INTEGRATED DEMAND FORECASTING TO SUPPORT URBAN PLANNING OF LOW-CARBON PRECINCTS: THE WASTE SCENARIO

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INTRODUCTION

Waste is a symbol of inefficiency in modern society and represents misallocated resources. This paper outlines an ongoing interdisciplinary research project entitled 'Integrated ETWW demand forecasting and scenario planning for low-carbon precincts' and reports on first findings and a literature review. This large multi-stakeholder research project has been designed to develop a shared platform for integrated ETWW (energy, transport, waste, and water) planning in a low-carbon urban future, focusing on synergies and alternative approaches to urban planning. The aim of the project is to develop a holistic integrated software tool for demand forecasting and scenario evaluation for residential precincts covering the four domains (ETWW), using identified commonalities in data requirements and model formulation. The authors of this paper are overseeing the waste domain, while other researchers in the team have expertise in the remaining domains.

A major component of the project will be developing a method for including the impacts of household behaviour change in demand forecasting. In this way the overall carbon impacts of urban developments or redevelopments of existing precincts can be assessed effectively and efficiently. The resulting tool will allow urban planners, municipalities, and developers to assess the future total demands for energy, transport, waste, and water while in the planning phase. The tool will also help to assess waste management performance and materials flow in relation to energy and water consumption and travel behaviour, supporting the design and management of urban systems in different city contexts.

KEYWORDS

low carbon, integrated demand estimation, forecasting, performance indicators, resource management, diversion rate, zero waste.

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1. INTRODUCTION AND PROBLEM FRAMING: 'RETHINK, REDUCE, RE-USE, REPAIR, REPURPOSE, RECYCLE'

For centuries, waste was regarded as 'pollution' that had to be hidden and buried as landfill. Today, the concept of 'zero waste' directly challenges the common assumption that waste is unavoidable and has no value by focusing on waste as a 'misallocated resource' (Lehmann, 2010) that should be recovered. It also focuses on the avoidance of waste creation (e.g., reducing construction waste). Recent research found that family size, socioeconomic status, and household income are primary determinants of household waste (greatly affecting waste generation and waste mix), while the effect of environmental awareness on waste generation behaviour is surprisingly small (EPA, 2009).

The creation of waste places pressure on land, pollutes the environment, and creates an economic burden of ongoing management while implying a loss of natural resources and embodied energy and water. The depletion of natural finite resources by urban populations can only be stopped through establishing sustainable consumption patterns and strategic waste management systems based on (1) waste avoidance, (2) material efficiency, using materials with less embodied energy, and (3) resource recovery (Lehmann, 2010). Preferably, we need to move to a position where there will be no such thing as waste, merely transformation and material cycling; this position can be called 'zero waste' (Massarutto, Carli and Graffi, 2011).

Consumer demand and consumer behaviour are also factors of considerable importance. The demand for a product or material, in what quantities and from which sources, is relevant to its environmental impact. The consumer sectors with the greatest impacts on the environment are building (construction), living, food, computing/electronics and mobility (transport). They involve significant amounts of energy and water, substantial flows of materials at any point in their life cycle, and can have serious adverse effects on the environment. They are therefore essential parameters for the design of the new demand forecasting tool.

Demand forecasting is a proven method in urban planning used for making planning and infrastructure design decisions based on future capacity requirements. It is the activity of estimating the quantity of a service or product that future residents (consumers) will require. Demand forecasting involves both informal methods, such as educated guesses, and quantitative methods, such as the use of historical or current data and statistics. Planning agencies, infrastructure providers and operators, utilities, municipalities, architects, and private developers all need to forecast future demands to plan for services and resources.

To define the commonalities between energy, water, transport, and waste demand forecasting, it is essential to understand all four domains. Assessing future policy options for ETWW demand will ultimately assist us to better understand the implications and to better manage the effects of falling overall demand and rising peak demand.

Forecasting tools have already been introduced in the domains of energy, transport, and water, but are not yet so well advanced for waste. However, the methods and tools used for each domain have been developed and used largely in isolation from each other. Compared with energy and water, the waste domain has frequently proven to be more difficult, as many factors affect the 'waste mix' and the multiple sources of inputs and outputs are not as easily measurable as the consumption of water or energy. The separation of these common domestic consumption categories has limited the efficiency of previous tools, yet it is likely that the various domains share similar data input requirements, even if their models and forecasting methods are different. For instance, basic socio-demographic and household variables are

