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Land use Planning in Ireland: a Life Cycle Energy Analysis of Recent Residential Development in the Greater Dublin Area

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LAND USE

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Abstract

Background, aim, and scope One third of the total housing stock in the Republic of Ireland has been built in 10 years up to and including 2006 and of this approximately 34% was built in the Greater Dublin Area (GDA). Much of the housing was low-density with poor public transport links leading to doubts over its sustainability—particularly in terms of energy use. Although the country is committed to reducing greenhouse gases to 13% above 1990 levels by the period 2008–2012, by 2005, emissions were already 25.4% higher than the baseline and current projections are that this figure will rise to 37% over the period. The residential sector is estimated to contribute to approximately 24.5% of energy-related CO_2 emissions. This paper estimates total emissions from residential developments in the GDA constructed between 1997 and 2006.

Materials and methods Carbon dioxide equivalent (CO_2) emissions are estimated using a life cycle assessment approach over a 100-year building lifespan and employing process, input–output and hybrid energy techniques. Life cycle stages include: construction, operation, transport, maintenance and demolition. The main data sources include: national population and industry census data, household travel survey data, residential energy performance surveys and national accounts. The GDA was split into four zones each encompassing development at increas-

ing radii from Dublin's city centre, namely: city centre, suburbs, exurbs and commuter towns.

Results Per capita CO_2 life cycle emissions in the GDA were found to be approximately 50–55% greater in the exurbs and commuter towns than in the city centre. Of the five life cycle stages studied, operational energy requirements (predominantly space heating and hot water, but including power) contributed most significantly to emissions (68%), followed by transport (17%), construction (9%) and maintenance/renovation (6%).

Discussion Operating emissions from dwellings in the commuter town and extra-urban zones were almost twice those in the city centre both due to larger dwelling sizes and the predominance of detached and semi-detached dwellings (with large amounts of exposed walls) in the former and the prevalence of smaller apartments in the latter. Car use was most pronounced in the zones furthest from the city centre where per capita emissions were almost twice those of residents in the city centre. Despite their smaller size, the per capita construction CO_2 emissions of apartments were approximately one third greater than for low-rise dwellings due to the greater energy intensity of the structure. However, this difference was more than compensated for by the significantly lower operational emissions referred to above.

Conclusions In 2006, recurrent CO_2 emissions (operational, transport and maintenance) from dwellings built in the GDA over the ten preceding years were 2,108 kt while construction-related emissions in that year were 1,325 kt giving a total contribution from the residential sector of 3,434 kt CO_2/annum—representing 4.9% of national emissions for that year. Had the development policy prescribed 'city centre'-type development and transport modes, then emissions for the year 2006 would have been 2,892 kt CO_2—a reduction of almost 16% over the actual figure. However, in this scenario recurrent emissions would have

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71 been reduced to 1,417 kt CO_2—a reduction of 33% over
72 actual levels.

73 *Recommendations and perspectives* This study supports
74 Irish and international governments' policies aimed at
75 curbing CO_2 emissions from the domestic sector which
76 focus primarily on reducing operational emissions from
77 new and existing housing through design and construction
78 improvements. However, it demonstrates that significant
79 reductions in operational emissions are associated with
80 high-density residential development with modest floor
81 areas. Furthermore, it highlights the scope for transport
82 emissions' reductions through better spatial planning
83 leading to reduced car travel.

84 **Keywords** Carbon dioxide equivalent · CO_2 · Domestic
85 dwellings · Embodied energy · Energy · Greenhouse gas
86 emissions · Life cycle assessment · Spatial planning

1 Background, aim, and scope

88 At the end of 2006 there were 1,835,515 domestic dwell-
89 ings in the Republic of Ireland (CSO 2007a). Of these,
90 607,961—representing one third of the total housing
91 stock—were built in the 10 years up to and including that
92 year (Fig. 1). Approximately 34% of this new housing was
93 built in Dublin and the greater Dublin region, much of
94 which was low-density with poor public transport links.
95 Indeed, much of the housing development in Ireland can be
96 characterised as 'once-off' or low-density located outside
97 urban centres: over one third of the development comprised
98 detached houses, 44% were semi-detached or terraced
99 housing units and only one fifth were apartments. In
100 contrast, multi-family dwellings account for almost half of
101 Europe's housing stock (Netherlands Ministry of Housing,
102 Spatial Planning and the Environment 2004). The adoption

103 in Ireland of such low density suburban and extra-urban
104 development policies may have resulted in increased
105 greenhouse gas emissions when compared with higher
106 density urban developments.

107 Ireland's energy emissions' performance is poor by
108 international standards: in 2004, energy use per capita was
109 3,870 kg of oil equivalent (kgoe) and associated greenhouse
110 gas emissions were 10,589 kg. This compares unfavourably
111 with EU27 figures of 3,689 kgoe and 8,180 kg, respectively
112 (Eurostat 2007). Although the country has committed to
113 reducing greenhouse gases to 13% above 1990 levels by
114 the period 2008–2012, by 2005, emissions were already
115 25.4% higher than the baseline (EPA 2007) and current
116 projections are that this figure will rise to 37% over the
117 period. Residential energy use accounted for almost one
118 quarter of total national fuel consumption in 2005 of which
119 almost 75% is used for space heating and hot water
120 (Howley et al. 2006).

