South African log resource availability and potential environmental impact of timber construction

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We investigated the South African log resource availability and the potential global warming impact of an increasing wood-based residential building market. We have shown that, with the use of wood resources currently exported as chips, as well as planting trees in areas that have been earmarked for afforestation, a sustainable residential building market, where all constructions are wood-based, is possible. However, in the short term, imports of wooden building components might be necessary if rapid growth in wood-based building occurs. Basic modelling analyses show that if the market share of wood-based buildings increases to 20% of new constructions, the embodied energy and global warming potential of the residential building sector could decrease by 4.9%. If *all* new constructions were wood based, the total embodied energy and global warming potential of the residential building sector could decrease by up to 30%.

Significance:

- A novel finding of this paper is that sufficient local log resource options exist to realise a sustainable all-wood residential construction market in South Africa.
- The likely implications in terms of embodied energy and potential global warming impact of using wood-based materials for residential buildings compared to conventional brick and mortar or reinforced concrete buildings were also analysed and found to be favourable.

1. Introduction

Numerous studies have shown that timber is not only renewable, but is also the best performer across most environmental impact factors when compared to building material alternatives such as steel and concrete, with particularly good performance in terms of greenhouse gas emissions.[1-6] Trees absorb carbon dioxide during the photosynthetic process to form wood, which is a largely carbon-based material. Timber structures effectively store a similar mass of carbon that was removed from the atmosphere by the tree and fixed as wood.

Approximately 70% of local residential roof truss systems are wood based.[7] However, only 1% of new residential housing structures in South Africa can be described as wood-based structures. [Note: wood-based building systems in this paper comprise timber frame, cross-laminated timber and other wood-based materials such as orientated strand board or plywood.]

The rest are brick and mortar or cement block with timber roof truss systems (Slabbert W 2017, email communication, November 15). In some countries, such as the USA, Canada and Australia, well over 90% of residential housing is timber frame.[8] According to Palmer[8], timber frames account for about 70% of all housing stock in developed countries, representing close to 150 million homes.

According to Beradi[9], the building sector in developed countries produces up to 40% of their total greenhouse gases (GHG). In South Africa, it is estimated that the energy used in the construction of buildings is responsible for about 27% of South Africa's total anthropogenic carbon dioxide emissions.[10] The environmental footprint of residential buildings in South Africa can be reduced in various ways. Firstly, the traditional brick and mortar building materials and constructions can be replaced by lower environmental impact systems such as timber frame or even new timber panel systems (i.e. cross-laminated timber). Secondly, various strategies to decrease the operating impact of buildings can be introduced (solar energy, insulation, LED technology, etc.).

Currently, operational life-cycle energy requirements of conventional buildings are higher than the embodied energy.[11] However, as low-energy and near-zero-energy buildings (and employing energy-saving technology) become more prevalent, embodied energy will become a larger part of the total building energy requirements.[12,13] The objective of this study was to determine whether local forest resources would be able to supply the required wood for substantial growth in wood-based residential development in South Africa by an analysis of (1) the residential housing footprint in South Africa, (2) available log resources for wood-based buildings and (3) likely building-system environmental impacts.

2. Background and literature review

2.1 Residential housing footprint in South Africa

The annual South African population growth rate decreased steadily from 2.8% in 1972 to 1.3% in 2017, and is expected to continue to decrease in the near future.[14] Data on national completed residential buildings demonstrate a rise and fall development curve during the period 2000–2016. Compiled building data from Statistics SA[15] were selected as background data for further scenario modelling. These data include all completed residential buildings reported by South African municipalities (Figure 1). Take note that not all government-subsidised low-cost housing units were included as, in many cases, these units are reported and financed separately. These data were not available and could not be included in this study.

According to Statistics SA, over the period 2000–2016, the average house in South Africa was 114 m^2 and an average of 54 111 houses were constructed annually. On average, 1 040 651 m^2 of houses smaller than 80 m^2, 3 436 302 m^2 of houses bigger than 80 m^2 and 1 665 624 m^2 of flats and townhouses were completed annually.

