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Article

Supporting Urban Planning of Low-Carbon Precincts: Integrated Demand Forecasting

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Abstract: Waste is a symbol of inefficiency in modern society and represents misallocated resources. This paper outlines an on-going 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 develops 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. A major component of the project will be developing a method for including the impacts of household behavior change in demand forecasting, as well as assessing the overall carbon impacts of urban developments or redevelopments of existing precincts. The resulting tool will allow urban planners, municipalities and developers to assess the future total demands for energy, transport, waste and water whilst 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 behavior, supporting the design and management of urban systems in different city contexts.

Keywords: low carbon precinct; integrated demand forecasting; performance indicators; resource management; waste diversion rate; zero waste

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1. Introduction and Problem Framing: "Rethink, Reduce, Re-Use, Repair, Repurpose, Recycle"

With rapid urbanization, the world is facing immense urban challenges that are without precedent. A large number of complex decisions have to be made by municipalities in regard to urban development, and these processes require solid data and an evidence-base for improved decision-making. It seems that larger cities use resources more efficiently than smaller cities because of economies of scale and inter-connectivity.

However, how should cities be transformed and organized for more effective environmental resource management? In regard to urban planning, waste management always poses a particular set of challenges. 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 valueless by focusing on waste as a "misallocated resource" [1]. Zero waste highlights the importance of avoiding waste creation (e.g., eliminating unnecessary construction waste or packaging) in the first instance. Australia, like many developed countries, is a wasteful nation: illustrated by the fact that around 30 percent of our daily food is thrown out without recovery [2]. Recent research found that family size, socioeconomic status and household income are primary determinants of household waste generation and composition, while the effect of environmental awareness on waste outcomes is surprisingly small [2]. This raises much wider social questions about attitudes and behavior, and our wastefulness has significant implications for future urban development [3–6]. How will we design, build, operate, maintain and renew/recycle cities in the future? What role will materials play in the city precinct of tomorrow? How can we deliver more effective environmental education for waste avoidance? And how can we adopt sustainable urban development principles and zero waste thinking? These are some of the topics relevant to this study.

The paper coveys some contexts of the work by explaining its place within the wider resource demand forecasting research. This waste demand forecasting project aims to integrate multidisciplinary issues such as consumption behavior, life style, cleaner production, waste generation, minimization, avoidance techniques and holistic waste management systems to forecast waste management scenarios for future urban development. It does this by integrating and synthesizing the waste domain with mainstream resource forecasting models.

Today's consumption-driven society produces an enormous amount of waste [7]. Our addiction to over-consumption, a linear "throw-away" mentality and inadequate or absent resource recovery [8] has depleted global stocks of non-renewable and renewable resources. As such, waste can be seen as a symbol of inefficiency in modern industrialized society and represents misallocated or undervalued resources. Annual municipal solid waste (MSW) generation varies widely among cities and can easily vary from 400 to 1400 kg of waste per resident per annum. Within every city waste is generated through a diverse range of consumption behavior by citizens and visitors, as we discuss further in Section 4.

The creation of waste places pressure on land, pollutes the environment and creates an economic burden of on-going management. Waste also represents and unnecessary 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 [1]. In the construction sector, this includes an improved construction process using modular prefabrication and digital fabrication, design for re-use and recycling principles, as well as weight saving by only using the minimum material required (lightweight construction). 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" [9].

The waste hierarchy diagram (Figure 1) illustrates how waste avoidance is the most preferred activity, above re-use and recycling. Disposal in landfill represents the lowest level of the waste hierarchy.

Figure 1. Waste hierarchy[10].

Recycling alone is not enough to deliver a sustainable waste management system. Organic waste is an increasing proportion of all waste generated and new technologies to convert the resource into energy or fertilizer are playing an increasingly important role in waste management [11]. The small Austrian town of Güssing, for instance, activates the biomass from its agricultural waste and has reached energy autonomy by composting and using bio-energy to generate power. In the available literature, a recommended split for a city (here a typical developed city in Germany or Australia) can be found where no MSW goes to landfill:

- Recycling and re-using: *minimum of 60 percent and 70–90 percent recommended*;
- Composting of organic waste: *around 30 percent recommended*;
- Incineration of residual waste (waste-to-energy): *generally to be avoided; maximum 10 percent only for what cannot be recovered*.

Of the 2.6 billion tons of municipal waste created within the European Union's 27 member countries in 2009 [12], 46 percent was recovered (recycled), 5 percent was incinerated and 49 percent was sent to landfill. However, landfill emits greenhouse gas emissions to air, which are proven to be a major contributor to global climate change. Aiming for zero waste to landfill will reduce these impacts. The UK government, for instance, has set some relatively modest targets to increase the recycling of all municipal waste. The targets require that at least 30 percent of household waste is recycled or composted by 2010 and 33 percent of household waste is recycled or composted by 2015.

The intensive use of resources increases environmental impact throughout the entire value chain—from extraction of resources, to processing, transport and the use of products, to their end-of-life and disposal. The potential for re-use of waste is significant (see Figure 2), but it depends widely on the material concerned and the degree of contamination with other waste streams. For example the re-use of timber, glass, cardboard and metal has a long tradition and these materials are easy to salvage at the end-of-life of the building or product; while bonded material combinations or sandwich panels are difficult to separate.