121 The impact of a domestic development on greenhouse
122 gas emissions is related to the quantity and carbon content
123 of the energy required over its lifetime. For example, two
124 similar buildings with different passive thermal perform-
125 ances will consume different amounts of energy: one will
126 emit more greenhouse gases than the other. Identical
127 buildings powered by fuels with different carbon contents
128 (for example, biomass- versus oil-fuelled boilers) will also
129 have differing impacts. The energy impact of a domestic
130 development over its entire life cycle can be viewed as the
131 sum of this operational energy use together with the
132 energy needed to produce and maintain it, demolish it as
133 well as the energy required to travel to and from it.
134 Similarly, the CO_2 impact is the global warming potential-
135 weighted sum of greenhouses gases (predominantly
136 carbon dioxide, nitrous oxide and methane) emitted by
137 this energy use.

138 Australian literature suggests that the average energy
139 required to produce a house in that country is approximately
140 5 GJ/m² producing some 0.49 tonnes/m² floor area of carbon
141 dioxide (CSIRO 2007) based on Australian emissions'
142 intensities. This is referred to as 'embodied energy' and
143 theoretically includes all direct and indirect production
144 energy inputs such as construction, material production,
145 raw material extraction and associated services. The
146 average floor area of a domestic dwelling in Ireland in
147 2004 was 112 m² (SEI 2005) and applying the Australian
148 data, this gives a per-dwelling embodied energy of
149 560 GJ and emissions of 55 tonnes of carbon dioxide
150 (CO_2). Assuming a 100-year building lifespan, this is
151 equal to annualised emissions of 0.55 tonnes of CO_2 and
152 5.6 GJ of energy use. Although these figures are rough
153 estimates—since the Australian embodied energies are
154 likely to differ from those in Ireland (no Irish data are
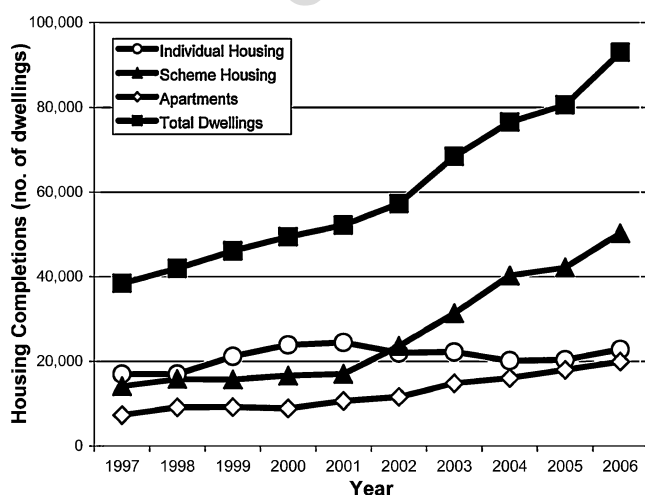155 available at the time of writing)—when used with the

Fig. 1 Annual housing completions in Ireland 1997–2006

operational and travel data below, they indicate the relative importance of embodied energy in the life cycle of a domestic building and will assist in the development of the life cycle assessment (LCA) methodology described in this paper.

In 2004, the mean energy use per Irish dwelling was 88 GJ resulting in the emission of 8.2 tonnes of CO_2 per annum. Some 79% of energy use was in the form of direct fossil fuel consumption, the remainder was electricity (SEI 2005).

In 2006, the Irish transport sector consumed 213,000 TJ of energy and emitted 15,273 kt of CO_2 (SEI 2006) of which 40% was attributable to private cars (SEI 2004). In the same year, there were 1,469,521 households in Ireland (CSO 2007b) giving average annual transport-related CO_2 and energy use figures of 4.2 tonnes and 58 GJ per dwelling, respectively. This approximation overestimates the direct energy inputs associated with moving to and from a domestic dwelling since many private car trips would be used for other purposes, although it ignores indirect energy inputs such as product development and manufacturing.

Little data are available on the maintenance-related energy requirements of domestic dwellings and associated emissions. Figures for the refurbishment and repair of office buildings are reported to lie in the range of 0.17 to 0.34 GJ/m^2 (Yohanis and Norton 2002). Taking the lower figure—since office refurbishment is likely to be more energy-intensive than domestic refurbishment—and assuming an interval between refurbishments of 7 years, the annual maintenance-related energy intensity for an average Irish house is 2.72 GJ/m^2 with associated emissions of 0.23 t CO_2. However, even the use of the lower office refurbishment energy intensity figure may overestimate domestic emissions.

Based on these data, the total approximate annualised life cycle energy requirement for an average domestic Irish dwelling is 154.3 GJ emitting 13.2 tonnes of CO_2. Transport and operation dominate life cycle energy requirements (38% and 56% respectively) and CO_2 emissions (32% and 62% respectively). Based on these preliminary results, the methodology outlined in this paper focuses therefore to a greater extent on operational and transport energy use and emissions than on construction, maintenance and demolition.

