Integrating Population, Land-use, Transport, Water and Energy-use Models to Improve the Sustainability of Urban Systems

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Abstract: This paper describes the thinking used to develop an integrated urban systems model of transport and domestic dwelling energy-use in association with domestic water-use. The model aims to identify common consumption trends — synergies and tensions — to improve the efficacy of urban development policies that target sustainability issues in these infrastructure sectors. Examining the limitations of four other models used to understand similar problems, highlights the potential benefits of such a model. Using Sydney as a case study, the paper provides examples of preliminary results.

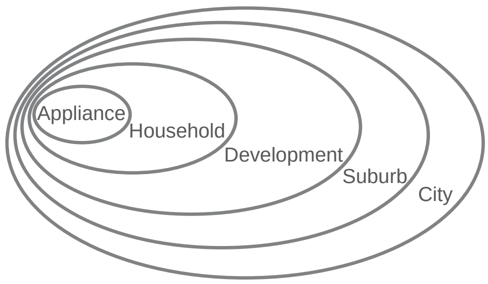
1 Introduction: key questions for urban sustainability

This paper is part of an on-going research collaboration that seeks to examine the working relationships between multiple infrastructure sectors through a single analysis platform. In the past, urban infrastructure consumption patterns have usually been analysed on a single sector basis, however such a practice necessarily overlooks important synergies between different infrastructures.

The need to integrate policy for multiple infrastructures is critical given the multiple fronts on which the sustainability of urban systems are now jeopardised. Growing awareness of the threats from climate change has focused attention on greenhouse gas (GHG) emissions and the need to reduce them (Stern, 2006). The current drought has focussed attention on the need to reduce water consumption (Moscaritolo, 2006) and recent increases in petrol prices have fuelled debate on the availability of petroleum-based fuels and the need to reform the transport sectors dependent on them (Farr, 2007; see also AGO, 2006).

These considerations raise three key policy questions. First, how sustainable are our cities in terms of water, energy and greenhouse gas (GHG) emissions? Second, what policies can be introduced to enhance sustainability? Third, what synergies and tensions exist between sectors?

Figure 1 Scales of investigation within the urban system



Source: authors.

As shown in Figure 1, the performance and impacts from infrastructures can be considered at a variety of levels ranging from the single household appliance to the complex relationships of entire urban systems. Urban sustainability studies have tended to focus on either end of this scale — the efficiency of appliances, like washing machines and light bulbs, or the level of city-wide comparisons. But such studies overlook important synergies between scales — an oversight this research addresses through the development of an integrated model of water and energy consumption patterns in Sydney. But before examining such a model, a brief review is provided of energy and water consumption patterns given the demographic and spatial structure of households.

1.1 Transport energy consumption

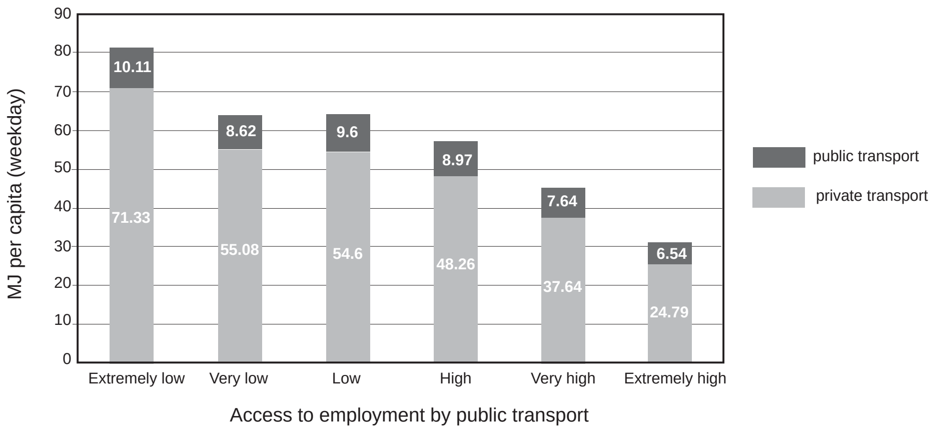
Passenger transport energy consumption in Sydney depends on many factors including, mode share, energy consumption by mode, and energy efficiency throughout the energy cycle[1]. Many energy-use

[1] Fuel consumption for cars depends on the characteristics of vehicles such as mass, engine size, air-conditioning, gearbox type, plus, traffic and driving conditions. Consequently, energy consumption is dependent on design decisions by manufacturers as well as average network speeds and the percent of driving done on slow suburban streets, arterials and freeways.

studies ignore the losses incurred when transferring energy from its primary source to its end-use. This factor is critical when analysing GHG emissions in addition to the more obvious differences in consumption that exist between modes.