Figure 2. Quantity of recyclable material collected in just two hours at one recycling facility in Sydney, December 2012 [10].

In general, we should promote waste management practices that as far as possible:

- Eliminate waste or its consignment to landfill;
- Advance the development of resource recovery and recycling;
- Install suitable infrastructure to increase the recovery of resources and reduce the amount of waste sent to landfill;
- Improve the efficiency and effectiveness of sorting facilities;
- Improve the recovery or processing of materials banned from landfill under the Environment Protection Policy (Waste to Resources) [13].

Industry is working hard to make products and processes more material-efficient [14]. The trend in the manufacturing industry is towards increased resource productivity and higher material efficiency ("doing more with less"), which will eventually help reduce the overall amount of waste generated.

Consumer demand and consumer behavior 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, and 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.

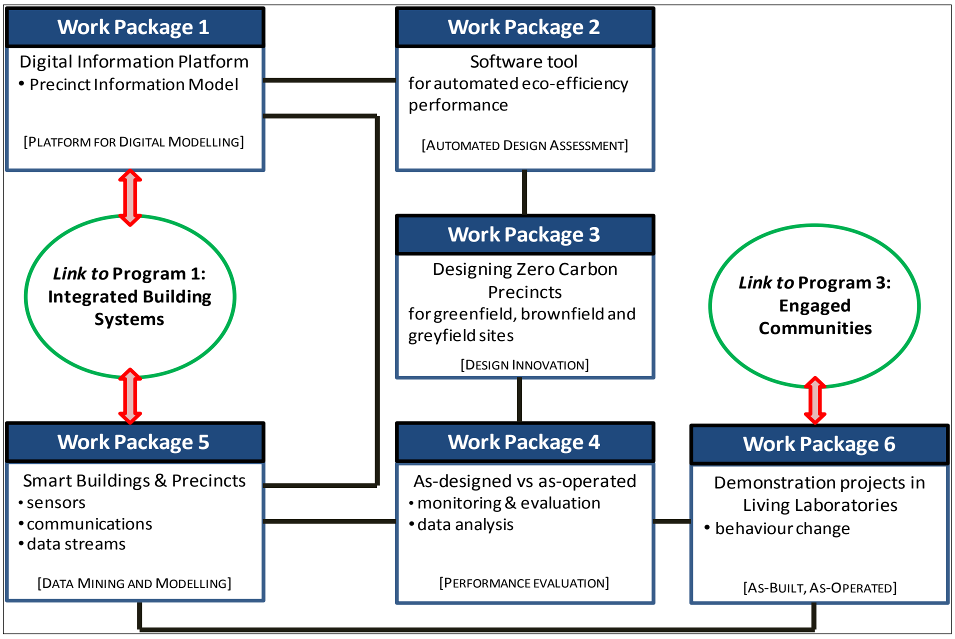
Demand forecasting is an urban planning method used for making planning and infrastructure design decisions based on future capacity requirements. It is the activity of estimating the quantity and quality of a service or product that future residents (consumers) will require. Demand forecasting involves 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. Energy, transport, water and waste are all significant parts of urban infrastructure and present logistical issues (e.g., to centralize or decentralize, how to distribute/collect) that planners need to resolve. All of them are central to production and consumption and, consequently, generate greenhouse gas emissions. Assessing future policy options for ETWW demand will ultimately assist us to better understand the implications and to better manage the effects of the 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 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 modeling (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 3) 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.

Figure 3. The program structure of the Cooperative Research Centre (CRC) for Low Carbon Living, Program 2—"Low Carbon Precincts" [15].



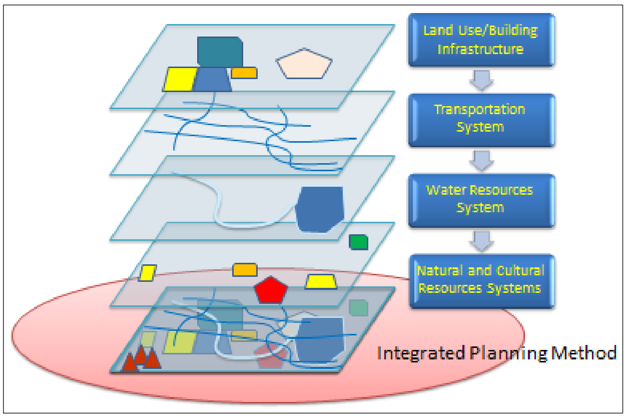
At an early stage it was noted that there are different methods for demand estimation in the different ETWW domains and a collaborative, cross-disciplinary approach is required to work towards a synthesis. The aim of the research project is synthesis and holistic integration, including an exploration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

This paper begins with a literature review and then reports on the framework development. In addition the team realized that there is a need to investigate methods for scenario planning in the development of low-carbon policies related to ETWW, and the vital role that demand forecasting tools play in scenario analysis and therefore policy formulation. The on-going research project is about to enter Phase 2, which will see the development, testing, application and evaluation of the integrated demand forecasting software tool (see Figure 4). This phase will be reported on in a subsequent paper.