The objectives of this study are to: determine the whole-life energy and CO_2 intensities of dwellings built in the Greater Dublin Area (GDA) between 1997 and 2006; assess the relative impact of different life cycle stages on energy use and CO_2 emissions; and quantify and compare the impact of urban, suburban and extra-urban residential developments in and around Dublin on national energy-related greenhouse gas emissions.

2 Materials and methods

Life cycle assessment (LCA) was used to determine energy use and carbon dioxide emissions for all stages of a residential development including:

- construction;
- operation including heating, hot water, lighting and small power loads;
- travel to and from the development;
- maintenance; and
- demolition

The study only considered the greenhouse gas impacts associated with energy use and ignored wider environmental impacts such as resource depletion, groundwater pollution and habitat loss. CO_2 emissions only were calculated since these data are easily available. However, since CO_2 accounts for only 93% of non-agricultural greenhouse gas (GHG) emissions in Ireland by global warming potential (CSO, 2007c), resulting figures were divided by 0.93 to correct for unaccounted energy-related GHG emissions (such as N_2O and CH4) to estimate total emissions in CO_2 equivalent (referred to hereafter simply as CO_2).

Energy requirements and emissions for each of the life stages of the residential development were determined using process, input–output or hybrid process analysis depending on data availability. These methodologies are described by inter alia Crawford (2007) and Bullard et al. (1978).

2.1 Developments

Two developments were selected to represent typical recent residential developments in the Greater Dublin Area (a term which is used to describe the city and county of Dublin as well as the adjacent counties of Kildare, Meath and Wicklow) which are described below.

A high density mixed-use urban development in the city of Dublin comprising 300 apartments of one, two and three bedrooms with a total gross floor area of 22,500 m^2. The scheme also contains retail and office units.

A development of 118 two-storey detached, semi-detached and terraced houses on a 5.7 ha site outside the city comprising detached, semi-detached and terraced houses ranging in size from three to five bedrooms.

2.2 Construction

The energy embodied in the above developments was determined using hybrid process analysis up to the point of completion of the construction process by the contractor and hand over to the new resident. This required material-

256 specific energy intensities (Hammond and Jones 2006)
257 which were used in conjunction with national input–output
258 tables (CSO 2006a) to quantify the total upstream and
259 direct energy requirements for the building. Upstream
260 energy requirements might include raw materials' extrac-
261 tion and building materials' manufacturing; direct energy
262 relates to energy expended during the construction process
263 itself.

264   Bills of quantities detailing material quantities and prices
265 were obtained from the contractor who built the schemes.
266 Where possible, materials were identified, characterised and
267 process energy intensities applied. Energy intensities of
268 unidentified expenditure were estimated using Irish con-
269 struction sector energy intensities derived from national
270 input–output tables, mean national energy tariffs, primary
271 energy factors and disaggregation coefficients (Acquaye
272 et al. 2008). An integral part of this methodology involved
273 calculating a carbon dioxide equivalent intensity based on
274 the mix of fuels used.

275 ### 2.3 Transport

276 Transport emissions for all trips to and from dwellings were
277 calculated based on data from the Dublin Transportation
278 Office's 2006 Household Survey (DTO 2006) of approxi-
279 mately 2,500 households in the Greater Dublin Area. The
280 survey was carried out over a 1-week period where
281 participants kept a detailed log of all movements to and
282 from their dwellings. Relevant variables were extracted
283 from the database which included:

284 •   mode of transport (for example train, rapid rail, tram,
285   bus, truck, van, car, taxi, motorbike, running, walking);
286 •   number of trips made;
287 •   trip distances; and
288 •   trip duration

289
290   It is accepted that development density and land-use mix
291 are inversely related to household-related travel distances
292 and vehicle emissions (Frank et al. 2000; Næss 2006;
293 Newman and Kenworthy 1999). Moreover, the distance of
294 a residence from concentrated employment and recreational
295 areas (typically a city centre) affects both transport mode
296 (DTO 2006) and travel distance and, therefore, fuel
297 consumption and CO_2 emissions. In order to capture the
298 effects of density and distance to urban centres, the Greater
299 Dublin Area Household Survey data were therefore divided
300 into four zones of increasing distance from the city centre
301 (Fig. 2). These are:

302 Zone 1   City Centre which is roughly bounded by two
303   canals and the inner ring roads to the north and
304   south giving a radius of up to 3.0 km around the
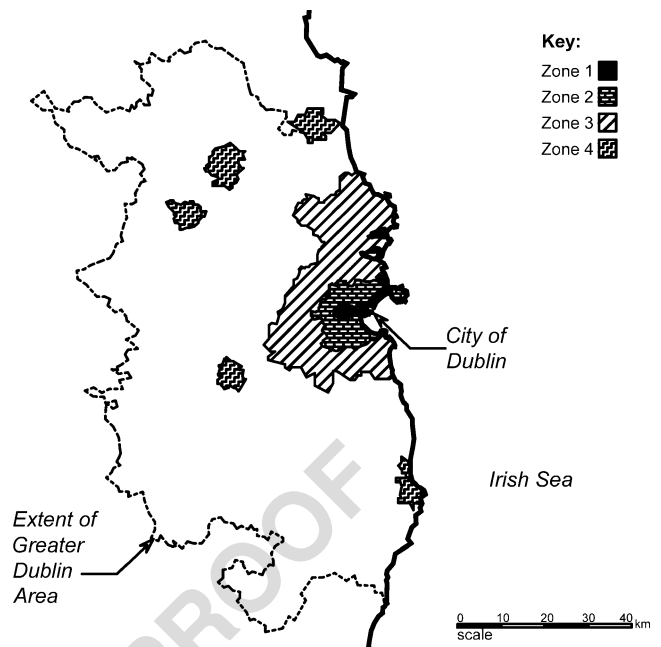305   city;

Fig. 2 Map of the Greater Dublin Area (GDA) showing the zones analysed

306 Zone 2   Suburbs which are located between the City
307   Centre and the M50 motorway ring road at a
308   radius of approximately 9.0 km around the city;
309 Zone 3   Exurbs covering the low density urban areas in the
310   remainder of county Dublin located outside the
311   M50 incorporating many of the closer commuter
312   towns at a radius of 15 to 30 km from the centre;
313   and
314 Zone 4   Commuter towns of Drogheda (42 km from the
315   centre), Navan (45 km), Enfield (40 km), Naas
316   (31 km) and Wicklow (43 km).

317
318   Data were then analysed by zone to determine the total
319 number of trips by mode of transport and total annualised
320 modal distances travelled. Mean data were then calculated
321 on a per household and per capita basis.
322   Fuel consumption and CO_2 emissions data were calcu-
323 lated in the following ways:

324   no carbon dioxide emissions or fuel consumption was
325   attributed to walking, running or cycling. This assumes
326   that the energy and CO_2 embodied in equipment such
327   as footwear, bicycles, special clothing and helmets is
328   negligible compared to that embodied in other forms of
329   transport. The food requirements of individuals are
330   outside the LCA boundary in all cases.
331   aeroplane, train, rapid rail transit, tram, bus, mini-bus,
332   truck and motorbike energy uses and emissions were
333   calculated using published average emissions per
334   person kilometre (Cox and Hickman 1998; Davies

and Diegel 2007). Trains, buses, mini-buses and trucks were assumed to be diesel-fuelled while DART (a rapid rail system) and LUAS (a tram system) use electricity only. The average fuel consumption and carbon dioxide emissions data used in the analysis is presented in Table 1.

Since emissions from cars were expected to predominate, these were calculated in the more detailed manner described below.

Engine size and fuel type (diesel/petrol) distributions were determined using 2005 local government car registration data and a weighted mean engine size was calculated for both fuel types.

Mean fuel consumption was calculated for this engine size based on published data and speed-related efficiencies (Davies and Diegel 2007) were combined to give an equation for fuel consumptions for the weighted mean engine size (calculated above) at different speeds.

Average speeds for all car trips were calculated and fuel consumption determined using the fuel consumption to speed relationship.

This represents the fuel consumed only and does not consider the full life-cycle energy use of the car. Research by Castro et al. (2003) suggests that direct fuel consumption represents approximately 95% of the total life cycle energy requirements of a car and the results were adjusted accordingly. In the absence of equivalent life cycle assessment literature for other modes of transport, this figure was also applied to buses, trains, vans, trucks and motorbikes.

2.4 Operation

Operational energy requirements were quantified using the Energy Performance Survey of Irish Housing undertaken jointly by Sustainable Energy Ireland and CODEMA between 2004 and 2005. This study involved a detailed survey of the energy use characteristics of dwellings in Ireland and covered a range of construction types, ages and occupancy patterns. Relevant survey data were selected to be representative of the development types chosen here, in particular:

Data in the fields 'Detached', 'Semi-Detached', 'Terraced' and 'Purpose-Built Apartment' were incor-porated whereas, 'Converted Apartment' and 'Other' were ignored and

Developments built since 1997 were included since different Building Regulations and energy performance standards pertained prior to this date and would not have been representative of the 1997–2006 housing stock. However, a lack of data for apartments neces-sitated the use of pre-1997 data which would have overestimated energy use and emissions to some extent.

Mean annualised energy use and carbon dioxide emis-sions data were calculated for the reduced sample of 59 dwellings based on recorded fuel mixes and quantities and these were validated against Scottish data. Data were converted from per-dwelling to per capita by dividing by the average number of persons per private household for the county or city as listed in the 2006 national census (CSO 2007a).

2.5 Maintenance and demolition

Maintenance requirements were determined using input–output analysis. Total expenditure for Irish housing repair, maintenance and improvements for the year 2004 were used (CSO 2006b) together with the energy intensity for the construction sector and total existing housing units for the period to determine the average annual domestic dwelling maintenance energy use.