In most cities, mass transit is significantly more energy efficient than cars (Kenworthy *et al.,* 1999; Kenworthy, 2002). In Sydney, trains and buses on average use 2.8 times less primary energy per passenger kilometre than cars (Glazebrook, 2002). Mode share, and consequently, energy consumption and GHG emissions, have been shown to be related to urban structure (Kenworthy *et al.,* 1999).

Figure 2 Energy consumption intensity by mode in Sydney



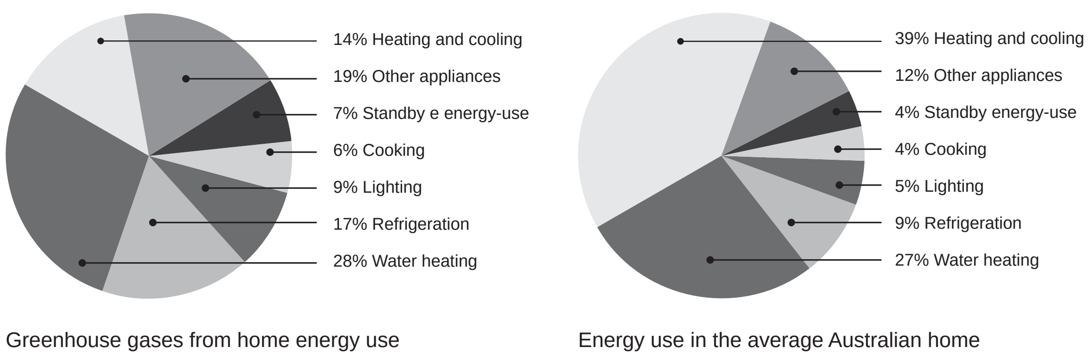
Adapted from: Kenworthy *et al.* (1999) and Glazebrook (2002).

Figure 2 shows energy consumption in MJ/person for weekday urban travel, for both private (cars) and public transport — buses, trains, ferries — in Sydney, for people living in areas of very low, low, medium, high and very high access to employment by public transport. This model will link these results with housing typologies and associated impacts.

1.2 Domestic building energy

Energy consumption within households is influenced by a complex interaction of user needs, such as affordability, lifestyle choices, user behaviour and efficiency of the built infrastructure and equipment. Consumption is also influenced by climate, population trends, household size and policy decisions around housing location. Household energy use by purpose is shown in Figure 3.

Figure 3 Energy-use and GHG emissions for Australian domestic dwellings by purpose (1999)



Source: Reardon (2005).

Figure 3 highlights energy consumption for those uses that individuals have greater control over such as refrigeration, other appliances, electric-standby and cooking. These end-uses constitute 29 per cent of energy use and 49 per cent of GHG emissions. Notwithstanding Minimum Energy Performance Standards (MEPS), user education and energy efficient labelling for many appliances, consumption in these areas has remained difficult to influence.

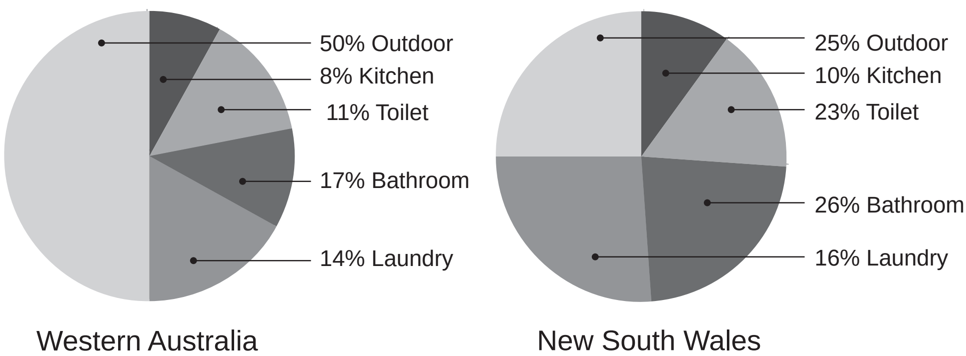
Water heating and space heating and cooling account for 66 per cent of energy use and 42 per cent of GHG emissions. While dependant on user behaviour, energy consumption can also be influenced by building design and urban structure. Although GHG emissions from space heating and cooling appear to be low at 14 per cent of total emissions (AGO, 1999), there has been an increase in the number of homes with air conditioners from 33 per cent in 1994 to 60 per cent in 2005 (ABS, 2006). This increase in electricity-based cooling is likely to erode reductions from new housing stock designed to be more thermally efficient.