FIGURE 1. The program structure of the CRC for Low Carbon Living, Program 2—'Low Carbon Precincts' (Taylor and Newton, 2012).
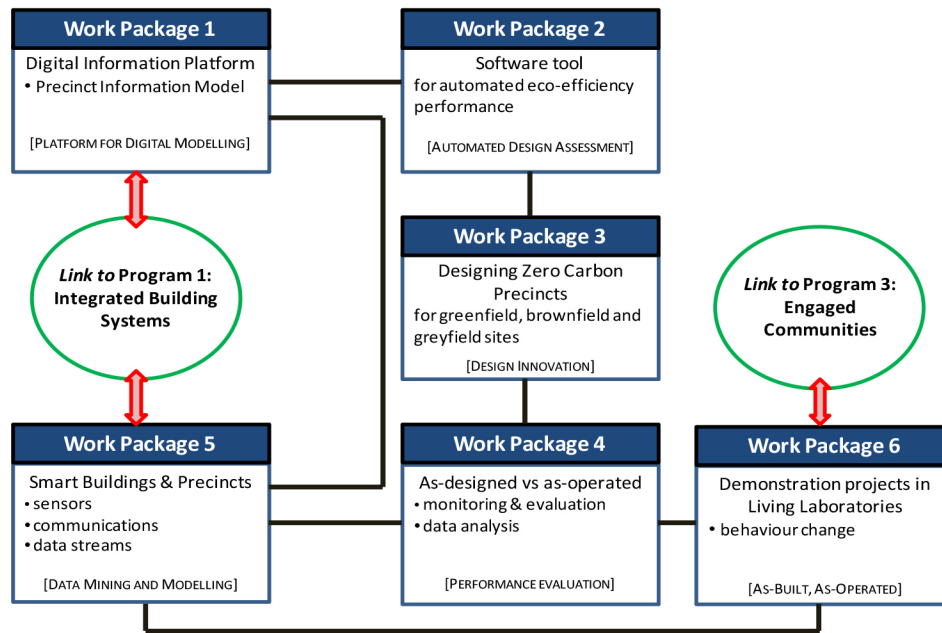
already used in several demand forecasting tools, such as the GreenStar—Communities rating tool (discussed below).

The interdisciplinary research project introduced here seeks to resolve these issues by developing an integrated suite of demand estimation tools, compatible with precinct information modelling (PIM) and other precinct design and assessment tools. The research project described herein is part of Program 2—'Low Carbon Precincts' of the Cooperative Research Centre (CRC) for Low Carbon Living based in Sydney. The program structure (shown in Figure 1) is based on six connected work packages, which also link to the other programs within the CRC. The ETWW project is an integral part of Work Package 2 (WP2) in the program. Urban planning, especially for low-carbon precincts, will be enhanced by the examination of the potential for an integrated approach to future demand estimation, across all key resource domains, to give better guidance to planners, designers and decision makers. It is time to accelerate the uptake of district-scale sustainability. After debating water and energy efficiency for the last two decades, the focus has now shifted to include resource and material efficiency.

The purpose of the tool is to arrive at a deeper understanding of sustainable urban development and allow a more structured approach to the development of appropriate infrastructure planning. The tool that is being developed will support decision-making for complex decisions on infrastructure planning between various stakeholders.

At an early stage it was noted that there are different methods for demand estimation in the different ETWW domains and a collaborative, cross-disciplinary approach is required to work towards a synthesis of possible approaches to demand estimation and forecasting. The aim of the research project is synthesis and holistic integration, including an exploration of the interconnectedness of the different domains.

Phase 1 of the project has brought together experts in forecasting from the different ETWW domains to share information and to commence designing the requirements and characteristics of the integrated demand forecasting system. As the backbones of society's economic activities and people's everyday actions, the four ETWW domains are major contributors to energy use and greenhouse gas emissions.

This paper begins with a literature review and then reports on the framework development. In addition the team realised that there is a need to investigate methods for scenario planning in the development of low-carbon policies related to ETWW, and how demand forecasting tools play a vital role in scenario analysis and policy formulation. The ongoing research project is about to enter Phase 2, which will see the development, testing, application, and evaluation of the integrated demand forecasting software tool.

The research team seeks to develop assessment tools and techniques at the precinct scale, seeking a higher level integration and coordination with other domains and service providers in city precincts. With increasing demands on the planning and management of urban infrastructure and the need for an integrated common data platform for better comparison of scenario planning, we need to define the evidence base underpinning design, planning, and policy, and ensure cost-effective operational scenarios for new low-carbon residential precincts.

The waste part of the tool focuses on residential municipal solid waste (MSW), packaging waste, e-waste and organic waste (such as food waste and biomass from kitchen scraps or gardens). Other types of waste (e.g. industrial waste) are not included. The demand forecasting tool (which is not a 'rating tool') will help planners, municipalities, and businesses create a built environment that encourages more efficient use of materials and increased recyclability. Outcomes of the project will include improvements in all facets of a zero waste management system, including prevention, reduction, re-use, recycling, and product/construction optimisation. These will help to minimise waste going to landfills, reduce carbon emissions and other pollutions, and guide future planning processes.

2. LITERATURE REVIEW AND ACTIVITIES CURRENTLY UNDERWAY

As a starting point, the team identified key concepts in the literature on integrated demand estimation of waste and identified the activities of other research teams who have explored similar planning challenges. Planning for sustainable waste management requires precise forecasting of solid waste generation to provide optimal collection, treatment, and landfill capacity configurations. Forecasting of organic waste from green spaces and kitchens is also essential; however, treatment options for organics are usually very different from those for other waste.