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. Vauban (a residential district in the Southern German city of Freiburg) demonstrates the possibility of an autonomous and self-sufficient low-carbon precinct with a decentralized energy supply system generating its own power.

Figure 4. Integrated planning method.



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 will help planners, municipalities and businesses create a built environment that encourages more efficient use of materials and increased recyclability. The tool will assist automated eco-efficiency performance; it will not rate the efficiency of ETWW provision. Ratings tools already exist and their usefulness is limited by their being ex post facto, *i.e.*, they measure something that has already occurred. The integrated demand forecasting tool, by contrast, will predict and, ideally, try to pre-empt use of resources. 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 optimization. These will help to minimize waste to landfills, reduce carbon emissions and other pollutions and guide future planning processes. The paper explores a possible research framework for developing the waste demand forecasting tool. Since the study is in progress, the paper first outlines the existing waste management tools and then a possible way forward to develop the new demand forecasting tool.

Smart City has become the buzz word of urban planning based on “big data”. “Smart” has become a primary tool in urban development and a new way to understanding the city, e.g., ICT is transforming cities with crowd-funding, WIFI, GPS and many other impactful developments, leading to the notion of the informed citizen. “Smart” promises improved decision-making, measuring, forecasting, productivity, and traffic flow and job creation. However, we have to ask: What kind of “smart” should we engage in and is there a misconception of what technology can offer? Does technology make the city more or less resilient? Frequently, planning appears not so much as a technical problem, but an organizational challenge. The crucial question—how should our society and cities be organized to lead to less consumption—is often left out of the discussion. No doubt, using the data to achieve a new infrastructural platform at metropolitan scale will have its merits: the resource-efficient city also creates strong local communities. However, integration of big data in urban development has so far been mainly about transportation and flows (logistics, traffic flow, water, energy and material flows, and supply chains; however, there is a lack of GIS spatial data for material flows). We first will need to reconfigure the infrastructure that conducts the flows to arrive at the resource-efficient city.

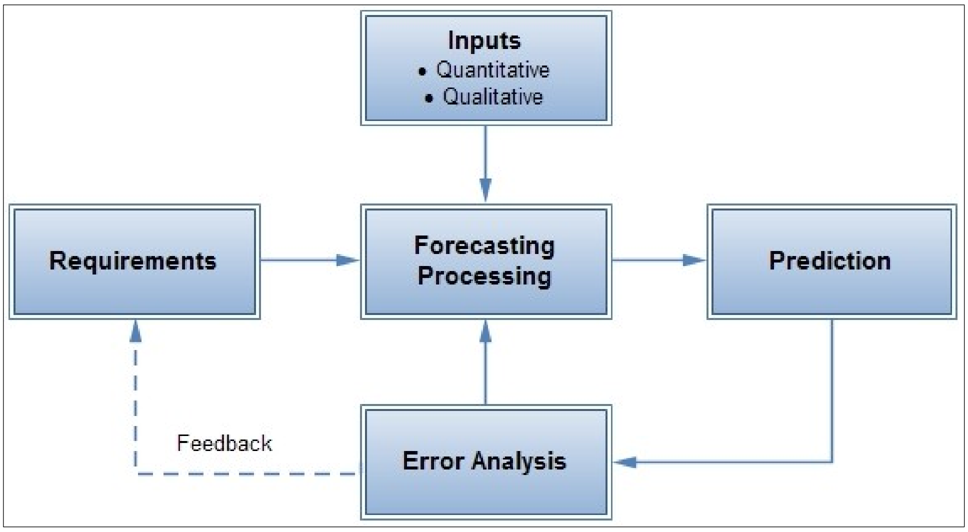
The new ETWW Demand Forecasting Tool will contribute to a way of better understanding these challenges and improve decision-making process.

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 accurate 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.

Historically, forecasting has been undertaken with the help of judgment gained from past experience over a longer period (e.g., “rule of thumb”). However, without accurate measurements of feedback or sufficient understanding of system behavior such judgment and estimation could be prone to inaccuracies. Whilst judgment is still recognized as an indispensable component of forecasting, it can now be augmented with large datasets and advanced modeling techniques [16]. In general, the forecasting process starts with prediction based on the patterns or anomalies of the previous history or data. The model predictions are then assessed against future results, errors are identified and finally the forecasting process is modified by considering the error of confidence. Figure 5 shows the typical forecasting process.

Figure 5. Typical forecasting process for waste management [17].



In general, demand forecasting tools are based on either qualitative (judgmental) or quantitative (numerical and statistical) methods, or a combination of both. Table 1 lists the common types of demand forecasting methods applied in most decision making.

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 [18]. 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.

Typical demand forecasting methods include input-output modeling combined with time series projection (e.g., consumption trend projection methods; reverse engineering); other methods combine qualitative data (e.g., forecasting from expert opinion, using Delphi Technique; expectation surveys) with quantitative assessment (e.g., from data mining, statistics, rule-based forecasting or discrete event simulation). Whilst no demand forecasting method can be 100 percent accurate, combined forecasts can improve accuracy and reduce the likelihood of large errors [18,19].