1.3 Domestic water use

Household water use is commonly divided into *discretionary* and *non-discretionary* consumption. Non-discretionary uses like drinking, cooking, bathing, washing clothes and toilet flushing are assumed to vary less due to the essential nature of the end-uses. By contrast, discretionary uses like watering lawns, washing cars and filling swimming pools is assumed to vary greatly in accordance with seasonal and weather trends as well as income and the effect of water restrictions.

Figure 4 shows the split of water demand among the common household end-uses in WA and NSW and demonstrates that the proportions of different end-uses is not the same everywhere. In this example, WA has a larger outdoor component than NSW — 50 per cent compared with 25 per cent. This is possibly caused by more outdoor watering due to WA's drier climate. These figures apply to consumption patterns before the introduction of water restrictions, which have reduced outdoor discretionary uses like watering gardens. In WA, domestic water use was found to be falling, with a reduction of 6 per cent from 2004–5 to 2005–6 attributed to water restrictions (NWC, 2007).

Figure 4 Water consumption by end-use in NSW and WA (2001)



Source: NWC (2007).

Uncertainty remains as to how domestic water consumption will change once restrictions are lifted. Water savings achieved through the take-up of water efficient showerheads and toilets will continue but behaviour changes, like the time taken to shower, may not endure. It is possible that savings achieved in relation to discretionary uses, like watering gardens, could return to previous levels.

The NSW Government regulator, IPART, conducted a survey of domestic water users in Sydney and found that a range of household characteristics were responsible for higher than average water consumption. These include household composition, income and type, owning a pool and whether or not the house received a water bill. This study identified the contribution of each factor to total household consumption to determine which was the most important. The statistical model suggested that household composition and whether or not the household received a water bill[2] were the two most important factors. Dwelling type was also shown to have a significant impact (IPART, 2004).

Studies in Melbourne corroborate the IPART findings showing that household composition is significant (Roberts, 2005). US studies show similar patterns (Mayer and DeOreo, 1999).

2 Current urban modelling

2.1 Urban structure, building design and domestic water use

Several publications have attempted to show water and energy profiles for Sydney by mapping the relationship between water-use and dwelling type (Troy *et al.,* 2005; Randolph and Troy, 2007; Troy and Randolph, 2006). These show that people in detached dwellings use more water than those in units, which is consistent with the IPART findings. The City Futures research disaggregated dwelling types further into semi-detached houses, high-rise and low-rise flats. It found high-rise flats use only marginally less water than houses, and low-rise flats and semi-detached houses only marginally lower than high-rise flats. The lack of consumption differentiation between houses and flats noted in the City Futures research are attributed to the effects of climate. The report suggests that for the majority of

[2] This highlights a clear sensitivity of consumption to price signals and the need to better understand occupant numbers for accurate modelling.

the year, there is enough rain to water gardens in many areas where houses have gardens. In other words, the resulting use of watering devices to maintain gardens may not be significant enough to dramatically distinguish houses from units in terms of water consumption.

By contrast other research demonstrates that dwelling type and block size are important factors that influence water consumption. The IPART research showed houses were greater consumers than units on a per dwelling basis which was attributed to differences in household size (the average number of people in units being less than in houses), and the fact that people in units are generally not responsible for maintaining outdoor areas and pools. On a per capita basis, water-use was found to be higher for people living in houses than in units, and again this was attributed to greater opportunities for outdoor water-use. Lot size is also an important factor influencing water-use, with medium and large block sizes generally consuming more water than small block sizes (IPART, 2004).

The implications of the IPART findings for planning are that policies that enable larger block sizes or and detached dwellings encourage higher levels of water consumption. Planning policy that favours smaller lot size and living in units may result in lower water consumption.

More research is required into the relationship between income and water-use. While several studies have found a positive correlation between income and water use (Beatty *et al.,* 2006; IPART, 2004), alone, income does not appear to be a significant driver for demand. Income has a positive affect on outdoor water use due to the higher incidence of appliances like pools. However, the higher incidence of water efficient appliances in higher income households partly offsets this.

2.2 Urban structure, building design and domestic energy use

A study (Randolph and Troy, 2007) designed to explore the extent to which dwelling type and socio-behavioural character of households influence the pattern of electricity and gas consumption reveals useful insights on household practices and attitudes towards energy consumption with notable difference between house dwellers and flat dwellers, and further variations between low-rise and high-rise flat dwellers. However, the researchers were unable to link actual energy consumption data with individual survey data due to data protection and privacy legislation.