For accuracy, quantitative analysis of demands is essential, and this has led to the development of mathematical models and computer-based tools for demand estimation in each of the domains of energy, transport, waste, and water (Alberti, 1996). A new demand forecasting
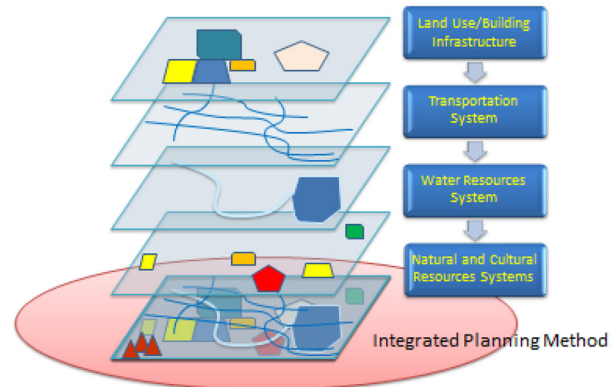
tool will have to work in an integrated and holistic manner, with an effort to overcome fragmentation of approaches and infrastructure; what is needed is the infrastructure that builds green cities.

Over the last fifteen years, a number of studies have been conducted and published by various researchers to forecast waste generation, collection, management, treatment, and recovery. For instance, in 2002, Barrett and his colleagues conducted a material flow analysis (MFA) and calculated the ecological footprint of the City of York, UK (Barrett, Vallack, Jones and Haq, 2002). Their technical report makes an interesting case for the development of a tool to measure the consequences of consumption and for addressing the key question of resource consumption. The study explores York's total material requirements and then establishes the ecological footprint associated with the consumption of these materials (also accounting for the 'hidden flows' of materials). The study analyses the efficiency of domestic waste collection, transport to landfill and processing at landfill, waste recycling and organic waste composting; units are measured by tonnage of materials and waste, for assumptions and calculations. The assumption made for the purpose of the material flow analysis was that items in the waste stream either entered the system in that year (e.g., paper) or have been replaced (e.g., computers). Therefore, the inputs of material are equal to the outputs (Wilson, 2002; Barrett et al., 2002).

An analysis of the methods and variables used for demand forecasting for waste management tools in key studies is given in Table 1.

2.1 Existing demand forecasting tools and approaches

For supply-chain planning, several software applications, such as Demand Commander, are commonly available. These are effective demand planning and forecasting solutions that can help growing companies gain complete, real-time visibility of their supply chain. So far, urban planners have not had the advantage of such valuable information. How could these advantages be transferred into the ETWW urban planning tool?

A series of existing precinct assessment tools are available, including: GreenStar—Communities, SMARTWaste, ReDi Index, MUtopia, Precinx, SSIM, Epicor and LESS. Two of these are analysed below.

2.1.1 GreenStar—Communities rating tool (Australia)

A relatively new tool developed for urban precincts comes from the Green Building Council of Australia (GBCA, 2012). The GreenStar—Communities rating tool was developed in 2012 to guide the design and construction of entire precincts and communities, moving from the building scale to the urban/precinct scale and to groupings of buildings (and their interaction). Like the LEED and BREAM tools, this is not a demand forecasting tool, but a rating tool. Questions of site planning, density, and land-use indicators are crucial to the approach taken by the developers of this tool. A pilot version was released in October 2012; it gives credit points across six sustainability categories for the planning, design, and delivery of sustainable mixed-use communities. Based on best practice benchmarking, it assesses the sustainability performance of projects' planning, design, and construction outcomes against six categories (called 'credit criteria'): governance (e.g., involving design review panels); design; liveability; economic prosperity; environment; innovation.

The GreenStar—Communities rating tool has a strong focus on the quality of the urban form and its integration within the surrounding context (e.g., transport connections), but less on the water, energy, and waste parameters.

2.1.2 WRAP Net Waste Tool (UK)

In 2012, WRAP developed a waste forecasting tool for the design stage of buildings and precincts, called the Net Waste Tool (freely available at: www.wrap.org.uk), which differentiates between two types of applications: 'tool for buildings' and 'tool for civil engineering'. The 'Designing out Waste Tool for Civil Engineering' (DoWT-CE) provides a means by which designers and engineers can analyse the waste implications of their design decisions from an early stage in the project. This allows them to calculate the impact of potential solutions and the embodied carbon, providing an indicative waste forecast for the construction waste of a project (which WRAP calls a Site Waste Management Plan, SWMP). The tool calculates the potential waste arising from construction and gives recommendations on how to improve recycling rates. The Net Waste Tool has been developed to facilitate better demand forecasting for municipalities and urban planners.

The advantage of the tool is that it offers a set of 'waste reduction actions' and 'waste recovery options' to select from (WRAP, 2012). The tool has a clear focus on construction and demolition waste and offers an impressive Excel sheet to categorise 700 different types of waste. This demand forecasting tool is not for the waste expected to be generated by a residential or mixed-use precinct in operation, but merely the waste that will be generated by the construction of the precinct. Again, while there are good lessons to be learned, it is quite different from what the research team is aiming for.

Other existing tools typically differentiate between transportation infrastructure and building infrastructure, also without any direct concern for the waste domain. While the transportation and building infrastructures have significant physical impacts, the proper integration of the waste domain poses a series of challenges.