Table 1. Common categories of demand forecasting methods.

Qualitative method ***(judgmental)***	**Combined method** ***(judgmental and statistical)***	**Quantitative method** ***(numerical and statistical)***
Survey Executive jury method Sale force composite Delphi Technique	Artificial intelligence methods • artificial neural networks • expert/group method of data handling • support/believe vector machines System dynamic (causal loop system)	Casual forecasting • regression analysis • econometric models • input-output models Time series • trend/pattern analysis • regression analysis • exploratory analysis

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 [20]. Their technical report makes an interesting case for the development of a tool to measure the consequences of 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 [20,21].

An analysis of the methods and variables used for demand forecasting for waste management tools in key studies is given in Table 2. The analysis shows that the models used to create other demand forecasting tools are limited in one (or more) of these ways: they focus on generation rather than management, their sample size has introduced potential inaccuracies, they do not measure the possibility of behavior change. Identifying these limitations should help to avoid introducing the same errors in the ETWW model. The proposed model will expand the scope of the demand forecasting model by integrating social, behavioral, economic, environmental and technical issues which were not integrated in any of the previous models.

A review shows that the available methods for assessment of metabolic flows include a range of diverse methodologies, including: Material flow analysis, input/output analysis, ecological footprint analysis, lifecycle assessment of cities and simulation methods (including system dynamics modeling).

Table 2. 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
[22]	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.
[23]	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.
[24]	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.
[25]	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.
[26]	Solid waste generation in the city of Tainan in Taiwan was determined by grey fuzzy dynamic modeling based on limited samples.	When waste data is limited, particularly in developing countries, grey fuzzy dynamic modeling gives more accurate predictions than the conventional grey dynamic model.	Modeling based on such a limited number of samples may give inaccurate predictions.
[27]	Paper and wood consumption in the Netherlands were measured by considering multiple regression analysis.	Material flows of wood and paper were analyzed by supply and use tables in the Netherlands.	The model is limited to a few variables such as supply, use and stock.

Table 2. *Cont.*

Study/Ref.	Method/technique	Variables and scope of study	Limitations
[28]	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.
[29]	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 behavior change on waste generation were not considered in the forecasting method.
[30]	The study applied system dynamics modeling 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.
[31]	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.
[32]	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 behavior and its impact on the generation of waste were excluded.
[33]	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.	Behavior change and social technology in waste recycling were not considered.

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 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?

Table 3 shows the design stage capabilities of a series of existing precinct assessment tools, including: GreenStar—Communities, WRAP Net Waste, SMARTWaste, ReDi Index, MUtopia, Precinx, SSIM, Epicor, PPDS, LESS and the "City Protocol" tool, which is a city-wide tool with sustainability indicators. MUtopia for instance, is an integrated visualization and a simulation tool for sustainable cities, developed by the University of Melbourne [34]. However, in this simulation platform, the waste domain remains insignificant (only per capita waste generation was considered) compared to the other domains. The difference between the MUtopia and ETWW tool is that the MUtopia tool was developed by considering all four domains without developing any sub-tool; however, the ETWW tool is based on four individual demand forecasting tools (E, T, W and W) and by linking them up, it offers holistic demand forecasting for precincts' development. Some information on waste forecast exists in GreenStar—Communities and WRAP Net Waste. These two tools are analyzed below.

Table 3. Overview of some selected existing tools.

Tools	Country	Scope	Design phase	Construction phase	Operational phase	Fore-cast
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	√	√

2.1.1. GreenStar—Communities Rating Tool (Australia)

A relatively new tool developed for urban precincts comes from the Green Building Council of Australia [35]. 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 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 the following categories (called "credit criteria"):

- Governance (e.g., involving design review panels);
- Design;
- Liveability;
- Economic prosperity;
- Environment;
- Innovation.

The Communities tool complies with recent recommendations by the Australian Government's Major Cities Unit (outlined in its report Creating Places for People: An Urban Design Protocol for Australian Cities [35]. However, the definition of "good urban design" is always difficult to quantify and depends widely on the capability and experience of the design team and review panel that assess the project. Furthermore, 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 application: "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 analyze 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. WRAP explains:

This tool will help you to:

- Forecast construction waste arising,
- Develop your Site Waste Management Plan,
- Reduce the costs of construction wastage,
- Optimize your waste disposal strategy,
- Measure reductions in construction waste to landfill (including carbon impact),
- Identify opportunities to increase re-used and recycled content,
- Meet corporate targets and client requirements [36].

The advantage of the tool is that it offers a set of "waste reduction actions" and "waste recovery options" to select from. In the user guide, WRAP notes:

> This web-based tool has been developed to help construction project teams forecast and measure the amount of construction waste generated by their projects, identify actions to reduce waste and recover more waste, quantify cost savings and report on waste management performance to their clients. It also calculates the opportunities to use more recovered materials (re-used and recycled content) [36].