Attempts to analyse interdependencies between urban structure and energy use are fraught with problems. First, data required for such a meta-analysis remains fragmented and access to linked data raises privacy problems. Second, many analyses fail to provide appropriate comparisons. Studies comparing recently built high-rise apartments and housing stock in general, often find higher levels of energy consumption in high-rise apartments (Myors, 2005). While such results point to the energy intensive nature of many high and medium rise developments, there is also evidence through ABS and IPART surveys that suggest larger dwelling size, smaller households, reliance on air conditioning and electrical energy for heating, and higher uptake of energy intensive appliances is spread across all types of new development. Consequently further comparative analyses of high and medium rise apartments with 'new' detached housing (i.e. of the same era) is needed before high and medium density development is rejected on the grounds of high energy consumption.

2.3 Urban structure and overall energy use

A Canadian study comparing high and low-rise residential density provides an empirical assessment of energy use and GHG emissions arising from transport, operational energy and materials (Norman *et al.,* 2006). It uses nationally and regionally averaged data for operational energy and transport and a life-cycle assessment model to estimate energy-use and GHG emissions associated with materials manufacture for buildings and urban infrastructure. Low-density suburban development was found to be twice as intensive as high density development on a per capita basis. However, the factor decreased to just over 1.0 when the energy-use was normalised per unit of floor area. The results highlight the importance of the measure for normalisation, particularly when studying the impact of operational energy. While floor area remains one of the more easily accessible forms of data for buildings, its use for normalisation can skew outcomes for energy when comparisons are made across a wide range of house sizes. Studies have shown that smaller houses can be shown to be more energy intensive if only assessed on a unit area basis without taking into account house size, number of occupants and total energy (Thomas *et al.,* 2001). This has led to subsequent corrections for house area in Accurate under the Nationwide House Energy Rating Scheme.

To the authors' knowledge, there is no single, integrated model for Sydney that focuses on the key areas of transport and domestic energy-use and domestic water use and how these relate to urban planning and other policies. There are several strategic policy models that address aspects of these issues for Sydney and other cities. The next section briefly discusses some examples.

3 Current urban models

Our review of urban models revealed four different types of urban model. Examples of each are briefly discussed in addition to their benefits and limitations.

3.1 Strategic Transport Model for Sydney

The Sydney Strategic Transport Model developed by the NSW Transport and Population Data Centre analyses transport and traffic patterns in a highly disaggregated form (TPDC, 2005). It draws on the five-yearly Census of population and housing, including detailed socio-demographic data as well as journey-to-work data, supplementing this with a continuous Household Travel Survey (HTS), based on a moving sample of approximately 4,000 households. This provides information on travel for all purposes — for example, shopping, business, education, social/recreational — and all modes. Sample sizes are too small to allow accurate estimates for minor modes such as cycling, or for analysis of travel patterns for specific purposes at fine geographic scale.

3.2 UrbanSim

UrbanSim comprises a collection of interacting models that simulate different processes within the urban environment and has been developed and applied in the USA.

The central objective of UrbanSim is to provide planners and stakeholders with tools to formulate different investment and policy scenarios, modelling their effect on patterns of development, transport and a range of environmental impacts. Specifying alternative packages of forecasts, land-use policy assumptions and other exogenous inputs creates scenarios. The results are analysed via the GIS viewer component of the user interface.

UrbanSim takes a behavioural approach to capture complex interactions is the urban system, by predicting the behavioural ramifications of a particular policy scenario. For example, the model predicts the location and type of particular businesses, and whether household owners will remain in their current residence or move at any particular point in time. At the development scale, UrbanSim models developed choices to build on undeveloped land and what this will look like in terms of the type of development and density.

Though the model has already had several applications, UrbanSim remains largely a work in progress. The researchers acknowledge (Waddell and Borning, 2004) that many technical challenges remain with regards to modelling complex systems in urban regions. As with all urban modelling the challenges involve structuring a theoretical basis for modelling such complex systems and the data requirements associated with modelling such situations in a meaningful level of detail. Also, improved integration of metropolitan land-use, transportation and environmental planning remains a key goal of the project that is yet to be achieved.

3.3 Melbourne Region Stocks and Flows Framework (MRSFF)

The MRSFF integrates a range of different models to analyse the *city metabolism* that characterise the interactions between model components like buildings and demography, within the w*hatIf?* modelling environment. The outputs are forecasts of development over short, medium and long-term time horizons (Baynes *et al.,* 2005).

The model is distinguished by the big picture aggregated level analysis of the main development patterns it provides as output. Analysing data at this aggregated level allows for modelling the inputs and outputs for a whole city and enables easy communication of results. This is distinct from more detailed analyses that employ large amounts of location specific data. The implications of the aggregated level analysis are that the impacts of policy decisions are described at a generation city scale, and the resultant impact on a whole industry can be calculated. Amounts of materials flowing in and out of the city are calculated, and the impact of the city on surrounding catchments.