3. DEMAND FORECASTING FOR PRECINCTS AND PERFORMANCE ASSESSMENT: A SUITABLE METHODOLOGY IN WASTE DEMAND FORECASTING

Current methods of quantitative waste and material flow demand estimation use the weight of waste generated as a unit to quantify different scenarios. Forecasting this amount and its impact is largely based on the following indicators:

1. total weight: kilogram/tonnage of waste per capita,
2. weight per cubic metre of the particular mix,
3. current recycling and re-use rate in percentage terms,
4. current diversion from landfill rate and rate of resource recovery,
5. consumption patterns and changes in affluence of residents (in $/GDP per capita),
6. expected household behaviour change towards waste avoidance,
7. implications of supply chain and disposal.

However, we need to be cautious when comparing rates of diversion from landfill; for instance, the weight per cubic metre varies when the waste is wet. Marpman (2011) explains why weight matters so much and how one of the main factors affecting diversion rate is weight. This is because waste and recycling information is typically reported in tons (weight), rather than volume (Marpman, 2011) and overestimation or underestimation may cause economic loss for the municipality, industry, or developer of the precinct.

TABLE 1. Summary of the available literature on waste forecasting tools: comparison of 12 sources and the methodologies applied.

Study/Ref.	Method/Technique	Variables and Scope of Study	Limitations
1. Abu Qdais, Hamoda and Newham, 1997	Household waste quantities and composition were measured by considering different socioeconomic variables; a linear regression analysis revealed that the generation rate was dependent on the household's income level.	Waste compositions such as food, paper and metal, glass, plastic, and putrescible were considered based on the household's income level.	The model outlined only the generation rather than the management of waste in a household.
2. Chang and Lin, 1997	The study applied a time series intervention model to evaluate recycling impacts on solid waste generation. The time series data of solid waste generation consist of observations made over a number of years at the same location.	The impact of recycling activities in waste generation in Taipei was measured based on time series data analysis.	The model relied on consistency in the sampling location but the determining variables might change significantly in the future. This implies inaccuracy in the model.
3. Parfitt and Flowerdew, 1997	The collection of reliable household waste statistics in the UK was examined from both applied and theoretical perspectives. The study was based on waste-collection-round samples selected by means of a geo-demographic classification package.	Group comparison was used to measure the relationship between households and the socioeconomic, institutional, spatial and temporal variables influencing waste quantity and composition.	The households had similar characteristics; however, a much greater sample size would be required to design an accurate model.
4. Christiansen and Fischer, 1999	The study was based on time series projection methodology for predicting specific waste streams such as household waste, paper and cardboard, glass and end-of-life vehicles.	Economic variables including historical observations and technical estimates of coefficients, t-statistics and plots were used in the model.	Countrywide data collection and maintaining consistent time series data may not be possible and hence the model's accuracy is questionable.
5. Chen and Chang, 2000	Solid waste generation in the city of Tainan in Taiwan was determined by grey fuzzy dynamic modelling based on limited samples.	When waste data is limited, particularly in developing countries, grey fuzzy dynamic modelling gives more accurate predictions than the conventional grey dynamic model.	Modelling based on such a limited number of samples may give inaccurate predictions.
6. Hekkert, Joosten and Worrell, 2000	Paper and wood consumption in the Netherlands were measured by considering multiple regression analysis.	Material flows of wood and paper were analysed by supply and use tables in the Netherlands.	The model is limited to a few variables such as supply, use, and stock.
7. European Commission, 2002	An equation-based group comparison study developed by the European Commission to estimate the generation of municipal solid waste by households.	Three broad consumption categories such as food, cloth, and furniture that eventually lead to the generation of household solid waste were considered.	The study acknowledged that the generational trend towards waste was explained by growing spending on private consumption; however, the model did not consider changing consumption patterns and their impacts on waste generation.

TABLE 1. *(continued)*

8. Navarro-Esbrí, Diamoadopoulos and Ginestar, 2002	The study applied dynamic waste generation analysis based on non-linear dynamics and comparing its performance with a seasonal auto-regressive and moving average methodology.	The model considered seasonal variations in waste generation and thus predicted short- and medium-term forecasting of waste generation using mean generation data in time series analysis.	Socioeconomic context and the impacts of individual behaviour change on waste generation were not considered in the forecasting method.
9. Chang and Dyson, 2005	The study applied system dynamics modelling to predict solid waste generation in the city of San Antonio, Texas based on a set of limited samples to address socioeconomic and environmental situations.	The analysis presented various trends in solid waste generation associated with five different solid waste generation models and tried to overcome the traditional limitations of statistical least-squares regression methods.	The study is based on generation forecasting rather than management and the overall life cycle of the waste streams.
10. Sufian and Bala, 2007	Solid waste generation, collection capacity and electricity generation from solid waste in Dhaka was predicted by the system dynamic model.	The model projected a relationship between population, waste sorting, collection, and treatment scenarios over time, and budget spending on waste collection.	The model used the ratio of the contaminated waste at any point in time to the base value as a weighting factor of 0.5, which may not be valid for every waste scenario.
11. Kollikkathara, Feng and Danlin, 2010	A system dynamics approach was designed to address several interconnected issues such as landfill capacity, environmental impacts, and financial expenditure in Newark, US.	The forecasting model explored the remaining landfill capacity of the state, and the economic cost or benefit of different waste processing options.	Consumption behaviour and its impact on the generation of waste were excluded.
12. Zaman and Lehmann, 2012	The study quantified the potential for virgin materials substitution by various waste management systems.	Re-use, recycling, and treatment of waste were measured based on the virgin material substitution factor.	Behaviour change and social technology in waste recycling were not considered.