Demolition costs were calculated using input–output analysis employing data from the 2004 Census of Building Construction (CSO 2006c). Turnover and input figures for Nace 45.1 'Site preparation, demolition and wrecking of buildings, earth moving, test drilling and boring' were used to determine energy intensities and these were used with 2004 published demolition costs (Davis Langdon and Everest 2004) to determine demolition energy requirements.

3 Results and discussion

3.1 Construction

Figure 3 shows the embodied CO_2 emissions per dwelling. It can be seen that detached dwellings were found to have

Table 1 Average fuel consumptions and CO_2 emissions for various modes of transport excluding cars (source: EEA 2003)

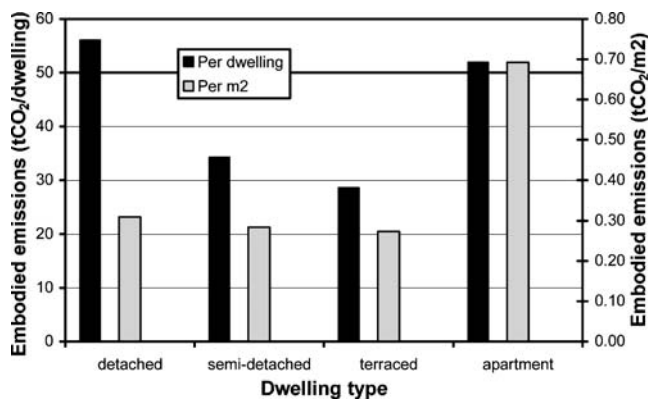| Mode	Fuel consumption (grams oil equivalent/passenger km)	CO_2 emissions (g/passenger km)
Bus	23	73
Truck	97	216
Motorbike	36	104
Rail	20	44

Fig. 3 Embodied CO_2 for each dwelling type studied expressed both on a per dwelling and a per m^2 of gross floor area basis
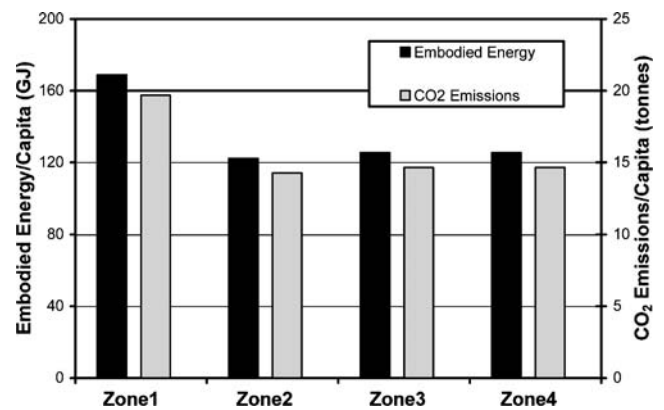

Fig. 5 Per capita embodied energy and construction-related CO_2 emissions for each zone

416 the highest embodied emissions due to their large size and
417 construction characteristics. For example, the mean size of
418 a detached house in the sample was 181.2 m^2 whereas
419 semi-detached houses, terraced houses and apartments were
420 120.6, 104.6 and 75.0 m^2, respectively. Detached houses
421 have greater construction materials' requirements since they
422 have no shared walls, unlike other dwelling types. Apart-
423 ments have the second highest embodied energy due to the
424 need for more structural elements and, consequently,
425 greater quantities of steel and concrete—both materials
426 which have relatively high energy intensities. The use of
427 these materials results in apartments producing the most
428 CO_2 emissions per constructed dwelling. Terraced houses
429 were found to have the lowest embodied energy and CO_2
430 emissions due to their relatively small size and use of
431 shared structure (such as party walls). When compared on a
432 per square metre of constructed gross floor area, it can be
433 seen that due to their relatively small size and large
434 structural requirements, apartments have almost two and a
435 half times more embodied energy and CO_2 emissions than
436 other forms of residential construction.
437 Figure 4 shows the percentage of house type completed
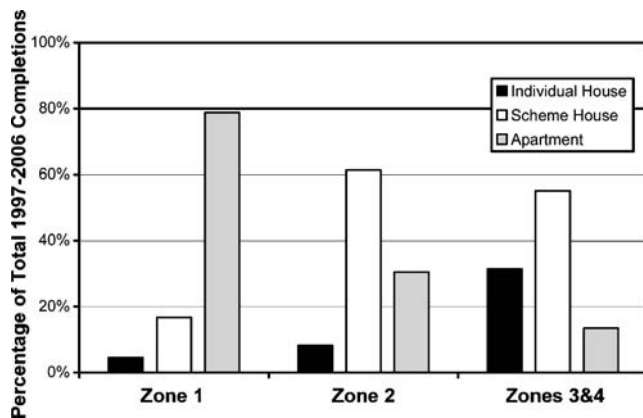438 in 2006 by zone where it can be seen that areas closest to

439 urban centres had the highest concentration of apartment
440 completions: almost four fifths of dwellings completed in
441 the city centre were apartments while this figure fell to 16%
442 in Zones 3 and 4 where the development of 'scheme
443 houses' comprising mixed housing units dominated.
444 Based on the mix of dwellings completed in the 10-year
445 period between 1997 and 2006 and on the average number
446 of persons per household (CSO 2007a), average embodied
447 energies and CO_2 emissions were calculated for each zone
448 and are shown in Fig. 5. It can be seen that both embodied
449 energy requirements and CO_2 emissions are highest in Zone
450 1 due to its high proportion of energy-intensive apartments
451 and relatively low occupancy figures (2.5 persons per
452 household compared to 3.0 for Zone 4).