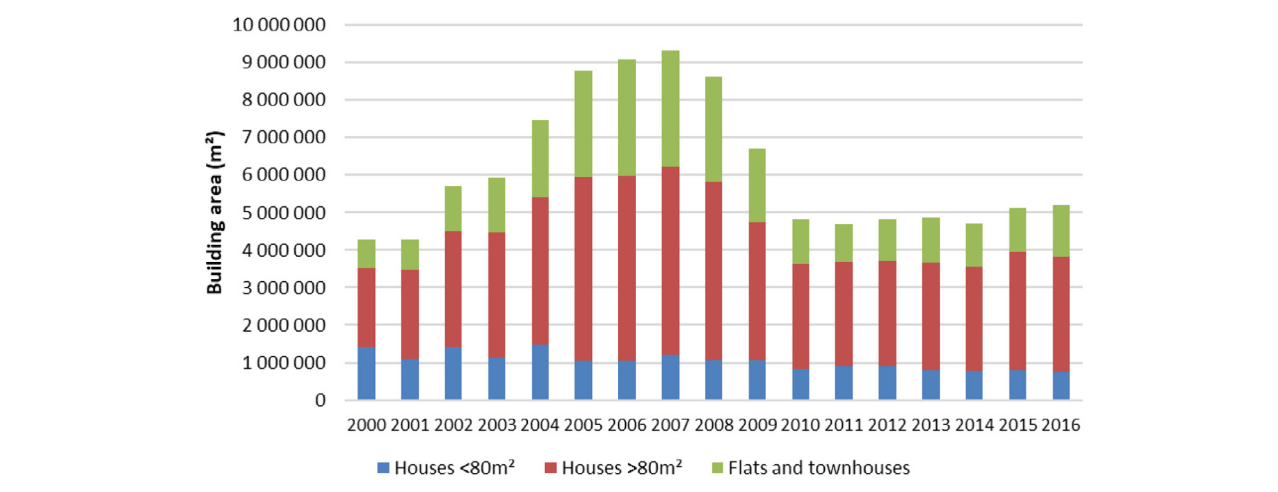

Figure 1: South Africa's completed residential building area.[15]

2.2 *Market growth potential of wood-based residential buildings*

The extent to which new building systems can increase its market share in a country is dependent on many factors. Cost, resource availability, legislation, building culture, user's perception of a building method and type, skills availability and the perception of the environmental credentials of the building system, can play a role also.

In Germany, the number of new, single family and two-family houses built with wood has tripled in the past 25 years from 6% of the market share in the early 1990s to 18% in 2017.[16] The UK timber frame housing share of all new buildings reached 27.6% in 2015 and was predicted to rise to around 32% by 2018.[17]

South Africa is generally perceived as a country with limited forest resources. However, the South African plantation forestry industry is very productive. Despite having only about 1.8 million ha covered with closed canopy plantations and forests, the annual national industrial roundwood production was 17.5 million m^3 in 2015.[7]

Wood resources for future houses can come from either (2.2.1) a change in forest resource use, (2.2.2) new forest plantings, or (2.2.3) imports. South Africa's industrial roundwood production is used mainly for the production of pulp and board products (51%), sawn lumber (24%) and chip exports to Asia (17%) (Figure 2). In 2016, sawn timber production was 2.3 million m^3 of which 70% was used in construction, mainly for roof truss material.[7] Sawn timber resources are already oversubscribed and mainly used in house construction (roof trusses), therefore it is not likely that any additional timber could be sourced for future house construction from the current sawmilling resource. Table 1 provides estimates of potential future log resources available for timber-based housing components such as sawn timber and board products.

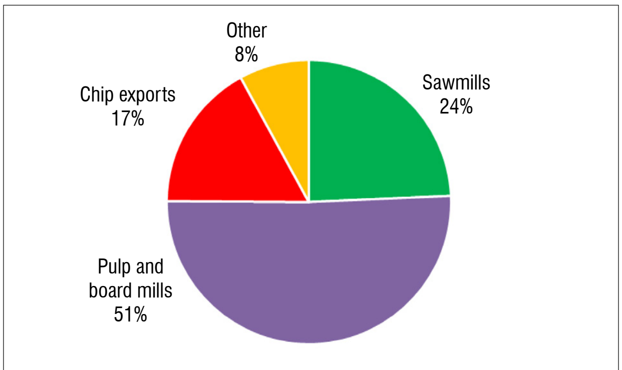

Figure 2: South African industrial roundwood consumption by different sectors.[7]

Chip exports is the most likely available resource which could potentially be used for future housing elements. Export chips are either from eucalypt or wattle trees. Recently developed new technology such as green-gluing of eucalypt timber enable the manufacture of engineered, high-grade structural timber from fast-grown pulp wood resources.[20] Cross-laminated timber (CLT) would offer another product solution for young eucalypt or trees grown for pine pulp or wood chip. According to Guo et al.[21], CLT is a relatively new product. CLT is a European developed product, with an 80% installed market share in Europe, but countries like Canada, the USA and Australia are also showing rapid market growth.[21] Globally, production increased from 25 000 m^3 in 1996 to 600 000 m^3 in 2014 and was estimated to reach 1 000 000 m^3 in 2016. Other housing components that could potentially be manufactured from young pulp tree resources include products such as oriented strand board, and possibly parallel strand lumber.