TABLE 2. Overview of some selected existing tools.

Tools	Country	Scope	Design Phase	Construction Phase	Operational Phase	Forecast
NABERS OFFICE waste	Aus	Office building	X	X	√	X
EnviroDevelopment (UDIA)	Aus	Multi-residential developments	√	√	X	X
SMARTWaste	UK	Development site waste management	√	√	X	X
GreenStar	Aus	Communities Rating tool	√	√	X	X
WRAP Net Waste Tool	UK	Building waste	X	√	√	√
ReDi Index	USA	Municipal solid waste	X	X	√	√

The characteristics of waste streams can vary widely. Some waste streams continue to be uncontrolled, some are highly regulated, and some products and systems are becoming 'greener' and based on life cycles (Browne, O'Regan and Moles, 2009). Improvements in basic data and methods for long- and short-term demand estimation and input-output analysis have ramifications for waste treatment and composting facilities and the wider waste treatment infrastructure interdependencies. Indicators such as alternative collection systems of waste, different waste types (e.g., bulky item collection or free e-waste disposal), and alternatives for treatment and disposal must be taken into account.

3.1 Methodological considerations for MSW generation

The following part illustrates the specific difficulties for forecasting when it comes to waste.

3.1.1 Waste generation in the City of Adelaide, Australia

The official waste generation per capita figure for the Australian state of South Australia for 2006–2007 was 2.1 kilograms of MSW per person, which is slightly above the national average. However, it is likely that the real figure is actually higher (getting reliable data is a constant challenge in the waste sector). Table 3 details the situation in Adelaide, the capital city of South Australia.

Calibration of the tool will require user input of parameters for each individual city precinct or district. For instance, the following information is relevant for Adelaide.
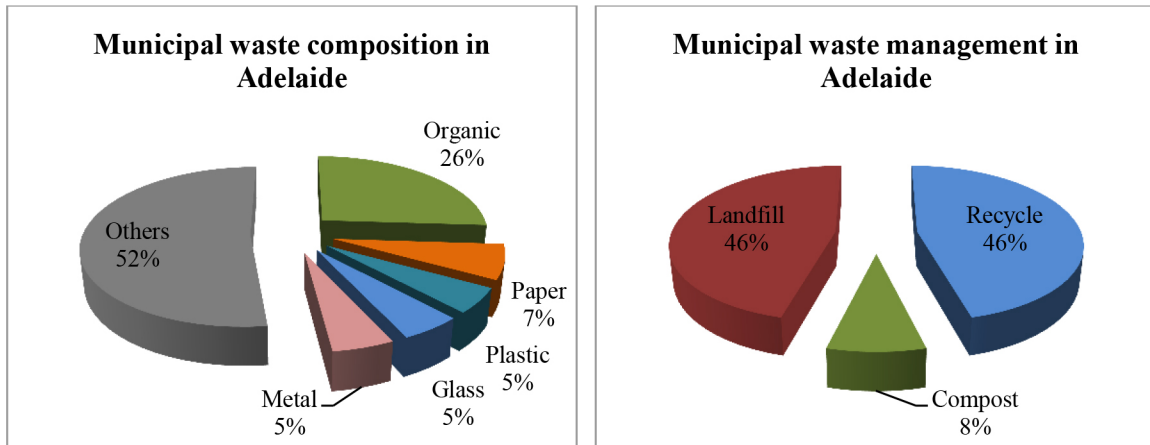
The greater metropolitan area of Adelaide has a total of around 1.1 million inhabitants in an urban area of 841.5 km^2 (UN-Habitat, 2010). Australian average per capita GDP in 2010 was US$41,300 (UN-Habitat, 2010). The introduction of a drinking container deposit system and a ban on lightweight, checkout-style plastic shopping bags have been some of the key government initiatives to avoid creation of waste in Adelaide. Container deposit legislation was adopted in 1977; therefore, certain packing containers have been recycled in Adelaide for more than three decades. The composition of municipal solid waste in Adelaide varies widely, both between location and between seasons of the year (UN-Habitat, 2010). Municipal solid waste in Adelaide includes a significant amount of construction and demolition waste (over 30 per cent).

In 2008–2009, the average person in Adelaide generated around 681 kg per annum of MSW. Around 46 percent of all MSW was recycled, 8 percent was composted and the remaining 46 percent was disposed to landfill. Figure 3a shows the composition of MSW in Adelaide and 3b shows the available waste management systems.

TABLE 3. MSW generation and recycling rates in metropolitan Adelaide.

Year	MSW generation (kg/day/person)	Recycling rate (as approx. diversion from landfill)
2002	1.9	50%
2007	2.1	59%
2012	2.5	68%
2020	1.6 or less *(recommended target; this will be difficult to achieve)*	at least 85% *(recommended government target)*

FIGURES 3A AND 3B. Waste composition and waste management systems in Adelaide (UN-Habitat, 2010).