3.4 BASIX

The potential to hardwire water and energy efficiency into building design and fixed appliances has led to the development of regulatory and policy frameworks like BASIX. BASIX is a compulsory assessment tool for sustainability designed to ensure each new domestic dwelling meets the NSW Government's targets that include a 40 per cent reduction in water consumption and 25 per cent reduction in GHG emissions, compared to the average home. Compliance can be achieved through a range of options assessed against indices for water, thermal comfort and energy.

A critical component of the policy tool is the database for each application that includes information on location, house size, and building design and includes measures for energy and water efficiency. In conjunction with post occupancy assessment data, it can be used to track whether environmental targets are being met. In terms of the present research, the database is constrained in that it only contains information regarding buildings where development consent has been granted since July 2004 for new single dwellings and dual occupancy in Sydney since October 2005.

3.5 Limitations and potential

The above examples have both limitations and a potential to move forward with an integrated approach to Sydney. However, none of these models on their own can answer the key question of how changes to planning policies — such as the extent and calibre of urban consolidation — might influence GHG emissions, energy and water-use. They do show the potential for answering such questions with an integrated model. For example integrated approaches such as w*hatIf?* have been used to examine other aspects of future urban growth, while the Sydney Strategic Transport Model has been used to explore the affect of spatial patterns on fuel consumption.

The following section sets out the key requirements — outputs, inputs and data sources — that would be needed to generate an integrated urban policy model for Sydney.

4 Developing an integrated urban policy model

As we see it, the key requirements for an integrated urban policy model are:

- Capability of providing high-level outputs of key parameters and how these vary in response to selected policy levers available to government, in particular those in the urban planning sphere such as transport investment and integration, land-use zoning and building controls.
- Incorporate key input parameters that influence energy, GHG emissions and water consumption, including technical, demographic and policy parameters.
- Utilise data at the finest degree of dis-aggregation possible, while at the same time avoiding the need for one-off or new data collections that are unlikely to be replicated on a regular basis.
- The structure should enable a range of scenarios to be tested, and be developed in modular form to allow extensions or enhancements over time without altering the underlying structure.

Further details are provided in the following sub-sections.

4.1 Outputs

The most salient outputs for a model that evaluates environmental outcomes are energy consumption, GHG gas emissions, and water consumption. Given current concerns about global warming, energy is an obvious choice due to the current contribution of fossil fuel based energy sources to global warming. Energy is also a useful proxy indicator for overall environmental performance (Graedel, 1998), although specific toxic emissions of concern should be noted separately. Water is also a clear choice, as water shortages — and accompanying restrictions — are almost ubiquitous in urban areas across the country, and, according to IPCC consensus, are projected to worsen over the long term (Houghton *et al*., 2001; McCarthy *et al*., 2001). The actions and policies of local, state and federal governments also reflect the importance of energy and water. The specific focus of our model is on residential energy and water-use. Our definition of residential water-use comprises operational (day-to-day) water used on premises by households. However, we take a somewhat broader definition of residential energy-use than is common. In particular, we include both in-home and transport related energy-use. Furthermore, we include both operational (i.e. metered) and embodied (i.e. principally buildings and cars) energy.

Other things besides energy and water are of course important: loss of fertile land; particulate and other non GHG pollution; and such other metrics could be used in future models. Note that our model will not consider energy or water-use for non-travel out-of-dwelling lifestyle and general consumables — it is specifically restricted to transport and dwelling related energy and water. This is not to deny that energy or water use relating to the production of services and consumables is unimportant. Indeed, estimates of household energy consumption from lifecycle analysis based on input-output analysis or related methods, estimate it at around 35 per cent (Treloar *et al.*, 2000) to 45 per cent (Lenzen *et al*., 2004) of total direct and indirect energy use.

4.2 Inputs

The selection of inputs to the model is determined by three requirements. The first is the usefulness in underlying modelling. The second is ease of specification. The third is data availability.

These requirements are often conflicting. For example, there is a natural tension between the first requirement (usefulness in underlying modelling) and the second (ease of specification), since more detailed data is almost always more useful from a modelling perspective, and almost always more cumbersome to specify. With the above requirements in mind, we have selected two types of exogenous inputs to our model: population and demographic inputs; and, planning policy.