2.2.1 Wood chips

Over the past 10 years, an average of 3.5 million tons of wood chips was exported from South Africa annually.[7] A slight decrease in chip exports was evident in 2015 with only 2.3 million tons exported. Depending on chip moisture content and using a sawmill volume recovery rate of 40%, an average of 2.3 million tons of chips would result in 2.6 million m^3 sawlogs or 1.04 million m^3 of sawn timber. The national average sawmill volume recovery rate of softwood sawmills in South Africa is 47.4%.[22] Generally, smaller diameter logs such as pulp logs will result in lower volume recovery rates.[23] Some processors of small diameter eucalypt logs into green, unseasoned sawn timber obtain volume recovery rates of 50% but do not include shrinkage loss as they sell products wet off saw.[24] A volume recovery rate of 40% was assumed to be a reasonable estimation of dry sawn timber that will be recoverable. For board products such as oriented strand board or reconstituted lumber such as parallel strand lumber, the volume recovery rates will depend on the process and final product, but could vary between 70% and 80%.[25] In this study, a conservative 40% recovery rate was assumed for a timber product such as CLT and 55% for a combination of sawn timber and board products (i.e. for timber-frame building).

2.2.2 Afforestation

In South Africa, afforestation with fast growing plantation species is also a possibility. Although available land considered suitable for plantations is limited in South Africa, communal areas of 100 000 ha were earmarked by the government for afforestation in the Eastern Cape. There is also about 40 000 ha private farmland available in KwaZulu-Natal for afforestation.[26] If successful, these afforestation plans have the potential to produce an additional annual sustainable supply of 2.07 million m^3 roundwood or about 1 million m^3 of timber within about 24 years of establishment, if destined for sawlogs only. These figures were calculated using a mean annual increment of 14.8 m^3/ha/year for softwood sawlogs[27] and the national average sawmill volume recovery rate of 47.4%[22].

There is also potential for afforestation in areas previously not considered suitable for plantation forestry. Recent research shows the potential of dryland forestry in the Western Cape coastal areas.[28] Von Doderer[19] identified 175 000 ha of potential dryland forest plantation area in the Western Cape. This area could result in a potential annual yield of 738 255 m^3 of timber (based on a mean annual increment of 8.9 m^3/ha/year and a 47.4% volume recovery rate) within about 30 years of establishment. In addition, research by Wessels et al.[29] showed that some species grown on the dry west coast of southern Africa could produce high-value sawn timber. Undoubtedly there are other areas in the country where trees can be grown in dry areas previously not considered suitable for forestry. However, research is required to quantify this potential.

2.2.3 Import

Although it is not always the preferable option from a socio-economic perspective, import of sawn timber is also a possibility. Research from other countries has shown that where shipping is over short land transport distances, the environmental impact of timber imports can be relatively low.[30] In 2016, South Africa only imported 2% of its annual structural timber.[22] Currently, the three major import countries include Brazil, Chile and Zimbabwe. Past trade and most likely future countries for import include Argentina, New Zealand, Germany, Zambia and Mozambique (Stears A 2020, email communication, February 1). Board products such as oriented strand board, the preferred option for timber frame housing wall covering, are currently only available from imported sources. However, research will be required to quantify the environmental impacts of importing these materials into South Africa.

Table 1: Potential future log resources available for timber-based housing components such as sawn timber and board products

Description	Log volume (m^3/year)	Availability (years)†	Data source
Current chip export resources: eucalypt and wattle logs	2 600 000	Immediate	Forestry South Africa[7]
Current pulp, board, and other log resources: eucalypt, wattle and pine	11 850 000	Immediate	Forestry South Africa[7]
Import logs or wood products	–	Immediate	
Afforestation Eastern Cape / KwaZulu-Natal: 140 000 ha	2 070 000	24 (8)	South African Department of Environmental Affairs[18]
Dryland afforestation Western Cape: 175 000 ha	1 557 500	30 (10)	Von Doderer[19]

†Values in parentheses indicate availability for pulpwood rotations and thinnings.

From the data in Table 1, it can be seen that – excluding imports and current pulp, board, and other log resources – there could be an estimated 6.23 million m^3 of log resources available for wood house components in the future. This amount could be processed into between 2.9 and 4.9 million m^3 of products depending on the product type and recovery rates. If timber frame construction requires on average 0.3 m^3 of processed wood-based products per square metre (similar in volume to CLT according to Table 2), it means that between 9.6 and 16.3 million m^2, or between 84 210 and 142 982 houses of 114 m^2, can be built sustainably per annum. This is nearly double the amount of formal annual residential development at present. This clearly indicates the resource potential for an increased wood-based construction market in South Africa.

2.3 Water availability

The South African forest industry has informally standardised on Forestry Stewardship Council (FSC) certification and, already in 2007, 97.8% of all industrial roundwood produced in South Africa was FSC and ISO certified.[31]

Numerous research projects on water use efficiency and stream flow reduction of plantation species in South Africa have been completed.[32,33] Most of the research indicates that water balance is a location- and species-specific issue, and is likely to be a constraint in future, for example, on high water use agricultural food crops.

