
$GeGHG_h$	Onsite generation	NA

The next step was to multiply the LCGHG emissions of the dwelling by the market price for carbon so as to understand effective cost of the building's life cycle emissions. The price used for this study was A$16.50/t (as reported by RepuTex Energy (2019) and further noted to be a 12-month high). The total carbon cost for Year 1 is A$2,911. The subsequent year's cost is roughly A$140 (with a 2% carbon price inflation each year), based on annual OGHG. However, by year 10 the cost increases to A$4,990, factoring in recurrent embodied GHG emissions (which in this case relates to the replacement of internal finishes such as paint which has an average lifetime of 10 years (Fay et al., 2000). The total carbon cost at 2030, based on the LCGHG emissions of the case study house is A$5,341.

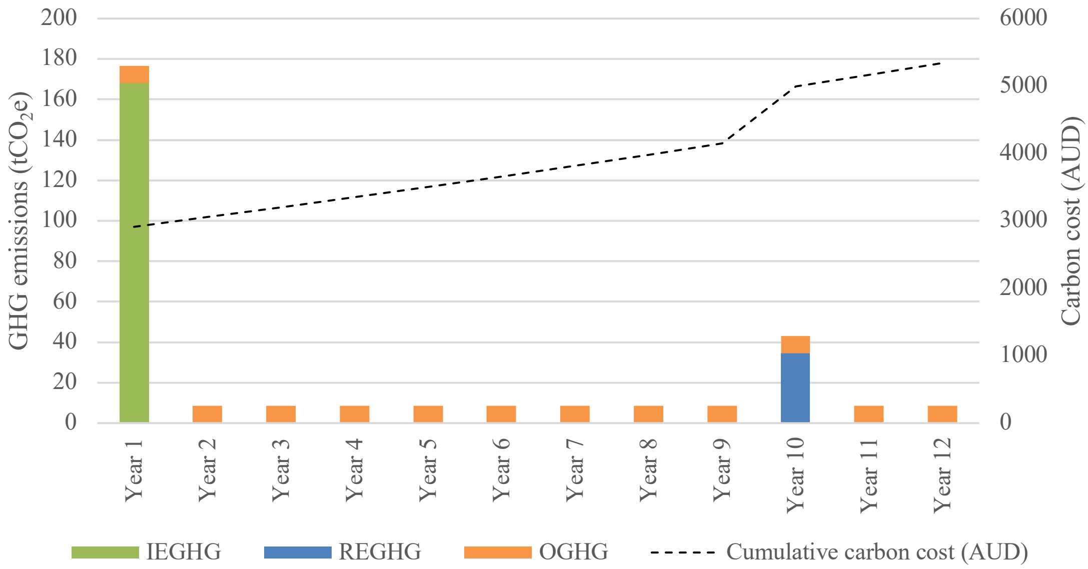

Figure 5 Life cycle greenhouse gas emissions and carbon cost for case study house

Stage 2 then looks to anticipate how this information could be applied in a policy context as a form of property tax. The subsequent calculation of how the potential GHG emission could be applied to form an economic value for individual years could take several forms, depending on where the carbon cost is capitalised and its timing. Table 4 presents several scenarios of modelling how the valuation approaches could be considered and calculated. The research borrows from the income valuation approaches, specifically in the concepts of cash flow analysis and discounted cash flow analysis. The analysis presented here, examines the implications of different approaches and considerations of calculations all based on the income cash flow approach. However, how and when prices are determined for calculation of the economic value of GHG emissions has implications for the end consideration of value. In considering how this can be communicated, the analysis examines the approach from a payment perspective of valuing the different components, from a singular present value, a discounted present value and then annual cash flows that are then considered as a whole. The first approach, examines a once off assessment could be made to cover the initial and recurrent embodied GHG emissions and forecast operational GHG emissions. This would comprise the forecast calculation of the carbon price multiplied by the embodied and operational GHG emissions. This would comprise a total carbon cost of A$3,339 to cover embodied GHG emissions plus A$1,683 for forecast operational GHG emissions. In whole terms, with no discounting, this could be attributed as a once of payment at the beginning of the build.

Option 2 considers the sum of the initial and recurrent embodied GHG emissions and divides it by the life of the house, in this case 12 years. These annualised emissions are added to the actual forecast operational emissions (or if on a yearly basis, the actual emissions) then multiplied by the carbon price for that year. This results in the initial embodied GHG emissions effectively equating to a larger financial burden, because of the carbon price inflation year on year calculated on an annual basis for the lifecycle.