Municipal waste composition in Adelaide

Organic 26%
Others 52%
Paper 7%
Plastic 5%
Glass 5%
Metal 5%

Municipal waste management in Adelaide

Landfill 46%
Recycle 46%
Compost 8%

3.2 Development of a holistic framework for our new tool

The literature review confirms that the proposed ETWW tool will be different from existing work and available tools, and is likely to fill an important gap.

The team expects that the tool will have to be calibrated to each specific location. Precincts in different climates and development status vary widely. An important outcome of the tool will be density recommendations and an increased clarity about what impact different density scenarios may have on waste management (e.g., lack of space for collection, storage, and treatment in a high-density multi-apartment context).

There is now a trend towards smaller, decentralised systems (e.g., decentralised recycling stations to avoid unnecessary waste transport; or district-scale biofuel generators, which run on waste cooking oil collected from local restaurants, operating at district level and supplying a district cooling system), and it looks like such systems can deliver a range of sustainability advantages. To transport waste on trucks to distant landfill sites is very inefficient and damaging for the environment.

The forecasting tool will need to provide broad principles for urban development of low-carbon precincts that take into account the unique characteristics of a location, and the reduction of greenhouse gas emissions achievable at the location—encouraging collaboration between disciplines in the design and custodianship of precincts. Therefore, the tool will not take a one-size-fits-all approach. For each new project, it will be necessary to enter the various data and basic parameters in the demand forecasting tool, calibrating the tool to the specifics of the individual location. Parameters for the tool will include:

- the amount, volume and weight of current waste generation in a city (usually, this information is available from the municipality)
- material type and content analysis (typical waste mix, e.g., there might be a high amount of e-waste or organics)
- capacity for resource recovery based on content (e.g., treatment facilities for resource recovery already in operation) and type of network and infrastructure system available
- distance to waste treatment facilities and accessibility of waste destinations

- assumed population growth and existing/future consumption patterns (e.g., expected increase in affluence and consumption), including the socioeconomic context and the impacts of individual/household behaviour change on waste generation
- the expected quantity of waste arising from new population and future consumption growth
- possible changes in legislation (e.g., significant increases in waste levies or new extended producer responsibility legislation would have an impact).

Beyond these examples there are still certain questions that need to be addressed, such as:

- Will short-term or long-term demand forecasting be more useful, e.g., is a 3-year or 10-year time frame suitable?
- How can we assume details of a future supply chain with some certainty?

Advancement in ICT technologies will affect how the forecasting tool is used. Cloud computing and information management will further transform the way we manage and operate urban precincts. It is likely that we will soon see green buildings and precincts being managed in the 'information cloud', supported by innovative building automation, wireless controls, and building services information management. In future, intelligent urban precincts will monitor their own ETWW demands.

4. DEVELOPMENT OF THE INTEGRATED DEMAND ESTIMATION FRAMEWORK FOR ETWW

Each of the four domains (ETWW) has its own predetermined protocol of operation and offers opportunities for continuous performance optimisation. The functionality of an ETWW tool will depend on key decisions made by the development team about what aspects of reality are being represented in the model. These decisions have not yet been resolved, and may even defy resolution, but the process of designing the software specification has brought to light some interesting properties of waste and its relationship with the other domains. These emerging methodological considerations from Phase 1 are now introduced through a discussion of the what, how, where, when, and why of waste detection and forecasting.

General forecasting principles state that accurate predictions rely on an understanding of the situation and processes at hand. Urban informatics can utilise numerous methods to collect, analyse, and display data that can then be interpreted in multiple ways. Technological limitations require there to be boundaries and assumptions in any model, despite an awareness of their artificiality. For our ETWW tool, where this boundary is placed has significant implications for the forecasts that can be made, and to what degree these forecasts are reliable.

We stated earlier that waste is a 'misallocated resource'. This implies that waste is potentially only a temporary state that an object finds itself in. What is 'waste' to the householder may well be a 'valuable resource' to someone else, so long as appropriate infrastructure and knowledge exists to realise this inherent value. Whereas 10 kWh of energy and 10 litres of potable water will always be energy and water; the definition of performance metrics for waste is significantly more complex. That the concept of waste has these subjective and contextual elements has rarely been considered in previous models. However, new data collection methods are creating new possibilities: as with the other three domains in our tool, waste has a qualitative aspect that must be captured in order to appreciate the reason for its creation.

So where should waste be measured? If measured at each bin in the household, the point of consumer disposal, it would be possible to gain some understanding of the impacts locational quirks have on behaviour. However, if we simply add up the weight of all these bins, what figure have we just calculated? When the smaller bins aggregate into bigger piles it becomes difficult to determine the origin of each of the elements in the waste mix; it becomes harder to know exactly why the object became waste, or what the waste is made of. Some models treat waste as an input and output, so the tool could collect data about the waste that leaves the precinct and make some statement about that. However, different inputs have different time lags between entering and leaving the house. Food scraps may come and go in a week, whereas electronic goods could be stored in a shed for many years beyond their end-of-life.