The tool has a clear focus on construction and demolition waste and offers an impressive Excel sheet to categorize 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 learnt, it is quite different from what the research team is aiming for.

3. Demand Forecasting for Precincts and Performance Assessment: A Suitable Methodology in Waste Demand Forecasting

Current quantitative methods of 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 meter 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 behavior 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 meter varies when the waste is wet. Marpman [37] explains waste and recycling information is typically reported in tons (weight), rather than volume [37], and that overestimation or underestimation may cause economic loss for the municipality, industry or developer of the precinct.

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 [38]. 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 community interaction with alternative systems of waste management (such as eBay, garage sales, communal consumption), 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 waste generation and management demands.

Waste Generation in Australia and in the City of Adelaide

What is the situation with waste generation in Australia and what are reasonable targets? In 2007, the total MSW generated in Australia, by 20 million people, was 44 million tons, of which 52 percent was recycled. The 2020 forecast is 80 million tons (this seems unavoidable, given the current growth rate), of which a minimum of 80 percent will be recycled, according to government recommendations.

Per capita, Australians generated around 2,080 kg per capita per annum of total waste (all waste streams together) in 2006–2007 (this includes around 750 kg MSW per person p.a.). This is around 5.7 kg per day, among the highest figures worldwide [39].

The official waste generation per capita figure for South Australia for 2006–2007 was 2.1 kg 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 4 details the situation in Adelaide.

Table 4. Municipal solid waste (MSW) generation and recycling rates in metropolitan Adelaide.

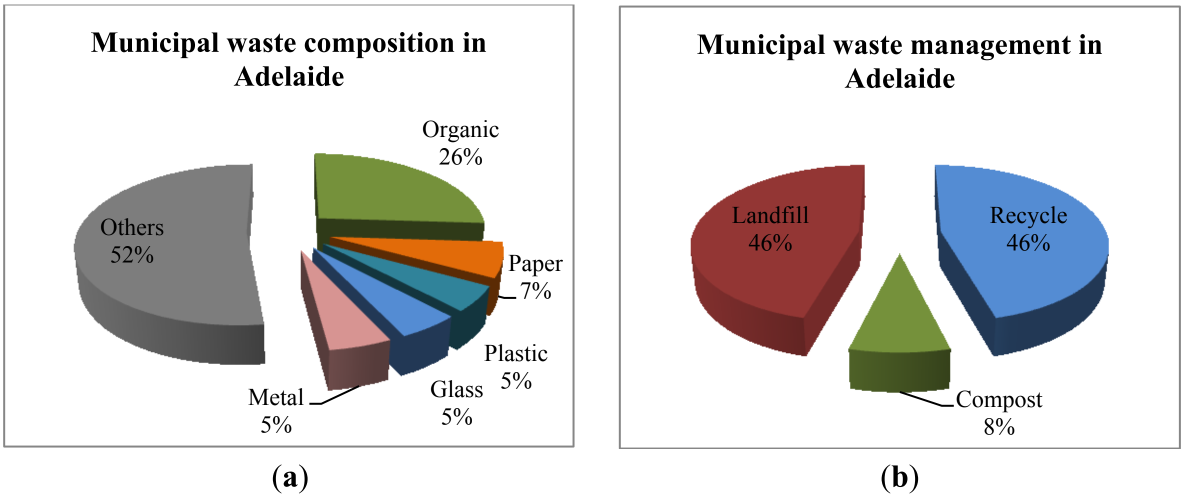
Year	MSW generation (kg/day/person)	Recycling rate (as approx. diversion from landfill)
2002	1.9	50 percent
2007	2.1	59 percent
2012	2.5	68 percent
2020	1.6 or less *(recommended target; this will be difficult to achieve)*	at least 85 percent *(recommended government target)*

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.

Adelaide is the capital city of South Australia. The greater metropolitan area of Adelaide has a total of around 1.1 million inhabitants in an urban area of 841.5 km^2 [40]. Australian average per capita GDP in 2010 was US$41,300 [40]. 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 [40]. Municipal solid waste in Adelaide includes a significant amount of construction and demolition waste (over 30 percent). The building sector has been slow to innovate and is still a very material-intensive industry, consuming a relatively high amount of raw materials and generating large quantities of waste.

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 6a shows the composition of MSW in Adelaide and Figure 6b shows the available waste management systems.

Figure 6. Waste composition and waste management systems in Adelaide [40].



(a) **(b)**

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.

During Phase 1 of the project, some of the recurring questions that will help to guide the next project phase include the following:

- *How city specific or region specific should the new tool be, or is it possible to have a universal tool for precincts? Or can there be one formula for low-carbon precincts?*

Based on the data specification, the team expects that the tool will have to be calibrated to each specific location. Precincts in different climates and development status vary widely.