453 **3.2 Transport**

454 It was found that the further a development is from the city
455 centre, the greater the reliance on the private car while less
456 trips are made using public transport. In Zone 1 some 31%
457 of trips are made by car compared to 49%, 58% and 63%
458 for Zones 2, 3 and 4, respectively. The percentage of trips
459 made by walking or cycling decreases with increasing
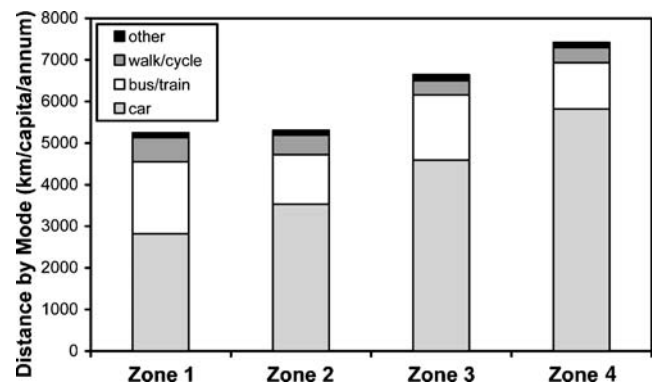460 distance from the city centre: for Zones 1, 2 and 3 the

Fig. 4 Percentage of housing completions by type for each zone

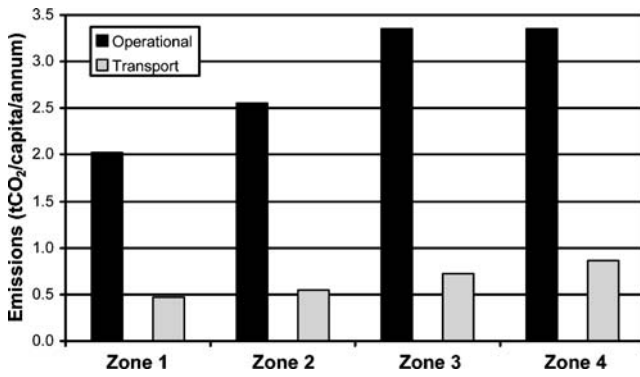**Fig. 6** Annual per capita distance travelled by mode for each zone

Fig. 7 Annual per-capita operational and transport-related CO_2 emissions for each zone

461 percentages of trips made using these modes are 40%, 29%
462 and 22%, respectively. However, for Zone 4—commuter
463 towns—the figure increases to 28% suggesting that local
464 employment centres and amenities situated close to resi-
465 dential areas create greater opportunities for walking or
466 cycling than in the Exurbs (Zone 3).

467 Figure 6 shows the annual modal distances travelled per
468 capita for each zone. There is a clear positive relationship
469 between distance from the centre of Dublin and distance
470 travelled by car. The per capita distances travelled by public
471 transport (bus and train) were highest for Zones 1 and 3 at
472 1,735 km and 1,566 km, respectively and lowest for Zones
473 2 and 4 at 1,196 km and 1,119 km, respectively.

474 Not surprisingly, transport-related fuel consumption and
475 CO_2 emissions also increase the further a residential
476 development is located from the city centre. Figure 7 shows
477 the annual transport-related CO_2 emissions per capita for
478 each zone. It can be seen that annual transport emissions in
479 Zone 4 were highest where the average person consumed
480 14.2 GJ of energy (equivalent to 449 l of petrol) and
481 emitted 866 kg of CO_2 in meeting their 2006 transport
482 needs. These figures decrease with increased proximity to
483 the city centre and reach a minimum of 8.3 GJ and 472 kg
484 CO_2 for Zone 1. Transport-related CO_2 emissions are
485 therefore almost 85% higher for residential developments
486 in the commuter towns than in the city centre and
487 approximately 16% and 54% higher for suburban (Zone 2)
488 and extra-urban (Zone 3) areas, respectively.

3.3 Operation   489

490 Results for the annual operational (heating, hot water and
491 small power) energy requirements and associated CO_2
492 emissions for four different dwelling types are shown in
493 Table 2 both on a per square metre and per dwelling basis.
494 Detached houses were found to emit 88 kg CO_2/m^2/annum
495 of floor area; the corresponding figures for semi-detached
496 houses, terraced houses and apartments were 67, 55 and
497 48 kg/m^2, respectively. Detached houses consume the
498 greatest amounts of energy due to their higher floor areas
499 and completely exposed external envelopes. Conversely,
500 apartments have the lowest per dwelling consumption due
501 to both their smaller size and reduced area of external
502 envelope. Results were compared to emissions statistics for
503 Scotland due to its similar weather and demographics; these
504 are presented in Fig. 8. It can be seen that Scottish
505 emissions compare favourably but are lower for detached
506 and, to a lesser extent, semi-detached houses and are similar
507 for terraced houses and apartments. These differences may
508 be accounted for by the lower CO_2-intensity of electricity
509 production in Scotland and the relatively large sizes of
510 detached and semi-detached houses constructed in the GDA
511 over the period being analysed.