According to Von Doderer[19], the introduction of selected plantation species may have a positive effect on the water balance, for example when replacing intensive agriculture under irrigation or when establishing short rotation plantations on land that is covered with so-called alien invader plants.

Although it is likely to be a constraining factor in some instances, water availability for afforestation in this study has been considered, as (earmarked dryland) areas not meeting the minimum water requirements were excluded in the land availability assessment by applying the so-called aridity index.[19]

2.4 Building system impacts

In 2014, cement-based building products such as mortar, screed, plaster, concrete and paving accounted for 3.59 million tons carbon dioxide equivalent ($mtCO_2$ eq.) GHG emissions or 29.4% of the emissions of the major building product groups in South Africa. An additional 3.36 $mtCO_2$ eq. (27.6%) of the emissions of the major building product groups was caused by masonry wall elements. More specifically, concrete hollow blocks and clay brick production contributed 60% and 40%, respectively, of masonry GHG impact.[13] Concrete stock blocks require a considerable amount of GHG-generating cement. Clay stock brick production requires energy intensive processes and the major GHG emissions arise from fossil fuel burning to fire brick kilns.[34] For South Africa, no data on embodied energy (EE), global warming potential (GWP) or life-cycle analysis for timber frame or wood-based building systems could be found.

Until now, the world has relied heavily on CO_2-intensive concrete development for building structures.[35] On the other hand, wood-based

Table 2: Research study results on building system embodied energy and global warming potential impacts

Building system	Description	MJ/m^2	CO^2 eq./m^2	Wood (m^3/m^2)	Gross floor area (m^2)	Life cycle (years)	Country	Year	Source
Brick	Low energy	5588	527.17[a]	0.1[b]	231	50	Australia	2017	Thomas and Ding[39]
Timber frame	Low energy	4717	445.00[a]	0.3[b]	231	50	Australia	2017	Thomas and Ding[39]
Reinforced concrete	Conventional	1541	308.2	–	4 floors	50	China	2017	Guo et al.[21]
CLT	Low energy	847	-84	–	4 floors	50	China	2017	Guo et al.[21]
Reinforced concrete	Conventional	3095.2[a]	292	–	4 floors	50	Sweden	2014	Dodoo et al.[40]
CLT	Conventional	1208.4[a]	114	0.27[c]	4 floors	50	Sweden	2014	Dodoo et al.[40]
Brick	Conventional	5400	509.43[a]	–	192	70	Italy	2010	Blengini and Di Carlo[41]
Brick	Conventional	6132	578.49[a]	–	150	30	Spain	2006	Casals[42]
Timber frame	Standard light	2212	208.68[a]	–	94	100	New Zealand	2004	Mithraratne and Vale[43]

[a]These results were obtained by multiplying a factor from the South African primary energy production and greenhouse gas emissions ratio in 2014.[13]
[b]Brick and timber-frame wood volume per square metre was obtained from Pajchrowski et al.[44]; the timber frame house had an all wood-based ground floor, first floor and roof structure.
[c]CLT (cross-laminated timber) showed a slightly lower volume of wood per square metre, most likely due to a reinforced concrete foundation and ground floor.

systems have been gaining market share in some areas[16,17] and have a comparatively lower CO_2 and EE impact. Bribian et al.[36] report that laminated wood absorbs 582 kg CO_2 per m^3 (not incinerated at end of life), while reinforced concrete emits 458 kg CO_2 and steel 12 087 kg CO_2 per m^3. In the same way, Ferguson[37] reported that rough-sawn timber produces 750 MJ/m^3, concrete 4800 MJ/m^3 and steel 266 000 MJ/m^3. Although these differences are quite large, material quantities do not enable any realistic building system comparisons in terms of building area because not all building systems require the same amount and format of materials per unit area.

A building system review by Cuchí et al.[38], performed in Spain, showed overall average GWP emissions of 500 kg CO_2 and EE of 5754 MJ for all building materials considered per building area (m^2). In another life-cycle energy study of brick and timber residential buildings, Thomas and Ding[41] compared 10 standard Australian brick buildings to similar thermal and structural performing timber designs. Three life-cycle stages were analysed, including materials and construction, maintenance and end-of-life over a 50-year life cycle. Compared to Cuchí et al.'s[38] findings, the material and construction phase resulted in similar EE and GWP impacts per square metre (Table 2).

Embodied energy carries an increasing importance in residential life-cycle impacts. Chastas et al.[11] performed an in-depth literature review which considered 90 life-cycle energy analysis case studies of residential buildings over a 50-year life cycle and constructed in the past decade. The results showed an increasing percentage of EE in the transformation from conventional to passive, low-energy and near-zero-energy buildings. EE dominates in low-energy and near-zero-energy buildings with a share of 26–57% and 74–100%, respectively.