Population and demographic inputs

The model requires specification of the relative proportion of future population in each of a small number of household types. Specifically, the ratio of each household type to all household types must be provided. For our household types, we use a subset of the standard ABS household types — see ABS (1996): single person, couple, couple with children all less than 15, couple with at least one child greater than or equal to 15, single parent and other. Our model internally attributes income distributions to households in each of these categories, to form a (household type x household income) matrix. Ideally, we would like to also distinguish families by age and/or labour force status, but such detail makes the model cumbersome, and may only result in small improvements to model accuracy, for two reasons:

1. Income is related to labour force status and age, and so is likely to partially capture their influence.
2. Only limited information on the influence of age and labour force status on energy and water-use is available, thereby limiting the benefits of trying to model the effect of these factors.

Planning policy inputs

For the urban area in question[3], the policy maker must classify regions in the urban area into different classes that are meaningful to the policy maker (e.g. CBD, major centre, inner suburbs, middle suburbs, existing outer suburbs, new-release area). The policy maker must then provide the total number of new dwellings, and the ratio of dwelling types, in each class[4]. For example, the policy maker may specify that 30 per cent of new dwellings will be constructed in major centres, of which 80 per cent will be high-rise — over nine stories — and 20 per cent medium rise (4–8 stories). The regions used can be any meaningful subdivision of the urban area. Local government area may be sufficient in some circumstances, depending on the policy maker's intent. For Sydney, we use TPDC travel-zones, of which there are around 800 in the Sydney metropolitan area.

4.3 Data sources and limitations

To properly estimate the independent effect of household type, income, dwelling type, and location, on energy or water use, one ideally wants to have at least this information, along with energy and water use, for individual households. In practice, such a data set is not obtainable, because:

- No-one collects this information in a combined form on a large scale at the household level. The Household Expenditure Survey comes close (ABS, 2000), but for confidentiality reasons, location is only available at a coarse city level, limiting its usefulness.
- Privacy concerns — discussed previously — often prevent the use of even the subset of this information collected by public and private entities, and certainly prevent the amalgamation of unit record level data from different entities.
- Survey limitations make independent collection unrealistic – six household types by six income bands by five dwelling types by, say, 30 regions, suggests a minimum sample size of around 5000, and, given unequal distributions across categories and the need for repeat sampling within categories, a realistic sample size is probably an order of magnitude larger again, even if simplifying interaction assumptions are made.

Federal and State privacy acts are a significant impediment to the collection of useful energy, water, and travel data. Residential energy-use data, for example, is held by energy retailers, who are generally unwilling to provide data at the household level given the current wording of the federal privacy act. This would be the most useful format for developing household energy-use models. Water data is held (in NSW) by Sydney Water, but the NSW privacy act also essentially prevents the dissemination of data at the household level. The difficulty in getting unit record data is illustrated by the fact that the NSW BASIX team (within the NSW Department of Planning) is unable to obtain access to household level water-use data from Sydney Water to assess the success of the State-legislated BASIX scheme, and must rely on selected aggregates provided by Sydney Water, which themselves were only obtained after extensive negotiation (Helstroom and Sullivan, 2007, pers.

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[3] Our reference implementation of the model will be for Sydney, but the general model structure could be applied to other urban areas.

[4] This implies a pre-defined set of dwelling types. We use a set based on the ABS dwelling types — see ABS (1996): detached house, semi-detached or townhouse, unit block less than 4 stories, unit block less than 9 stories, unit block greater than or equal to 9 stories.

comm.). It is not impossible, under the state and federal acts, to obtain household level data, but doing so requires the collaboration of government departments and utility companies who may perceive they have more to lose than to gain in any such collaboration. Studies that have negotiated access to household level information, either through utilities or at the household level, have generally done so for a small sample of homes (see, for example: Troy *et al.,* 2003), and additional data and assumptions are necessary to calibrate a metropolitan area wide model. Consequently, the data needed to fully estimate a household resource-use model is unavailable. Instead, several different data sources must be used with assumptions that combine the data to form a household resource usage model. Since the data available will be dependent on the urban area under study, no general approach is possible. Instead, the overall model architecture must allow for adaptation of resource-use models based on data availability.

Despite these difficulties, a relatively sophisticated working model can be obtained by judiciously combining different data sets. In Sydney, access has been given to aggregate electricity consumption data through Energy Australia — the largest retailer in Sydney— with all location information removed apart from postcode, and a binary (house/unit) dwelling type indicator. ABS Census data on household types and incomes, aggregated at the postcode level, along with this metered electricity data, can be used (along with some assumptions) to develop a residential energy use model that includes both demographic and dwelling characteristics.

