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Integrated Resource Planning

A Systems Approach to Utility Planning

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Introduction

This paper introduces integrated resource planning (IRP), a systems approach to utility planning. IRP has been used for decades in the energy and water sectors in several countries. Originating in the 1970s in the US electricity sector, IRP assists utility planners to go beyond historical practices of considering their role in terms of hard infrastructure delivery alone and towards more complex socio-technical system concepts. It emerged in parallel to the development of second wave systems thinking, as described by Midgley [1], and while not specifically using systems thinking nomenclature, it does apply many of the key tenets, making it inherently a systems approach.

The aim of IRP is to help consider how to provide utility "services", such as energy to a growing city, by not just building more power stations ("hard path" supply-options) but by simultaneously considering increased "end-use" efficiency and the provision of more localised generation such as rooftop solar power ("soft path" demand-side options). The approach continues to evolve as utility planning becomes more complex, needing to deal with increasing levels of uncertainty such as those posed by climate change.

A brief history of IRP, and its counterpart least cost planning (LCP), is provided here together with its key principles, an outline of the approach and how it applies systems thinking, even if implicitly. Illustrative case study examples from the Australian water and waste sectors are then provided before discussion on potential future directions.

History

In the US in the 1970s it was recognised that utility systems planning focused primarily on construction of large-scale supply-side infrastructure, effectively ignoring efficiency opportunities. Lovins [2] in his ground-breaking work identified that there were two paths the US could take in the face of the looming energy crisis. The first, was a "hard energy path" in which the US could continue building high cost coal-fired and nuclear-powered plants with high risk of social and environmental harm. The second, was a "soft energy path", which embraced efficient technologies and localised typically renewable sources (e.g. solar), at a fraction of the cost and with significant potential long-term social and environmental benefits.

Lovins work spurred a paradigm shift in utility planning. It highlighted the need to move away from concentrating solely on the reactive approach of supplying more and more energy through "supply-side" large-scale measures and towards looking at the components or subsystems of how energy was being used and opportunities for end-use efficiency and more localised energy generation on the "demand-side". During the late 1970s/early 1980s Sant [3] and Lovins et al [4] were influential in championing the "least-cost" approach (i.e. the emergence of LCP - the precursor to IRP) in which looking at the demand-side of utility service provision was key.

As computing power improved and the IRP/LCP approach gained traction, principles and methods for the approach were formed, including consideration of planning objectives/criteria, detailed demand forecasting and options analysis [5,6]. During this time IRP/LCP was also translated to the water industry in the US [7], with the term "soft water path" also coined [8]. Similarly, methodologies were developed to better forecast water demand and design demand-side options and assess them against supply-side options [9–11].

The approach was first used in the Australian water sector from around the mid 1990s in small regional towns and then by the late 1990s in Sydney, the largest city in Australia [12–14]. Driven by the Millennium drought that gripped Australia from the late 1990s for over a decade, IRP/LCP was used extensively for water planning in most major cities. This helped to advance the concepts and aid Australia in becoming a leader in water efficiency, the use of alternative supplies (i.e. rainwater tanks, stormwater harvesting and wastewater reuse) and the application of the IRP/LCP approach in urban water planning and drought management [14–16].

The terms LCP and IRP are often used interchangeably. Originally LCP focused more on the lowest cost options (i.e. Sant [3] and Lovins et al [4]), whilst IRP aimed to encapsulate a broader range of options and social and environmental factors [5]. According to Beecher et al [7], however, both consider a broad set of options and are open and transparent and thus interchangeable for most analytical purposes. Although, IRP places additional emphasis on integrating the institutions involved in planning and the many public policy issues they need to address [7]. In Australia, both terms have been used, with IRP being the more common term used in recent years to help focus attention not only on "least cost" but broader social and environmental issues.

IRP/LCP has also been applied to transport systems [17] and solid waste management [18]. While the conceptual development of IRP/LCP for planning these essential services/utility systems is less progressed than that for electricity or water, as a systems approach IRP has significant potential.