Embodied energy and GWP of buildings, particularly in residential dwellings, can be very complex to determine. Studies based on life-cycle analysis methodology and newly developed product category rules[45] for buildings, were selected as the most valid data sources from which to derive the normalised building impacts. Table 2 summarises the best available literature results for building system EE and GWP impact per square metre, compiled from multiple international sources. Mean volume of timber (including wood-based panels) per building system was also included.

It is important to note that operational, maintenance or end-of-life energy were not included and were assumed equal for all systems. End-of-life energy contributed on average less than 2% of total life-cycle energy for both timber frame and brick cladded homes.[39] In the same way, no notable differences between timber frame and brick home maintenance energy over 50 years was evident. In terms of CLT and reinforced concrete demolition energy demands, due to lack of CLT system demolition energy data, it was assumed equal.[21]

3. Methodology

3.1 Log resource analysis

The findings in Section 2 clearly show the timber resource potential for wood-based residential development in South Africa. Based on these findings, we continued with the environmental impact analysis by comparing selected scenarios as seen in Section 3.2. Table 3 presents a summary of the (potential) annual sustainable log resource supply and associated wood-based development coefficients for the South African sawmill industry. The values and volume/building recovery coefficients in Table 3 originate from Figure 1, Tables 1 and 2 and Section 2.2. These data (Tables 2 and 3) formed the basis for the final analysis as depicted in Figures 3 and 4.

A conservative approach was again followed and the 73% of houses (bigger and smaller than 80 m^2) was selected as timber frame systems and 27% (flats and townhouses) as CLT. Compared to timber frame, CLT is a very new building system, therefore an even higher timber frame market could have been assumed. In that case, a higher percentage (i.e. 73%+) of timber frame systems would realise a higher log to product recovery and ultimately equate to more potential homes. It is important to note, in terms of resource availability, that wood chips result in an immediate potential log resource, whereas afforestation could take up to 30 years to supply in log demand.

3.2 Building system impact

Four potential residential building scenarios were selected based on the existing international examples of growth in wood-based development, available building technology and local potential log resources. Table 4 presents these scenarios and input values for South Africa: current (1% residential wood-based buildings), 10%, 20% and 100% residential wood-based buildings. The 10% and 20% growth scenarios were based on market growth values in wood-based buildings experienced in western European countries such as Germany and England over a period of about two decades. The 100% scenario is an extreme value to illustrate the environmental impact of constructing only wood-based residential buildings. Mean building area values for houses smaller than 80 m^2, houses larger than 80 m^2 as well as flats and townhouses are indicated in Figure 1. Most applicable building system impacts (from the grey shaded areas in Table 2), i.e. brick and timber frame building, were assigned to all houses smaller and bigger than 80 m^2 whereas reinforced concrete and CLT system impacts were assigned to the remaining flats and townhouses portion. In each case, the carefully selected building system (i.e. brick, timber frame, reinforced concrete and CLT) with its impacts, either best represented South African building and climate conditions or provided the most conservative analyses in terms of GWP.

Building system impact values here represent EE impacts for all processes required to produce and construct each building, such as foundations, walls, roof, windows, and doors. These impacts include a wide range of materials and processes, for example, the brick and mortar system includes on average 0.1 m^3 of wood per square metre – mostly due to the roof structure.

End of life and maintenance energy was not included and assumed equal for all direct system comparisons. However, wood in buildings can be reused or used for heat or bio-energy, which both have positive climate effects. According to the literature[46,47], treated wood can be landfilled (as municipal solid waste), incinerated (waste to energy) and recycled (cleared from CCA treatment), of which proper incineration

Table 3: Annual sustainable log resource potential and wood-based development coefficients for South Africa for timber frame (TF) and cross-laminated timber (CLT) buildings

Resource	Building type	%	Log volume m^3	TF recovery†	TF m^3/m^2	CLT recovery†	CLT m^3/m^2
Wood chips	Total	100	2 600 000	0.55	0.3	0.4	0.27
	Houses	73	1 898 000	0.55	0.3	–	–
	Flats	27	702 000	–	–	0.4	0.27
Afforestation	Total	100	3 627 500	0.55	0.3	0.4	0.27
	Houses	73	2 648 075	0.55	0.3	–	–
	Flats	27	979 425	–	–	0.4	0.27
Total	Total	100	6 227 500	0.55	0.3	0.4	0.27
	Houses	73	4 546 075	0.55	0.3	–	–
	Flats	27	1 681 425	–	–	0.4	0.27

†TF and CLT recovery are the timber frame and cross-laminated timber construction material recovery coefficients as discussed in Section 2.2.1.