Option 3 and Option 4 monetise the emissions using the carbon price from the designated year (i.e. initial embodied GHG emissions in year 1 and recurrent embodied GHG emissions in year 10). Option 3 is generated using a discounted cash flow approach, creating a total present value and then the cumulative future cash flow is annualised to generate an annual payment. However, this wouldn't then have ongoing benefits of changing consumer behaviour; consequently, consideration on an annual basis of the actual GHG emissions should be incorporated from bill/rate information. This could potentially also incorporate any further recurrent embodied GHG emissions from further additions to the structure or major renovation. Therefore, the annualised estimate of the embodied GHG emissions would provide a baseline of A$310 per year (using the initial carbon price), and depending on actual energy consumption, further operational GHG emissions multiplied by the current carbon tax would then be payable, on an annual basis.
Therefore, Option 4 calculates the present value of the two embodied emissions values; then annualises the payments over the 12-year period, to which individual year on year operational emissions-related costs can then be added, thus starting at an annual payment of A$450 per annum increasing to A$484. However, should the occupier amend their actions this would result in variations occurring in the annual payment. The advantage of the last approach is that it fully allows for variations on a year by year basis depending on operational energy demand, while Option 3 is calculated considering a forecasted amount for operational energy demand.

Table 4 Scenarios for estimating the economic value of life cycle greenhouse gas emissions associated with housing

	Initial embodied GHG emissions	Recurrent embodied GHG emissions	Operational GHG emissions	Initial Assessment	Assessment frequency	Sum of Assessment
Option 1. Total GHG emissions - current carbon price	Actual emissions calculated and multiplied by fixed carbon price	Forecast emissions calculated and multiplied by fixed carbon price	Annual forecast emissions multiplied by fixed carbon price	$A5,023	Once off	A$5,023
Option 2. Total embodied GHG emissions annualised, operational GHG emissions for individual years x yearly carbon price	Sum of initial and recurrent emissions, divided by service life of the house, multiplied by the current carbon price		Annual forecast or actual emissions multiplied by current carbon price	A$419	Annual	A$5,614

(No discounting)						
Option 3. All GHG emissions are calculated at current carbon price rate	Actual emissions calculated and multiplied by carbon price in year 1	Forecast emissions calculated and multiplied by carbon price at year of material replacement	Annual forecast or actual emissions multiplied by current carbon price	A$398	Annual	A$5,332
Option 4. Present value of total embodied GHG emissions plus annual operational GHG emissions	Sum of initial and recurrent emissions annualised using relevant carbon price and present value formula		Annual forecast or actual emissions calculated and multiplied by current carbon price	A$450	Annual	A$5,596

Note: Discount rate 2%; Carbon price assumed at A$16.50/t escalated at 2% p.a.

DISCUSSION

The LCGHG emissions for the 2019 for a typical detached house in Victoria, Australia were found to be 176.4 tCO_2e. This figure was based on the IEGHG of 167.9 tCO_2e and OGHG emissions of 8.5 tCO_2e, which was been found to be comparable to figures from similar studies (such as Crawford, 2013, Stephan, 2013, Ren et al., 2013). When multiplied by a carbon price of A$16.50/t this equates to a carbon cot of almost $3,000 for the case study house. When taking into consideration the growth in GHG emissions over time by the house, by 2030 the LCGHG emissions would increase to just over 300 tCO_2e. When taking into account that in Victoria alone, 74,974 houses were built in the last year (HIA, 2018), the total IEGHG emissions alone for all new houses would equal in the vicinity of 13 $MtCO_2e$, which equates to over A$200 million in carbon costs. If this is taken further and one factors in that Victoria is estimated to need 717,000 new houses by 2030 (Australian Government, 2009), this brings the LCGHG emissions for all new detached houses to around 200 $MtCO_2e$. This is much higher than the 104 $MtCO_2e$ for all sectors of the economy that the Victoria State Government (2018) predicted for 2020. Based on a need for a further 1.6 million new houses in Victoria by 2050, it brings the total LCGHG to over 800 $MtCO_2e$, as illustrated in Figure 6.