Key IRP principles and process steps

The principles of IRP (adapted from Turner et al [14]) include:

- ***Service provision*** – IRP helps utility planners consider the "services" provided (e.g. clean clothes for water or heating for energy) not merely the commodity itself (e.g. water or electricity). Defining utility systems around service delivery allows more efficient or alternative ways of providing services to be considered.
- ***Detailed demand forecasting*** – IRP generally involves disaggregating demand into its component parts, typically sectors (i.e. residential, commercial), subsectors (e.g. houses, apartments, schools, factories) and where possible end-uses (e.g. toilets for water or lighting and heating for energy). Creating a detailed forecast allows analysis of the efficiency or conservation potential within each component of demand as well as a tool for thinking through alternative ways to provide the services needed (e.g. waterless composting toilets or insulation to help reduce heating/cooling energy needs in homes).
- ***Considering a broad spectrum of demand- and supply-side options*** – IRP aims to help satisfy service needs from soft path demand-side efficiency and alternative sources through to hard path supply-side options. The demand-side options include a mixture of technical (e.g. efficient showers) and behavioural (e.g. shorter showers) measures and one or more associated instruments (i.e. regulation, education, economic incentives).
- ***Comparison of options*** – IRP requires the use of a common metric, system boundary and assumptions to enable fair comparison between demand- and supply-side options. In IRP a kilolitre (kL) or kilowatt hour (kwh) saved is equivalent to a kL or kwh supplied. Analyses of options include consistent analysis of costs and where possible avoided costs and other benefits (i.e. monetised and non-monetised externalities).
- ***A participatory process*** – IRP recognises that services are provided to consumers and communities and thus planning should involve these groups as key stakeholders in identifying the service needs, objectives and potential options.
- ***Adaptive management*** – IRP recognises there is a level of irresolvable uncertainty, which is innate within complex systems dynamics. As such, it emphasises the need for iteration and learning including a cyclical process of planning, implementation, evaluation and revision to manage utility service systems over time.

A simplified version of the five-step IRP process used and developed in Australia for water management [14] is shown in Figure 1.

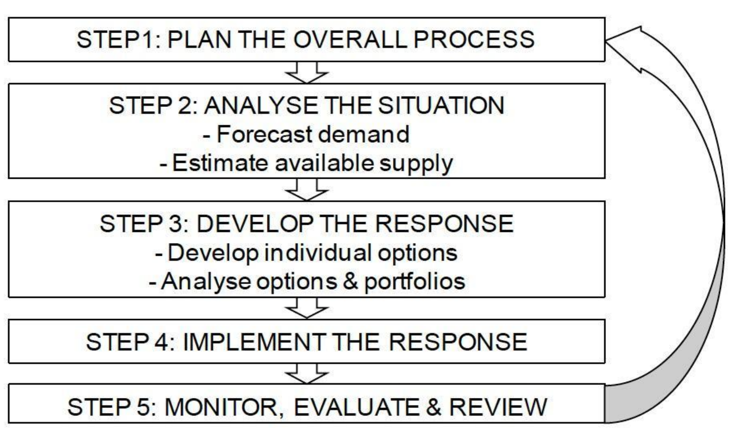

Figure 1: Simplified illustration of the IRP process

The process is highly flexible. It can and has been used for both small towns and large cities [14] as well regions with high tourism, industry and agricultural water demand [19]. It can be used at a conceptual level to aid systems understanding with little data or much more comprehensively when data is available for detailed modelling.

Key steps include [Turner et al 2010]:

- ***Step 1 – plan the overall process*** - Identify core planning team, stakeholders and resources available and familiarise stakeholders with the IRP process and specific context of the region under investigation.
- ***Step 2 - analyse the situation*** - Conduct situation analysis examining the supply-demand balance (historical, current and projected demand by end-use if possible). Consider factors affecting demand (e.g. demographics, economic growth) and possible future growth scenarios. In parallel assess current and projected system yield, including the potential impact of climate change. Based on information collated and analysed identify planning objectives (e.g. fill the supply-demand gap or meet a demand target to help defer supply augmentation).
- ***Step 3 – develop the response*** - Using a consistent boundary of analysis (and timelines and assumptions) develop potential interventions/options, both soft path demand-side and hard path supply-side. Analyse savings/supply potential for each option, whole-of-society costs and where possible benefits and assess broader factors (e.g. sustainability, feasibility, risk). Conduct stakeholder deliberation on the suite of options available to determine a preferred portfolio of options to implement based on identified criteria.
- ***Step 4 – implement the response*** **-** Consider team roles and responsibilities, cost sharing arrangements, timing, budgets, communication and education.
- ***Step 5 – monitor, evaluate and review*** **–** IRP should be iterative and allow for an on-going learning process. Monitor and evaluate savings achieved, participation, costs, progress against planning objectives and the IRP planning process overall. Ensure knowledge, data and experiences are used in subsequent iterations of the planning process to enable ongoing improvements.