- *Should a new precinct be based on centralized or decentralized supply systems?*

There is now a trend towards smaller, decentralized systems (e.g., decentralized 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; or micro-waste-to-energy gasification plants using on-site waste for power generation as well as cooling and heating), 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. Aside from the economic inefficiency, there are also the socio-political issues of landfill siting. The majority of residents do not want a waste disposal site in their immediate area, hence the well-known *NIMBY* (Not In My Back Yard) and *LULU* (Locally Unwanted Land Uses) phenomena whereby citizens' groups actively campaign against planning proposals. The proposed tool will help overcome these by engaging the community with innovative alternatives to typical technological solutions.

An important outcome of the tool will be density recommendations and an increased clarity about how different density scenarios may impact on waste management (e.g., lack of space for collection, storage and treatment in a high-density multi-apartment context).

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 this 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 (e.g., decentralized or centralized and far away) 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 behavior change on waste generation,
- the expected quantity of waste arising from new population and future consumption growth,
- expected 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?

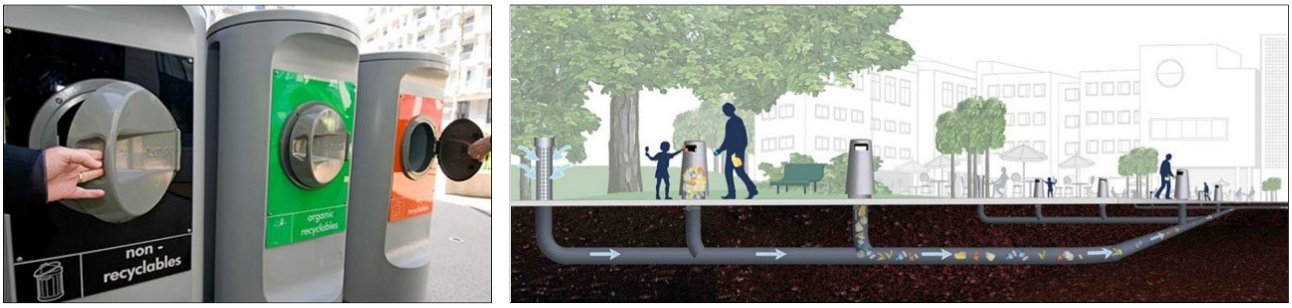
In future, intelligent urban precincts will monitor local ETWW demands. Intelligent buildings and precincts are essentially about processes and systems, where services and information systems can respond in an effective manner to real-time demands of the occupier and the natural and built environment. The interdisciplinary nature of the design and management processes of these precincts is important, supporting the demand forecasting of services. These processes include operation and management processes of precincts, the development of ICT and communication systems, and the application of control systems and sensor technologies.

Advancement in ICT technologies will affect how the forecasting tool is used. Eco-smart cities such as Songdo (Korea) and Masdar (United Arab Emirates) are already using smart sensors in their urban technology fabric. 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.

3.3. New Technologies for Waste Collection

An interesting development is the vacuum system recently developed in Sweden, which utilizes an underground pipe system to collect waste within districts (see Figure 7a,b). The system is in operation at Hammarby-Sjöstad, a green district in Stockholm. The system uses an airborne (pneumatic) pipe system with a vacuum pump for waste collection, reducing the need for transportation of waste. There are different refuse chutes, underground block-based recycling rooms and area-based waste collection points, which makes recycling and the segregation of waste at the source easier for residents. Collection points are carefully located next to bike sheds, easily accessible and clearly visible [41].

Figure 7. Automated vacuum system for waste collection, a distributed system installed in Stockholm [41].



(**a**) (**b**)

This innovative waste collection system triggered a positive behavior change at Hammarby-Sjöstad: the city claims that the introduction of the waste collection system is responsible for a reduction of the amount of household waste generated by over 15 percent per household from 2005 to 2010, and that overall recycling rates increased (to 90 percent diversion rate from landfill; however, Stockholm still uses incineration for district heating); however, these claims are inconclusive and cannot be confirmed. This system can result in a considerably cleaner city as it facilitates waste disposal for residents. In addition, there is no noisy waste collection by trucks, which can lead to lower operation costs. This is a good example of how technological solutions of automated underground waste collection are integrated into residential precincts: the underground waste disposal and transportation system is easy to use and has become a critical part of Sweden's new green precincts. The cities of Barcelona, Copenhagen and Melbourne are also introducing it.

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 optimization. The functionality of an ETWW tool will depend on key decisions 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 and when, and why of waste detection and forecasting.

As mentioned above, general forecasting principles state that accurate predictions rely on an understanding of the situation and processes at hand. Urban informatics can utilize numerous methods to collect, analyze 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 a “waste” to the householder may well be a “valuable resource” to someone else, so long as appropriate infrastructure and knowledge exists to realize this inherent value. Whereas 10 kWh of energy and 10 liters 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 behavior. 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 categorized 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) [39]. 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 neutralizing 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 [17,27]. 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 behavior or do the occupants travel long distances to work and consume off-site? We must be much more careful in our assumptions about waste. Often items that are discarded as waste by some households are in fact merely unsuitable for their changing needs. For example, baby chairs, prams, and other toys can be found in waste streams destined for landfill despite being in usable condition. The creation of convenient pathways for reuse of everyday items could eliminate much avoidable waste. If these material and energy savings could be quantified then public or private investment in such schemes might be justified.