Usually waste is categorised into waste streams, measured by weight or volume, and the system's performance is indicated by how much waste is diverted from landfill (as a percentage) (Wilson et al., 2012). This data is useful but not sufficient. Measuring waste by weight tends to ignore that waste is primarily a problem due to its hazardousness, or the particular difficulty of neutralising it and making it safe, or the scarcity of the material—not its size. Less 'waste' is not necessarily better; the composition of the mix must be accounted for (Hekkert, Joosten and Worrell, 2000; Hall and Virtue, 2002). For instance, if a certain percentage of food for Household A was provided on site it may exhibit increased water consumption, reduced packaging waste and increased organic waste. Household B may produce a fraction of the solid waste and use less water, but is this because of environmentally sensitive behaviour or do the occupants travel long distances to work and consume off-site? We must be much more careful in our assumptions about waste. Clearly, where and when we measure waste will have an impact on the accuracy of current and future estimates of demand. For instance, are we measuring the performance of the household, the building, the precinct, the city, or the lifestyles of the people who live there?

A focus on macro-scale waste makes sense for a centralised, reactive response—the data tells us what is there; however, this is mainly effective at the lower levels of the waste hierarchy. In order to explore waste avoidance scenarios effectively—the priority in zero waste city design—we believe that innovative measurements will need to be developed.

Forecasting future demand must be a tentative, iterative process, especially in medium to long-term time frames, because we surely affect the actual outcome by anticipating the direction we are heading. Suppose we were forecasting the demand for waste management infrastructure in an up-market housing estate in China with a population of predominantly young couples who are likely to have children in the short term. Given the spread of consumerism and the behaviours of more established middle classes we could base our model on the waste outputs of Australians or Europeans. Our tool might tell the planners that, given the trends, the current landfill is far too small and the capacity needs extending significantly. But would it be sensible to respond to these forecasted demands with actual infrastructure development, or should we try to engineer a different future by changing the lifestyles of the population now? If this tool is to fulfil its potential, it must be used as part of a proactive approach to waste avoidance and not a simple, passive acceptance of an unsustainable 'growth' scenario. Therefore, it seems the tool will be most powerful if it can be used to influence design choices before unsustainable consumption patterns can be established.

Every person interacts with products in a slightly different way. We respond differently to education campaigns, prompts, and rules based on our currently-held beliefs and past experience. The same person reacts differently to similar situations depending on their mood and condition. In order to understand these intricacies, waste informatics will have to collect information using 'community engagement'. A quantified environment can provide instant feedback so waste can be avoided, rather than accepted and managed. Inhabitants could tweak their environment to suit changing needs, such as those brought on by changes in family composition, illness, or ageing.

The living laboratory in Work Package 6 (see Figure 3) will make it possible to monitor how changes in the built environment cause different amounts and types of waste to be generated. In an adaptable habitat, it will be possible to reconfigure the basic components of the structure to study reactions and outputs in detail. If certain patterns of behaviour look like they will generate unsustainable outcomes, the most appropriate response is to act now and change the most immediate environment that people interact with. Waste avoidance cannot be achieved through willpower and know-how alone; the buildings and other precinct features must facilitate low demand lifestyles.

Waste is a problem that has been tackled in physical science disciplines such as engineering and chemistry, and lately there has been considerable qualitative research in social sciences with education, behaviour change programs, and values being particular areas of interest. Both perspectives add something vital to the design of zero waste scenarios, yet integrating these two approaches is a challenge that perhaps has not adequately been met (El-Haggar, 2007).

One of the major challenges of the project is to establish commonalities between the four domains. It may be that the commonalities come through the activities and lifestyles that impact on the consumption of each resource in each domain. Why do we travel, why are water and energy wasted, and how much solid waste is necessary to provide the people living in the precinct with the things they need? Generally, we want our activities to be as safe as possible and to be affordable and easy.

4.1 How will zero waste principles and policy making become important?

Forecasting plays a role in policy development and our tool will help government to achieve its targets for waste reduction/recycling.

A waste management approach is sustainable if it meets the needs of present generations while maintaining the options available to future generations. Thus, a call for more efficient use of resources includes the improved productivity of raw materials, where waste is recovered and re-used as far as possible (what is called 'closed-cycle management'). This implies an economy that decouples economic growth and prosperity from the consumption of natural resources, reducing resource consumption (and waste generation) in absolute terms (Lehmann, 2012). When discussing the relevance of waste management on urban planning it is important to point to recent developments of zero waste concepts that go beyond sustainability and seek to optimise production/construction methods and resource consumption.

Urban planners frequently wonder which is the best scale to operate on and to introduce zero waste concepts. The district and precinct scales appear to be the most effective. Most modern societies have been implementing integrated waste management systems to recycle and recover resources from waste. However, the concept of zero waste is not limited to

optimum recycling or resource recovery, as it also requires elimination of unnecessary waste creation at the design stage of a product/building design. Therefore, zero waste principles focus firstly on avoidance and reduction of waste by innovative design and behaviour change, and then on recycling and composting the rest (Palmer, 2004).