A shift to service defined utility systems

By shifting attention to the "functions" a utility system provides and "how" water/energy or other resources are used, an IRP approach defines utility systems around the "services" being provided. This system definition not only includes the multiple subsystems making up a hard infrastructure system that utilities are used to managing, but also the technologies within customers' homes and businesses as well as the behaviour of those customers using the technologies (the end-uses). Such a system definition opens up hundreds of new potential interventions/options to utility managers.

The concept of breaking demand down into individual components (or end-uses) and service provision, exposes the opportunity for resource efficiency and local sources. For example, in Australia this has led to a reduction in water demand in end-uses such as toilets by the gradual replacement of inefficient models prevalent in the 1980s (i.e. 12 litre single-flush) with more efficient technology (i.e. current 4.5/3 litre dual-flush). Such toilets use a fraction of the water yet provide the same service. Taken a step further, vacuum toilets use as little as 0.8 litres/flush and composting toilets no water to provide the same service. Driving demand down in multiple end-uses (e.g. toilets, showers and washing machines), through efficient technology, efficient behaviour and the use of local sources (e.g. rainwater) has assisted in a dramatic reduction in water usage in Australia since the 1980s. For example, Sydney bulk water demand has dropped from 500 to 300 litres/person/day between the mid-1980s and 2010s [20].

With many interventions not only water is saved. With efficient showers for example, wastewater generation and hot water energy usage are also avoided, providing significant economic and environmental benefits. Analysis of these benefits requires a broader definition of the system being examined (i.e. the interconnected subsystems of water, wastewater and energy). This reconsideration of the utility service system or systems extending beyond water supply (in this case) would also follow through to the boundaries of analysis for all options considered.

A lack of adequate consideration of the whole system and associated subsystems or interconnected systems (however these are conceived) can result in unintended consequences of options implemented (i.e. “feedback loops” in systems thinking) or missed opportunities. For example, during the Millennium drought policy drove a major increase in the number of rainwater tanks installed in existing and new houses. In Brisbane, tank ownership rose from 5% to 38% between 2004 and 2010 through both incentives and regulation [16]. Whilst tanks, used for both indoor and outdoor end-uses, act to reduce potable water demand, depending on installation, their energy use for pumping can be significant, thereby inadvertently increasing the energy intensity of water supply [16].

Linkage with systems thinking

IRP portrays both first and second wave systems thinking according to Midgley’s [1,21] interpretation or Ulrich’s [22] operational and strategic systems practice nomenclature. For example, looking at the first wave/operational approach, IRP breaks demand down into components and types of use (i.e. sectors, subsectors, end-uses and services) through numerical modelling and using a goal orientated approach which considers how to improve efficiency for real or hard infrastructure systems.

However, it also draws on more abstract “soft systems” concepts (i.e. socio-technically influenced end-uses and behaviours leading to services that are a function of and directly influence the management of a hard infrastructure system). As a second wave/strategic approach, IRP brings into focus the human elements both in terms of the detailed interaction with the service of the end-use technologies and behaviour but also the consideration of the broader context of the system including communities, institutions and identifying policy interventions to achieve preferred outcomes.

These preferred outcomes are not necessarily known at the start of the planning exercise and can emerge from having a diverse spectrum of options developed and considered by a broad range of stakeholders in a deliberative way. Such deliberative processes, when planned well, can often lead to multiple benefits that would not have been evident when using traditional hard systems planning approaches alone. Also looking at the second wave/strategic approach IRP has developed a focus on cyclical implementation based on monitoring, evaluation, review and then revision. Ideally giving a learning-oriented approach for the interventions adopted.

Key systems thinking tenets the IRP approach uses include:

- Not seeing utility planning in terms of the hard infrastructure alone but as a socio-technical system defined around service provision.
- Breaking demand down into components (i.e. end-uses and associated services) for analysis and as a tool for thinking through service needs.
- Considering such components not as independent items but a system of interconnected elements which, as well as providing services, can have emergent functionality.
- A hierarchy of systems within systems (i.e. components, subsystems and systems) each with their closed or open system boundaries that interact or have the potential to interact with other systems and their environment to varying extents.
- Dynamic systems and subsystems that have varying levels of complexity, interconnectedness and predictability. Sometimes with emergent properties and also with potential for irresolvable uncertainty.
- The presence of interventions that will have both positive and negative feedback loops.