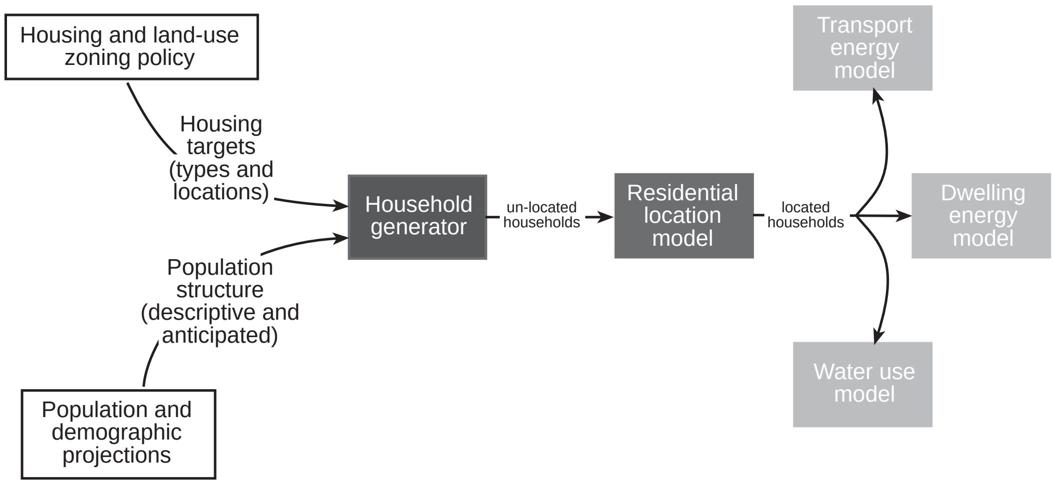
Sydney is also in the position of having the most detailed record of travel behaviour of any Australian city, in the form of the TPDC's Household Travel Survey (HTS). However, access to the unit record data is currently prevented due to complications arising from the NSW Privacy Act, and so currently we must rely on aggregate models such as that presented in Corpuz *et al.* (2006). Negotiations for more detailed access that allay the privacy concerns of the TPDC are ongoing, and the model structure presented in Section 4.4 allows for future refinement of the transport energy sub-model (or indeed any other sub-model) if and when data become available.

Negotiations over access to data on residential water use are still taking place.

4.4 Model structure

The high-level model structure, which is essentially independent of both the urban area under investigation, or any particular resource use sub-model, is shown in Figure 5.

Figure 5 Integrated Model Structure



Source: authors.

The model structure is spatial — requiring a sub-division of the urban region into disjoint sub-regions. Such a sub-division is necessary, not only because spatial information is essential to any transport model, but also because climatic and demographic factors are common to all resource models, and are themselves spatially heterogeneous. This is especially true for demographic factors – it is, after all, the first rule of urban geography and economics that 'location matters'. To capture such spatial variation, our spatial sub-division will be finer than other work such as that by Lenzen *et al.* (2004), where the relatively coarse ABS statistical subdivision is used as the unit of spatial analysis. In addition, the Input/Output approach used by Lenzen *et al.* (2004) has a limited ability to inform urban planning policy or model future planning scenarios.

Requiring two inputs (shown in white boxes in Figure 5) avoids the need for complicated time-series modelling to estimate future population inflows/outflows, household formation, and housing requirements. Given the inevitable inaccuracies in such models, we believe it better to develop a tool capable of assessing different plausible scenarios. The model assumes future household numbers and types are given, as described in Section 4.2.

Households are then assigned to dwellings via a residential location sub-model, which assigns households to dwellings in particular sub-regions based on household type and income. This presupposes that residential location is determined by the four factors: household type; household income; dwelling location; and dwelling type. After assignment of households to dwellings, we have vectors of the form [household type x household income x dwelling type x location] which are the inputs to the resource models. Each resource model is then essentially a function mapping a vector of this form to a real number representing the quantity of resources used.

4.5 Transport energy model for Sydney

A modified version of the household Vehicle Kilometres Travelled (VKT) regression model developed by Corpuz *et al*. (2006) is used to obtain average VKT per household for each sub-region, which, using certain fuel efficiency assumptions and direct energy conversion factors, can be converted back to either MJ or GHG equivalent emissions.

4.6 Residential energy model for Sydney

This model is still under development. End-use data comes from unit record data at the household level, but with only postcode level location information and binary (unit/house) dwelling type information. Combining this data with demographic and dwelling type ABS Census data aggregated at the postcode level will be possible given certain assumptions supported by end-use studies such as IPART (2004) and Isaacs *et al.* (2006).

4.7 Residential water model for Sydney

This model is still under development and would look to include the possibility of using end-use level data where available, together with aggregated water usage data where not available.