Table 4: Four projected development scenarios with minimum and maximum impact values

Building system		Brick / reinforced concrete			Timber frame / cross-laminated timber		
System EE and GWP impacts		MJ/m^2	kg CO_2 eq./m^2	m^2	MJ/m^2	kg CO_2 eq./m^2	m^2
Current (1% wood)	<80 m^2 and >80 m^2	5400/5588	509/527	4 432 183	2212/4717	208/445	44 770
	Flats and townhouses	1541/3095	308/292	1 648 968	847/1208	-84/114	16 656
10% wood	<80 m^2 and >80 m^2	5400/5588	509/527	4 029 257	2212/4717	208/445	447 695
	Flats and townhouses	1541/3095	308/292	1 499 061	847/1208	-84/114	166 562
20% wood	<80 m^2 and >80 m^2	5400/5588	509/527	3 581 562	2212/4717	208/445	895 391
	Flats and townhouses	1541/3095	308/292	1 332 499	847/1208	-84/114	333 125
100% wood	<80 m^2 and >80 m^2	5400/5588	509/527	0	2212/4717	208/445	4 476 953
	Flats and townhouses	1541/3095	308/292	0	847/1208	-84/114	1 665 624

EE, embodied energy; GWP, global warming potential

technology and methodology according to US EPA does not emit GHGs. However, incineration is not a viable/available option across South Africa yet and was not included in the South African Wood Preservers Association guidelines.

3.3 Sensitivity analyses and limitations

This study focused on log resource availability for an increased wood-based residential building market. Important impacts such as GDP generation and job creation per development scenario were not in the scope of this study. Although elements such as water quality, air pollution and economy are critical in building system comparison, these were not included in the study due to scope and resource constraints. This limits the impact of this research.

Population growth was not included as a direct parameter in the analyses, because the South African population growth is already fairly low, and declining. However, many other factors such as political instability of neighbouring countries and subsequent immigration to South Africa, diseases such as HIV and malaria, and economic growth influence population growth and building rates. Excluding growth also allowed the model to be time independent and therefore easier to apply. All these factors introduce uncertainty in the analysis – which should be taken into consideration by the user.

Simple cradle to gate (material and construction) system boundaries were selected to evaluate likely residential GWP impact comparisons. No local life-cycle assessment building system impacts were available for timber frame and CLT residential houses. Therefore, best available literature for total building system EE and GWP impacts was used to explain the likely system impacts and the expected variation between conventional and low energy technologies.

4. Results and discussion

4.1 Log resource potential

The number of potential wood-based residential houses per annum are shown in Figure 3. This number was computed from data in Table 3 and the average house footprint of 114 m^2 as per Section 2.1. The total number of potential wood-based houses per annum, considering only current available wood chips (2.2.1) as resource, equates to 39 646 houses (30 523 houses and 9123 flats).

The total number of potential wood-based houses per annum, considering only afforestation (2.2.2) resources, equates to 55 314 houses (42 586 houses and 12 728 flats). That is 1203 more than the average new builds in the past 17 years. Considering both wood chips and afforestation resource potential, close to 95 000 wood-based houses (172% of current supply) could be realised each year.

Import of wood-based materials offers a further resource to consider, if a very large wood-based residential market in South Africa develops. Import allows for a immediate supply option of all required wood-based materials. In this case, economics, quality and environmental considerations will determine the potential housing units, which in theory, is extensive.

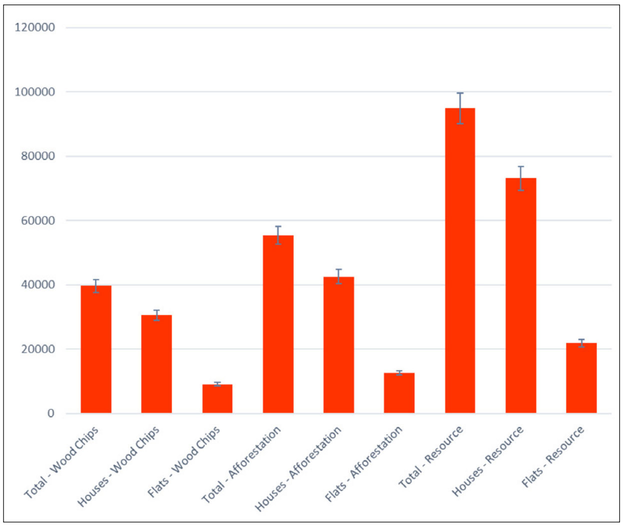

Figure 3: Potential number of 114-m^2 wood-based houses per annum, with 5% error bars.

4.2 Building system impact

The results discussed here are based on the development scenarios as defined in Table 4 and, more specifically, the maximum impact values (to best represent South African development practices). Impact values comprise a range of annual building system EE and GWP impacts per building system, translated in mean area (m^2) as seen in Table 2. Output values in Figure 4a and 4b are minimum and maximum annual residential EE (MJ) and GWP (kg CO_2 eq.) per development scenario. Each impact bar in Figure 4b for EE consists of at least three major categories – energy for construction (0.2–1%), transport (0.1–7%) and material production (92–99.7%) – and, depending on the system, varies considerably in mean EE contribution.[11]

Building material and material production, thus building system choice, represent by far the biggest EE quantity, with transportation of goods being second. These findings support the rationale for an increased wood-based system introduction, as it is the best performer across most environmental impact factors – especially in terms of GWP, compared to building material alternatives such as steel and concrete, with particularly good performance in terms of greenhouse gas emissions.[1-6] It is important to note that, in this study, the total embodied building *system* impact was selected as output values. If comparing purely building *structures* (excluding furnishing, painting, plumbing, insulation, etc.), in relation, an even greater difference would be expected between wood-based and other systems.