As illustrated in Figure 1, IRP uses five steps to follow a process of inquiry and analysis in practice. These steps hinge on key systems thinking tenets/IRP principles. As with other strategic planning systems approaches, such as Systemic Planning [23], both hard and soft systems methods/tools are used in combination (e.g. forecasting, cost effectiveness analysis and multi-criteria analysis (hard tools) as well as simple stakeholder analysis and brainstorming (soft tools)). Such combining of methods/tools is fundamental to third wave systems thinking [24]. Also similar to Systemic Planning, IRP places significant importance on developing criteria beyond costs to assess options, typically using multi-criteria analysis and participatory processes to do so [25].

The following case studies illustrate how IRP puts into practice systems thinking tenets and tools to varying extents. More details of each case can be found in the references provided.

Case Study #1 - water management

This case study focuses on water management in Alice Springs, a town of 25,000 people in the center of Australia, with average annual rainfall of only 300 mm/year. Being isolated and having such low rainfall, the town relies on fossil groundwater for its main water supply, not replenished by rainfall or runoff.

At the beginning of the century the water levels of the boreholes supplying the town were more than 150 m below ground level. With water levels dropping at over 1.5m/year, significant capital expenditure was needed to extend the bores and additional operating costs incurred by the local utility (providing both water and energy services to the town) due to the extra energy required for pumping [26].

Hence a strategy group was set up, involving diverse stakeholders, with the aim of developing a combination of soft and hard path interventions to deal with the water resource constraints. These interventions aimed to focus on efficiency and alternative sources including wastewater reuse to help reduce potable water demand but also wastewater production which was causing mosquito and pollution issues in the local swamp receiving town wastewater discharge. The problems were acknowledged to be complex due to the need to focus not only on the water supply but the interconnected systems of wastewater and energy as well as the broader environmental, social and equity issues including the large indigenous community.

A water efficiency study [27], based on IRP, was conducted involving development of a detailed water demand forecasting and options model and design of a suite of efficiency options to assist in achieving specified targets for reduction of average and peak water demand and wastewater production.

The study results showed: an average detached house in the town was using over 700 kL/household/year (double that of Sydney); over 65% of household demand was used for garden watering; and a further 10% of demand was being used for air-conditioning and pools [27]. These findings highlighted the unique characteristics of the town water demand and associated emergent functionality (i.e. garden watering predominantly used for urban greening and cooling and air-conditioning and pools for cooling in a challenging arid climate). These end-uses contributed to high average and seasonal peak water demand and associated pumping energy costs but not the wastewater production problems affecting the local swamp. Certain sectors such as tourism however, were found to contribute significantly to average and seasonal peak water demand as well as wastewater discharge.

By understanding water demand, at the component end-use and service level together with how this affected interconnected systems such as wastewater and energy, aided in the development of a suite of targeted options. The options developed focusing on reduction of average and peak water demand as well as wastewater production. Twelve options were developed. For the residential sector these included incentive programs for household indoor retrofits, washing machine replacement, garden efficiency and pool covers (to reduce evaporation). Non-residential programs focused on hotel efficiency, hospital efficiency through audit/action plans, school indoor retrofitting and garden irrigation/management.

From 2005 to 2007 another study [26] iterated on the 2003 research by expanding on the suite of efficiency options and developing new options including distribution network leakage, alternative sources (i.e. rainwater tanks), non-potable supply and wastewater reuse. Due to the large component of demand needed for outdoor water usage/non-potable supply, expanding the options was seen as essential. The options were expanded from 12 to 31. Figure 2 shows a “supply curve” illustrating the 31 demand- and supply-side options generated and ranked in order of unit cost against the marginal cost (MC) of water. The whole-of-society costs and quantifiable benefits were considered together with assessment of the potential distribution of costs and benefits to the community and financial implications for the utility.