4.2 Lessons learnt: development of the integrated framework

The framework for integrated demand estimation and forecasting will use commonalities of approaches and data requirements from each of the domains (ETWW), so that each discipline stands to learn from the others and contribute ideas. This process will be enhanced by the consideration of a range of alternative models and applications from each area of expertise. The focus is on residential precincts, and methods to incorporate behaviour change in demand estimation for the four domains will be sought. The inclusion of behaviour change factors in demand estimation will be a major advance, allowing for the testing and analysis of forecast scenarios sensitive to policy strategies and low-carbon initiatives.

Phase 2 of the project will involve the development of an integrated set of demand estimation models that together will form the forecasting tool. It will produce, among other things, harmonised outputs about carbon performance across the ETWW domains. Close cooperation between the domain experts and researchers will enable the use of the best available methodologies for all of them, with cross-fertilisation expected to lead to major innovations in the component models and their applications. As a result, the demand model will assist the end-user to assess the total demands for energy, transport, waste and water in the planning, design, and evaluation of urban developments, including their carbon impacts.

5. DISCUSSION: BUILDING LOW-CARBON PRECINCTS

Buildings are an integral part of precincts, forming districts, which form the larger urban context comprised of flows of people, transportation, electricity, water, waste, food, data, and other forms of information (Kennedy, Cuddihy and Engel-Yan, 2008; Siemens, 2012). This interconnection has inspired new network and smart city concepts of interconnected urban systems (such as described by Manuel Castells in 1996, in his pivotal book *The Rise of the Network Society*), which consider theories of urban morphology that affect the individual and collective performance of structures within a broader ecological context.

The link between increasing urbanisation and increasing waste generation has been established for some time. However, the impact of urban form and density on resource consumption is still not fully understood. The human population has increased fourfold over the last hundred years, while in the same time period material and energy use has increased tenfold (Lehmann, 2012).

Speculative propositions about the future call into question the way we currently experience and engage with our urban environment. Climate change, population growth and a globalised economy have placed new demands on cities as places of habitation and commerce. As such, urban development must adapt. Much of today's sustainability focus is progressing from green buildings to green precincts, then scaling up to districts.

'Best practice' of waste management needs to adjust to each location, type of waste stream, and other highly variable factors. Costs for waste handling and treatment can be staggering; so reducing the amount of waste improves efficiency and avoids the need for expensive

controls (Letcher and Vallero, 2011). It is obvious that the design of low-carbon precincts will have to focus on the challenges of greater efficiency and longer product life (WEF, 2010).

6. REFLECTION AND OUTLOOK

Former head of UN-Habitat, Anna Tibaijuka, noted that 'managing solid waste is always in the top five of the most challenging problems for city managers and it is somewhat strange that it receives so little attention compared to other urban management issues. The quality of waste management services is a good indicator of a city's governance' (UN-Habitat, 2010, p.v). Clearly waste is a serious topic. It is obvious that waste management is not just about waste recycling, but also waste prevention and many other challenges.

Waste has occupied civilisation for thousands of years and is usually considered a nuisance (Strasser, 2000). Controlling and forecasting waste is a fairly new concept, a result of our expanding technologies over the past decades. Most recently, waste concerns have grown exponentially with rapid growth in world population, greater consumerism, and related greenhouse gas emissions (Integrated Waste Management Board, 2001). This paper has touched on some of the complexities surrounding waste management and its links with urban development and infrastructure networks (it should probably be noted that there are experts warning that this new 'smart' infrastructure might be too expensive to retrofit on a large scale).

The amount of waste and the type of mass or energy that exit along the waste streams are always indicators of systemic inefficiency. Accurate prediction of future solid waste generation will help improve the accuracy of urban planning and allow for better long-term infrastructure system planning (hence, allowing also for better resource efficient planning, construction, operation, and logistical/supply chain/disposal chain decisions).

This paper has also touched on the planning scenario of the waste category and the relationship between policymaking and forecasting. It is intended that the forecasting tool will help architects and planners in thinking holistically about possible future low-carbon forms of the city that feature significantly reduced greenhouse gas emissions (Girardet, 2008).

Building a new robust 'demand theory' would allow governments to improve the management of precincts within the constraints of resources. It would help them to assess how centralised or decentralised their planning and infrastructure should be (Adger et al., 2003). For example, are small, distributed technologies really more prone to innovation than large, capital-intensive technologies?

This research project will deliver improved and streamlined methods for demand forecasting and simultaneously account for the four domains of energy, transport, waste, and water. The benefits of this approach may help break down barriers caused by present administrative structures and planning silos where demand estimation for each domain is conducted and applied separately. Integration should lead to improved efficiency in the planning process and to improved effectiveness, as it allows unified estimation of carbon emissions and impacts for a given precinct or design, maximising the use of common data resources. Integration will also allow improved efficiency and accuracy in the estimation of carbon impacts of new developments or redevelopments of precincts.

Having such a holistic demand forecasting tool will help planners, municipalities and businesses to think about more efficient use of materials and to allow for increased recycling. This will help to minimise landfills, reduce carbon emissions, and improve the environment.

Progressive planning policies, waste prevention, waste reduction and product/building optimisation are expected outcomes from this research project.

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