Brick and mortar residential homes (<80 m^2 and >80 m^2) comprise the bulk (73%) of the formal residential housing market in South Africa. However, the mean EE and GWP impact from residential homes (<80 m^2 and >80 m^2) contribute 83% of the total annual South African footprint. This proportion is mostly due to the smaller scale and subsequent

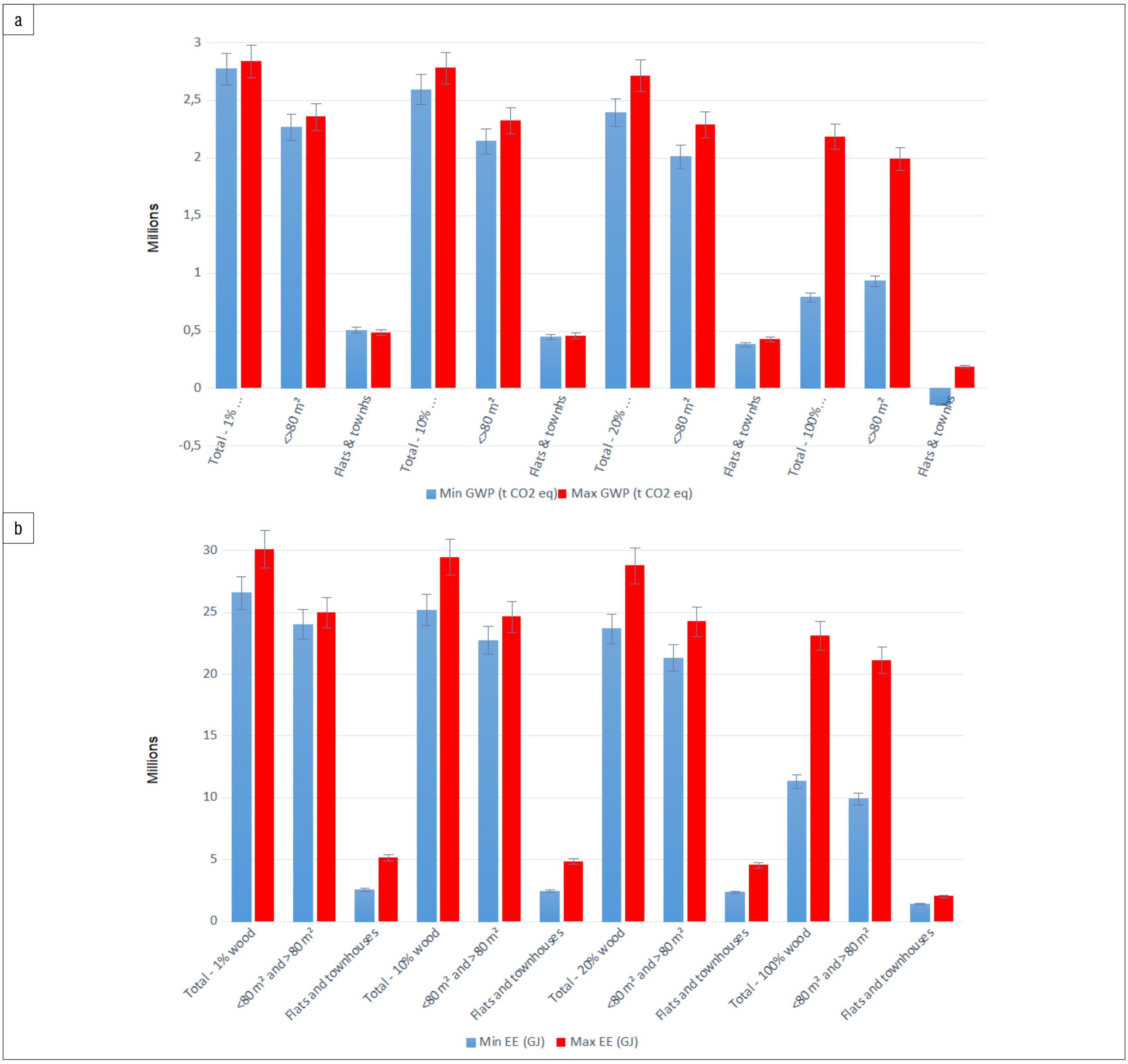

Figure 4: South African minimum and maximum annual residential building (a) global warming potential (GWP) and (b) embodied energy (EE) impacts, with 5% error bars.

inefficiencies as well as the building system difference compared to multi-storey flats and townhouses.