5 Initial findings and future directions

Although our data collection and modelling methodology is still in development, some preliminary analysis is available to show likely future outputs and usefulness. Figure 6 shows estimated average household primary energy consumption for automobile transport for Sydney at the travel-zone level.

Figure 7 shows household in-dwelling primary energy consumption. Variability in this model is less than that for transport energy consumption shown in Figure 6 with the maximum household energy consumption being only 10 times the lowest — as opposed to 40 times for the transport data. As with Figure 6 there are strong location effects in the in-dwelling energy-use model. While wealth effects are apparent, there are strong spatial patterns that cannot be explained by either climate or wealth.

While the results presented here are preliminary — certain simplifying assumptions were made to produce these model estimates as data collection is still incomplete — we believe the broad pattern shown and Figure 6 and Figure 7 are unlikely to change significantly, and reflect similar findings by other researchers (for example, Lenzen *et al.,* 2004; Perkins, 2002).

Wishing to move beyond a description of current patterns of energy consumption, our research aim is to develop an integrated water and energy-use model that allows us to go beyond a description of current energy use, and, instead, will allow us to assess the outcomes of particular planning policies on future energy and water use. We believe this is important because, while economic instruments and technological innovation may show the greatest promise for future reductions in resource usage, the nature of land-use, transport, and housing policies are such that their effects persist, and are reinforced, over long time periods. Thus, while the absolute effect of urban planning policies on energy use may be relatively small compared to economic policies and technology, they are more persistent, and hence may serve to place a limit on the savings made possible through other means. To be more concrete, it is easy to envisage that changes to private automobile size and fuel technology could increase fuel efficiency by 50 per cent, but if our urban structure dictates that car-based mobility is the only practical option, then this effectively puts a limit on possible savings.

Figure 6 Transport energy-use in the Sydney Metropolitan Region

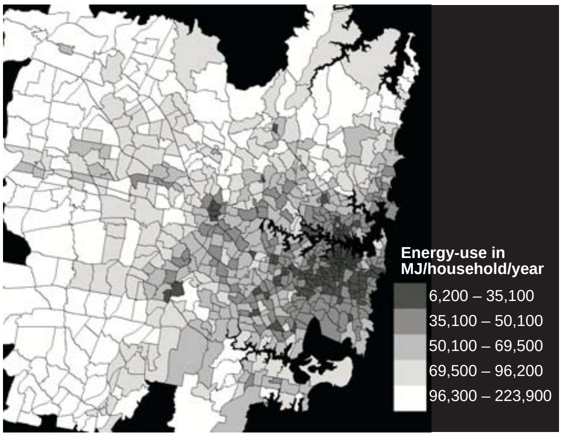
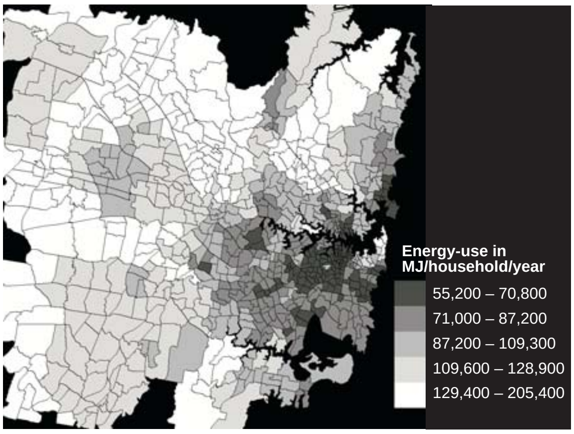


Figure 7 In-dwelling energy use in the Sydney Metropolitan Region



Source for Figure 6 and Figure 7: authors.

In considering the future development of the model, the link between the objectives for the model and the required level of information detail and data necessary to inform decision-making must be examined. In turn different data requirements, needed for modelling to meet different policy objectives, require consideration of parallel issues such as data management and privacy issues. To meet higher integrated policy objectives we need an integrated model. To realise the full benefits of such a model we need an anonymous unit record data. This raises the question of how new data management protocols should be structured for the public good.

There is a move in electricity, but also in water and gas, to measure real-time data over the coming years, which offers potential benefits but also challenges. The pressing challenge is to establish a framework for the central co-ordination of data by a trusted body in a way that can be used for policy planning. This may not be at the identifiable unit record level for privacy and commercial confidentiality reasons, but ways to overcome these obstacles must be found if sound data are to be used to inform planning decisions.

6 Acknowledgements

The results reported in this paper are part of a project that has received funding from the University of Technology, Sydney through its Challenge Grant Scheme for 2007–2008. The authors wish to thank UTS for its support.

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