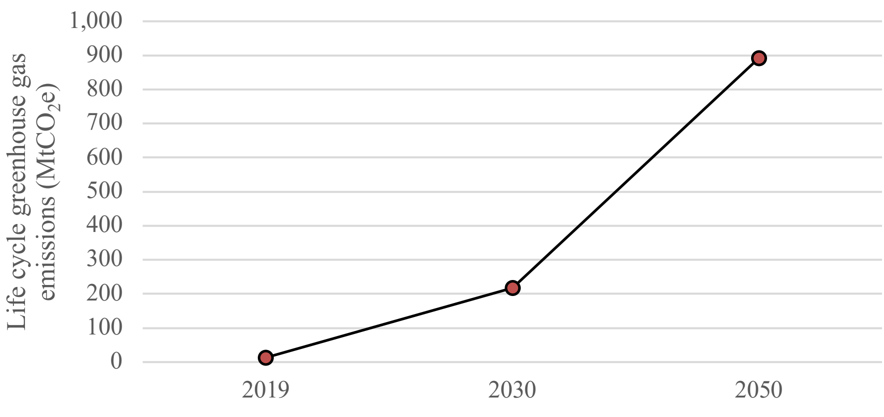

Figure 6 Estimated life cycle greenhouse gas emissions for all new detached houses from 2019 to 2050 in Victoria, Australia

Seeing as Victoria has set a target to reduce its GHG emissions to net zero by 2050, these case study figures make it quite apparent that first of all the predicted emissions (which exclude embodied emissions) greatly underestimate the amount of GHG emissions associated with new construction as these targets will not be met if the current trajectory of building design and construction is maintained. These underestimated figures emphasise yet again how important it is to look at GHG emissions from a life cycle perspective, one can no longer keep ignoring the embodied life cycle stage as it has been shown to represent a large portion of total life cycle emissions (for the case study dwelling it has been shown to represent 70% of the total LCGHG emissions). Secondly from a financial perspective (based on the current carbon price) will end up costing the state and the homeowners an exorbitant amount of money.

It is important to be aware that due to the subjective nature of life cycle studies a large amount of uncertainty is inherent in any life cycle study (Säynäjoki et al., 2017). When interpreting the LCGHG results of this study a larger amount of uncertainty is associated with the final values. Hybrid embodied results have a variability range of ±40% (Crawford, 2013) and operational results have a variability range of ±20% (Juodis et al., 2009). Several assumptions have also been made as part of this study's calculations. These assumptions include that the operational energy needs of the case study dwelling will remain the same throughout the POA and that the energy generation will remain the same (for example there will not be a greater inclusion of renewables). In addition, conservative growth measures have been applied to carbon pricing and inflationary figures; which depending on the global approach to carbon pricing could stimulate a range of scenarios in regards to where pricing might escalate to.

Creating an approach which demonstrates to the potential purchasers the GHG emission cost of their new home in financial terms; either as an initial cash payment; or what has a greater effect is the ongoing annual payment required. By focusing on an annualised payment of the GHG emissions; two aspects are achieved; firstly provide a greater understanding of the real cost of GHG emissions; secondly, through the annual figure (Options 2 or 4) behaviour change can be altered due to the real time assessment of operational energy use. Options 2 and 4 would enable not only behaviour changes in the home; but adjustment to where consumers source their energy and the subsequent energy mix they are using, which would then reduce their annual liability.

Further research is obviously required to further explore sensitivities relating to approaches used; carbon pricing; discount rates; inflation rates and life cycle timeframes. In addition, consideration of energy generation; and sequestration needs to be incorporated into the equation to examine how this may provide positive benefits to the overall equation; which may then provide further encouragement for onsite renewable energy generation.

CONCLUSIONS

Greater efforts are needed within the property sector to mitigate growing GHG emissions. While significant emphasis has been placed on reducing operational GHG emissions over recent decades, embodied GHG emissions have become a significant component of the life cycle emissions attributable to property. Yet, there has been very limited focus on their reduction. Increasingly stringent national and global emissions targets will further exacerbate the already considerable liability of the emissions for property owners, occupiers, investors and developers.

This paper has demonstrated a number of options for valuing the life cycle GHG emissions of new housing, considering emissions liability across the entire housing life cycle. These options range from a single upfront payment to cover actual initial embodied emissions as well as forecast recurrent embodied and operational emissions over the life of the house; to an ongoing annual payment that covers annualised forecast embodied emissions and actual operational emissions. It is hoped that by valuing the emissions occurring across the entire housing life cycle, particularly the embodied emissions, that this would provide a greater incentive for emissions reduction within the property sector.

This paper demonstrates the extent of housing life cycle emissions and emphasises the scale of the potential GHG emissions liability for the state of Victoria, Australia, given the predicted number of houses needed over the coming decades. Further research is needed to test the broader implications of the various valuation options presented here and how these may be integrated into existing housing and environmental policy in Australia.

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