512 Figure 7 shows annual operational CO_2 emissions per
513 capita in each zone, taking account of the mix of house
514 types and average occupancies for each zone. On average,
515 each person in Zones 3 and 4 consumes approximately 85%
516 more energy than in Zone 1 and 30% more than in Zone 2
517 in order to heat and power their home. This is due to the
518 dominance of detached houses in the exurbs and commuter
519 towns and the greater concentration of apartments in the
520 city centre and suburbs. This effect of housing type
521 distribution on increasing per capita operational energy
522 use in Zones 3 and 4 is offset to some degree by higher
523 dwelling occupancy rates in these areas (3.0 per dwelling
524 versus 2.5 for urban).

3.4 Maintenance and demolition   525

526 The average energy requirements associated with maintain-
527 ing and improving a domestic dwelling were estimated

t2.1 **Table 2** Annual operational energy requirements and associated CO_2 emissions for different dwelling types

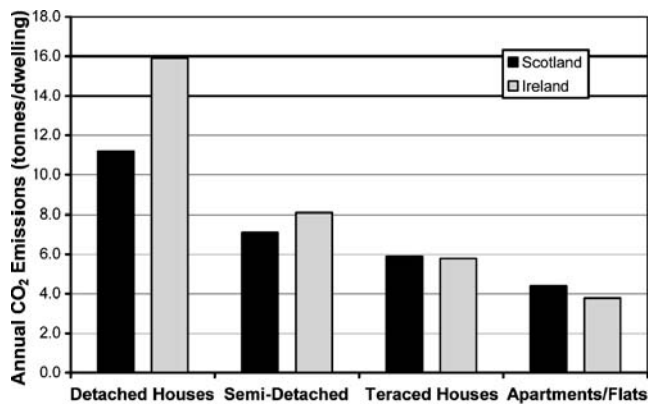| Dwelling type	Energy requirements		CO_2 output		Average size (m^2)
	(GJ/dwelling/year)	(MJ/m^2/year)	(t/dwelling/year)	(kg/m^2/year)	
Apartments	32	400	3.8	48	75
Terraced	65	623	5.8	55	105
Semi-Detached	92	763	8.1	67	121
Detached	161	886	15.9	88	181

Fig. 8 CO_2 emissions per dwelling for Scottish housing stock and GDA sample (source: Hinchliffe 2005)

Fig. 9 Life cycle component CO_2 emissions for each zone (demolition has been excluded since emissions are negligible compared to other life cycle stages)

528 using input–output analysis (as described in Section 2.5) to
529 be 0.046 GJ/m^2/annum producing 6.8 kg CO_2/m^2/annum.
530 Due to a lack of data it was not possible to differentiate
531 between maintenance requirements for different dwelling
532 types. It is likely that this aggregation problem under-
533 estimates maintenance energy requirements for detached
534 and semi-detached houses given the greater opportunities
535 for the major refurbishment and extension of such
536 properties over apartments and—to a lesser extent—
537 terraced houses. Therefore, in the absence of more
538 disaggregated data, the same per square metre energy and
539 CO_2 emissions intensities were applied to the average
540 house size for each zone.

541 The cost of demolishing a typical 120 m^2 domestic
542 dwelling (brick, block and timber floor construction) was
543 estimated at € 17,500 in 2004 and the energy intensity for
544 Nace 45.1 was calculated to be 2.25 MJ/€ of demolition
545 expenditure. Combining these figures gives a housing
546 demolition energy requirement of approximately 0.33 GJ/m^2
547 with associated emissions of 8.3 kg CO_2/m^2. The additional
548 cost of demolishing the concrete or steel structure in an
549 apartment is estimated to be approximately € 14,300,
550 resulting in an apartment demolition energy intensity of
551 0.60 GJ/m^2 with associated emissions of 15.1 kg CO_2/m^2.
552 These figures do not allow for recycling.

553 3.5 Life cycle

554 Figure 9 shows the CO_2 emissions for a residence built in
555 the last 10 years in each of the four zones in the GDA. This
556 assumes a building lifespan of 100 years. On average Zone
557 3 and 4 occupants consumed 92–98% more energy than
558 those in Zone 1 and approximately one third more than
559 Zone 2. Per capita CO_2 emissions in Zones 3 and 4 were
560 approximately 50–55% greater than Zone 1 and almost
561 33% greater than Zone 2. The higher CO_2/energy ratio in
562 Zone 1 can be accounted for by the high incidence of CO_2-
563 intensive electrical storage heating in Zone 1 apartments.