A 10% wood residential market increase will amount to a 2.4% savings in mean annual EE and GWP compared to the current scenario. The 20% market increase will amount to a 4.9% savings in mean annual EE and GWP compared to the current scenario. Finally, an all wood market would amount to a 30% savings in mean annual EE and GWP compared to the current scenario.

South Africa had an estimated total GWP of 590 million ton CO_2 eq. in 2014 – an extraordinary 243 million ton more than in 2006.[7] The major building products amounted to 12.2 million ton CO_2 eq. in 2014 and represented only 2.1% of the total national GHG impact. These major building material impacts include all industries, i.e. roads, commercial, government and industrial sectors. Figure 4 presents minimum and maximum annual residential GWP and EE building impacts, respectively, with 5% error bars to explain likely variability for total development, normal houses and townhouses and flats. It is evident that, if selected minimum (low-energy technology) impact values were considered, much greater GWP and EE savings could be anticipated for wood-based development.

As mentioned earlier, we evaluated only residential EE and not operational energy impacts. Recent studies show that EE for conventional buildings contributes as little as 10% of total building life-cycle energy impacts compared to operational energy impacts.[11] Although not considered in this study, wood-based buildings generally also perform well in terms of operational energy efficiency. Wood is 400 times better than steel and 10 times better than concrete (per volume) in resisting the flow of heat due to its low conductivity and good insulating ability, which can lead to considerable energy savings.[48] However, EE can contribute up to 100% in modern near-zero-energy buildings and, therefore, plays an ever-increasing role in total life-cycle energy.

This modelling study showed that, with market growth of wood-based residential buildings similar to those in Germany and England (i.e. 10–20% of new buildings), there will be a moderate reduction in EE and GWP emissions of less than 5% of total residential building values. If all new residential buildings were wood based, the total reduction in EE and GWP could be a substantial 30%. Even though the potential to reduce EE and GWP in the short to medium term seems to be moderate, it will still be an important contribution to climate change mitigation. The Wedges Theory of Pacala and Socolow[49] showed that it was not possible to reduce GWP to acceptable target levels with a single initiative or technology. Many different industries, sectors and technologies will all have to contribute to combat global warming. If the effects of climate change result in more severe weather events, it could also be that more dramatic changes in consumer behaviour or even government intervention will result in faster and more dramatic changes in building methods and materials, such as the 100% wood-based residential building scenario modelled here.

Only residential housing construction was considered in this study, as it has traditionally been the market segment of choice for wood-based building in other countries. New technologies and products such as CLT also make it possible to build medium-rise buildings from wood-based materials. An 18-storey building was built in Vancouver (Canada) in 2017 from mainly CLT and glulam beams.[50] The commercial and industrial building sectors might therefore in future become adopters of wood-based building.

Due to the limited forest cover in South Africa, the perception is often that significant increases in the market share of wood-based buildings are not possible (at least from local wood resources). This study showed that this perception is not correct. Current resources, available in large volumes such as eucalyptus for chip export, could potentially support considerable growth in wood buildings. In the longer term, however, new afforestation will be required if wood-based buildings become the norm in South Africa. In the short term, supply gaps of wood building components could potentially be alleviated by imports using shipping with short land transport distances. However, research is required to quantify the environmental transport impacts from such imports.

Apart from the environmental advantages of building with wood, wood-based development also has many other positive spin-offs, such as job creation, technological advancement and development of other ecosystem services.[17]

5. Conclusion and recommendations

5.1 Log resource potential

It was shown that with the use of wood resources currently exported as chips, as well as planting trees in areas that have been earmarked for afforestation, it will be possible (in the long term) to sustain a future residential building market where all constructions are wood based. However, in the short term, imports of wood building components might be necessary if rapid growth in the wood-based building market occurs in residential development.

5.2 Building system impact

The basic impact modelling showed that incremental 10% and 20% increases in residential wood-based buildings market share show a moderate environmental benefit, compared to current national GHG impacts of the residential building sector. Further, we demonstrated that (based on maximum impact values), a 100% increase in local wood-based development could result in a substantial 30% GWP saving in residential building impact. However, if selected minimum (low-energy technology) impact values were considered, far greater GWP and EE savings can be expected for wood-based development.

5.3 Further consideration

Contrary to Australia and the USA, South Africa does not have a culture of designing and building with wood. Therefore, further research that includes other impacts such as social and economic comparisons with regard to an increase in wood-based building, is recommended. Finally, the interaction of operational energy and embodied energy of wood-based buildings compared to conventional buildings in South Africa should be investigated – a life-cycle analysis approach is recommended.

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Authors' contributions

P.L.C. was responsible for the article design, technical analyses and write-up. C.B.W. supervised the research and assisted with the write-up and language editing.

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