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 centralized, 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 behaviors 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. However, 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 fulfill 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 behavior 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 will power and knowhow alone; the buildings and other precinct features must facilitate low demand lifestyles. The Living Labs will help provide information about the larger-scale implementation of the tool in planning and managing the eco-smart city.

In the future, a "complete" digital model of the urban environment could allow participants to virtually interact with possible modes of operation before they make significant financial outlay into what usually ends up being very permanent and long-lasting infrastructure. Such a tool would be extremely useful in multiple stakeholder meetings where major design decisions need to be made about where low demand infrastructure should be installed in the existing city fabric to facilitate zero waste lifestyles. A fundamental limitation in simulation modeling is the attempt to predict an unpredictable system, but when we see the simulation as a tool, rather than a reliable prediction, it matters far less. Urban planners should be seeking configurations that appear to indicate a sustainable future. This illustrates that the tool indicates the performance of not only the precinct or the buildings, but also the lifestyles of the people who live there.

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, behavior change programs and attitude 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 [42].

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 [6,43]. 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 optimize production/construction methods and resource consumption.

Urban planners frequently wonder which is the best scale to operate on and to introduce the zero waste concept. 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 behavior change, and then on recycling and composting the rest [44]. The five concepts of the zero waste city are: behavior change and sustainable consumption, extended producer and consumer responsibility, 100 percent recycling of MSW, legislation to end landfill and ensure zero incineration of waste, and 100 percent recovery of resources [45].

Planning better cities will also require that composting facilities and recycling centers are in close proximity to each other to avoid transporting materials over long distances. Urban farming is a key strategy to recover biomass and close the cycle for organic waste. Compost is an important source of plant nutrients and is a healthy, low-cost alternative to chemical fertilizers. Composting has become a necessary part of contemporary landscape management, inner-city gardening and urban farming, as it uses "reverse supply chain" principles, giving organic components back to the soil, thus improving the quality of agriculture. Paying attention to the nutrient cycle and to phosphorus replacement is part of sustainable urban agriculture.

Another area of zero waste urban policy-making that will result is the minimization of food waste by facilitating the collection of left-over food from restaurants, shops and cafes for distribution to disadvantaged residents. As well as the obvious social benefits, this will contribute to cities meeting zero waste objectives by diverting "unwanted" food from landfill. The Australian not-for-profit organization OzHarvest, which began in Sydney in 2004 and is now spreading to other cities, is a great example of what can be done.

Figure 8 shows an extended conceptualization of the zero waste city and its key principles, as noted by Zaman and Lehmann [33]. With proper implementation of all these principles, current cities could be transformed into zero waste cities. The key drivers are based on short-term and long-term implementation strategies. Awareness and education, behavior change and systems thinking are immediate strategies to avoid and reduce waste through perceptual transformations, whereas innovations in building design and legislation aimed at achieving 100 percent recycling are long-term strategies to be implemented on a precinct scale. One of the important aspects of the zero waste cities is the conversion of the linear city metabolism to a circular, closed-loop city metabolism (see Figures 8–11).

Figure 8. Drivers for transforming current cities into zero waste cities [33].

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 behavior change in demand estimation for the four domains will be sought.

The inclusion of behavior 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.

The integrated framework is being developed using a series of national workshops that bring domain experts together, and features a synthesis of approaches, data needs and model forms. The project engages four PhD students to work on the development of the various aspects of the integrated framework, each under the supervision of a domain expert, and in a cooperative environment where expertise and endeavor is fully shared.

In Phase 1, the project specifies an integrated framework for demand forecasting that is then fully developed and synthesized in Phase 2. Phase 1 occupied the first year of the three-year project, developing the specification of an integrated framework for residential demand estimation for ETWW. This required clear espousal and comparison of the methods used for demand estimation in each of the domains, and a strong collaborative effort between experts and practitioners from the various domains. This allowed for the establishment of potential and required commonalities, shared data needs and possible approaches to the development and implementation of models and tools for integrated demand forecasting. Recognizing and addressing the existence of under-researched project elements and gaps will also progress and maintain the momentum of the study into the following stages.

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, harmonized outputs about carbon performance across the ETWW domains. 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.

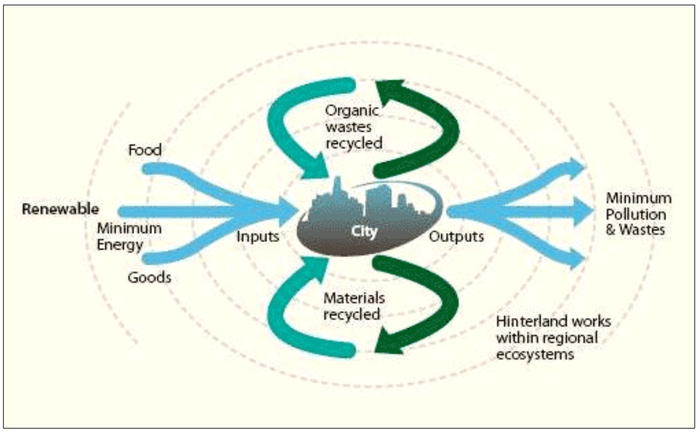
5. Discussion: Building Low-Carbon Precincts

The link between increasing urbanization 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.