564 Figure 10 shows CO_2 emissions for each dwelling type
565 excluding transport but including the construction,
566 operation and maintenance life cycle stages (demolition
567 has been excluded since these emissions are negligible).
568 It can be seen that operational emissions dominate and
569 that total emissions over 100 years are significantly
570 higher for detached houses (1,773 t) than for semi-
571 detached (929 t), terraced (680 t) and apartments (482 t).
572 This is due to the greater electrical and space heating
573 requirement associated with the large floor areas of
574 detached houses in Ireland and their relatively greater
575 exposed-envelope/volume ratios. These figures demon-
576 strate significant benefits in promoting high-density
577 spatial planning policies.

578 When the data for all zones are aggregated, operational
579 requirements dominate accounting for 68% of all CO_2
580 emissions followed by transport at 17%, construction at 9%
581 and maintenance at 6%. Demolition contributes to less than
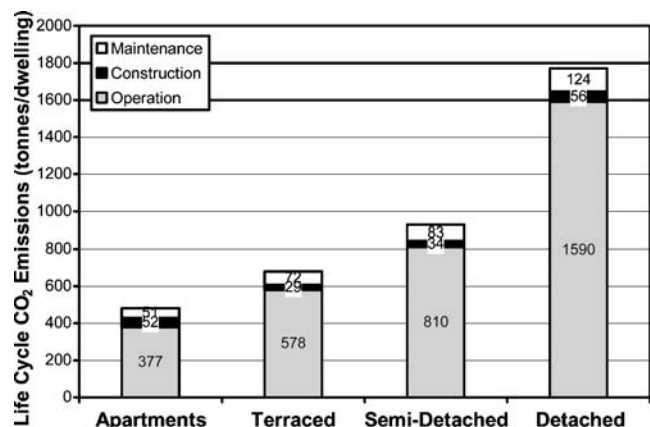582 0.5% of life cycle emissions.

Fig. 10 CO_2 emissions for each dwelling type excluding transport (demolition has been excluded since emissions are negligible compared to other life cycle stages)

4 Conclusions

The life cycle per capita CO_2 emissions in the GDA are approximately 50–55% greater in the exurbs and commuter towns than in the city centre; corresponding energy intensities vary by almost 100%. Per capita residential emissions over a 100-year life span taking into account construction, operational, transport, maintenance and demolition energy requirements were 323, 378, 482 and 496 tonnes, respectively for the urban, suburban, extra-urban and commuter town zones studied.

Of the five life cycle stages studied, operational energy requirements (predominantly space heating and hot water, but including power) contributed most significantly to emissions (68%), followed by transport (17%), construction (9%) and maintenance/renovation (6%); demolition was found to have a negligible effect. Annual per-capita operational emissions in Zones 3 and 4 were almost twice as great as those in Zone 1 both due to larger dwelling sizes and the predominance of detached and semi-detached dwellings (with large amounts of exposed walls) in the former and the predominance of smaller apartments in the latter. The car dominated as the preferred mode of transport in all zones; however, this was most pronounced in the zones furthest from the city centre (zones 3 and 4) where per capita emissions were almost twice those of residents in the city centre. It is interesting to note that despite their smaller size, the per capita construction energy intensities of apartments were approximately one third greater than for traditional detached, semi-detached and terraced residences due to the greater energy intensity of the structure. However, this difference was more than compensated for by the significantly lower operational emissions referred to above.

By 2006 residential development in the GDA completed over the 10 years up to and including that year was contributing 3,434 kt CO_2/annum—representing 4.9% of national emissions for that year; this comprised 2,108 tonnes of recurrent emissions (operational, transport, maintenance) and 1,325 kt of once off construction-related emissions. Had the development policy required Zone 1-type development and transport modes, then emissions for the year 2006 would have been 2,892 kt CO_2—a reduction of almost 16% over the actual figure and representing approximately 4.1% of national emissions. However, in this scenario recurrent emissions would have been reduced to 1,417 kt CO_2—a reduction of 33% over actual levels.

5 Recommendations and perspectives

Irish and other governments' residential sector energy policies tend to focus on minimising operational energy use and emissions. This approach is broadly supported by the findings of this paper that approximately two thirds of emissions arise from heating and powering dwellings in the GDA. However, although operational CO_2 emissions dominate those from transport, maintenance and construction, assessing only operational emissions would underestimate 100-year emissions by approximately one third. This demonstrates the benefits of LCA in evidence-based policy-making and highlights the need for policy measures targeted at mitigating non-operational emissions. Indeed, the relative importance of these emissions will increase as existing energy policies further reduce operational emissions.

An additional weakness of existing policies is the emphasis placed on reducing unit area emissions through energy efficiency measures. In Ireland, this policy has run concurrently with the development of large detached dwellings in the area studied. However, the results above clearly indicate that large, detached dwellings achieve national emissions policy objectives despite having a significantly higher environmental impact than smaller 'attached' dwellings such as apartments. Although other social and functional considerations must be taken into account, a policy favouring high-density residential development with more modest floor areas would reduce emissions. Such a 'high density' planning approach would have the added benefit of reducing car dependency since residences could be constructed closer to urban centres and public transport infrastructure with relatively low emissions intensities. The operational and transport emissions from the worst performing zones could be reduced by approximately 40% with suitable policies.

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