Buildings are an integral part of precincts, creating districts, which form the larger urban context comprised of flows of people, transportation, electricity, water, waste, food, data and other forms of information [46,47]. 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.

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 globalized 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.

Figure 9. Diagram of circular urban metabolism, with inputs and outputs [48].



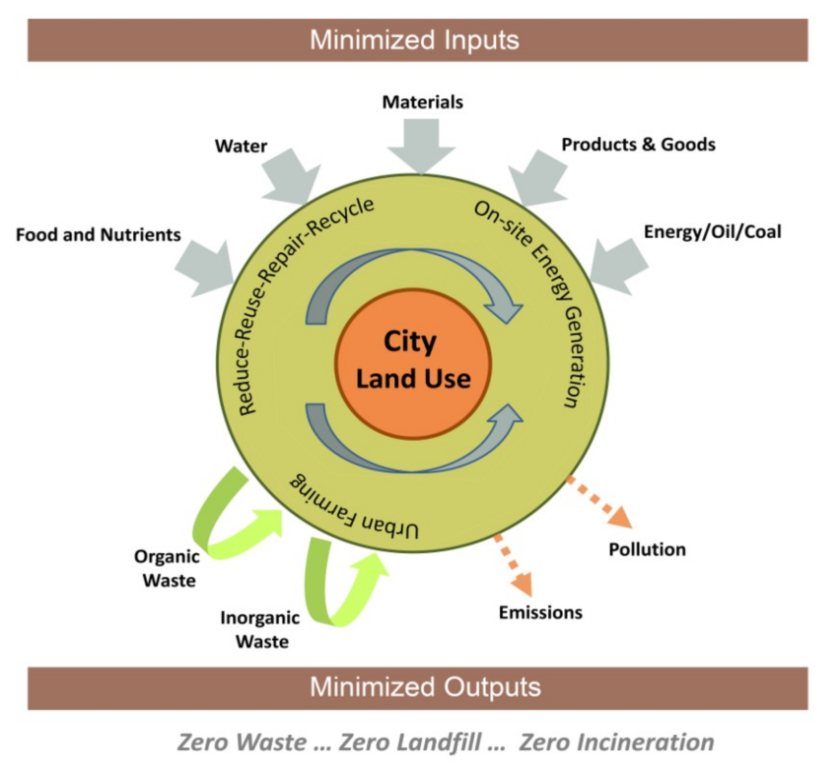
"Best practice" of waste management needs to adjust to each location, type of waste stream and other highly variable factors. Costs for waste handling and treatment can be staggering; so reducing the amount of waste improves efficiency and avoids the need for expensive controls [49]. It is obvious that the design of low-carbon precincts will have to focus on the challenges of greater efficiency and longer product life [50], including:

- significantly increased recovery of recyclable materials from waste streams;
- making sustainable use of raw materials, which means first and foremost using them much more efficiently (e.g., durability and longevity—designing products, buildings and precincts that last longer and are capable of being recycled);
- each waste stream has its own unique energy, material and mass characteristics, each presenting an engineering challenge unique to these conditions;
- low waste production processes (e.g., in construction, this implies the utilization of prefabrication and lightweight construction technologies to reduce embodied energy);
- long-lasting and repair-friendly design solutions that help to save resources and reduce material consumption;
- increased use of recycling and reuse through communal consumption platforms and events such as eBay, garage sales, and local exchange networks to avoid the purchase of new goods
- optimization software and ICT to enable better utilization of waste and materials;
- applying systems thinking.

Figure 10. Waste piled up for curb-side collection, a consequence of consumption.

(a) **(b)**

Figure 11. Diagram explains resource-efficient cities and sustainable consumption.



6. Conclusion 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" [33]. 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 civilization for thousands of years and is usually considered a nuisance [17]. 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 [51]. 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 policy making 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 [52]. With the threat of global warming it has become vital to fundamentally rethink how cities work in a symbiotic relationship between humans and nature; for example to speculate on alternative realities to re-evaluate the city from nature's point of view and investigate the possibilities of how "*waste = resources and nutrients*" can be a sustainable catalyst for future city districts.

For most of the time, managing waste is decision making with a large amount of uncertainty about numerous variables (e.g., how much is really known about each waste stream?). Obviously, the first aim of a sustainable future is to avoid the creation of waste and to select materials and products based on their embodied energy, their lifecycle assessment and supply chain analysis [53,54].

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 centralized or decentralized their planning and infrastructure should be [55]. 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, maximizing 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.

While technology will continue to change rapidly, the forecasting tool will inform behavior, predict the carbon impact associated with the uptake of new technologies and provide evidence for low-carbon precincts that will support government and municipalities in the formulation of policy.

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 minimize landfills, reduce carbon emissions and improve the environment. Therefore, progressive planning policies, waste prevention, waste reduction and product/building optimization are expected outcomes from this research project.

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Conflicts of Interest

The authors declare no conflict of interest.

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