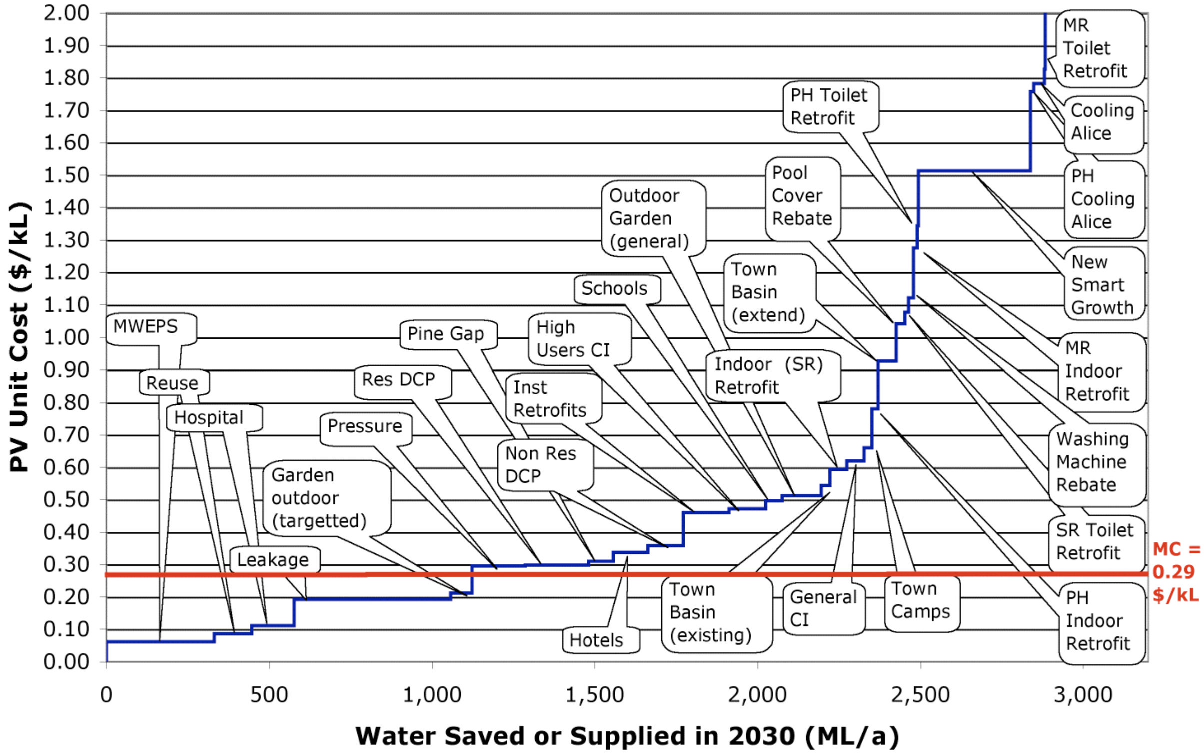

Figure 2: Supply curve of ranked demand- and supply-side options

In addition, an implementation plan was developed including identifying additional information needed. The ultimate aim of the investigations being to engage the stakeholder reference group in a participatory process of developing and making decisions on the options for implementation taking into consideration whole-of-society costs and benefits and broader sustainability and equity issues. These aims being in line with not only first wave/operational and second wave/strategic systems thinking but also third wave/normative systems practice.

The preferred suite of options (or portfolio) had an average unit cost of only AUD 0.30/m^3. Despite this relatively low unit cost it had significant benefits beyond water savings such as reduced sewage management costs, greenhouse gas emissions and customer energy bills together with social and equity improvements, with overall benefits significantly outweighing costs.

The studies informed the “Alice Water Smart” program implemented and later a similar program “Living Water Smart” adopted by the utility and Territory Government in Darwin.

Case Study #2 - waste management

Whilst IRP/LCP has been used extensively in the water and electricity sectors, it has received less attention in other sectors such as the solid waste industry. In 2011/12 a worked example for IRP in waste was conducted [18] as part of broader research into the future of landfill in Australia. The key aim of the example being to provide an illustration of the use of IRP in waste and to spur further research.

Waste data sets in Australia are limited, however, the Australian Capital Territory (ACT), with Canberra the main urban area, has been active for many years in auditing to determine progress towards their "no waste" target [28]. Hence the example used the ACT, current population of over 400,000, to enable access to the most reliable public data at that time. Figure 3 is derived from this data [18]. The graph shows historical waste (2000–2010) by sector together with projections to 2030, with organics the largest component.

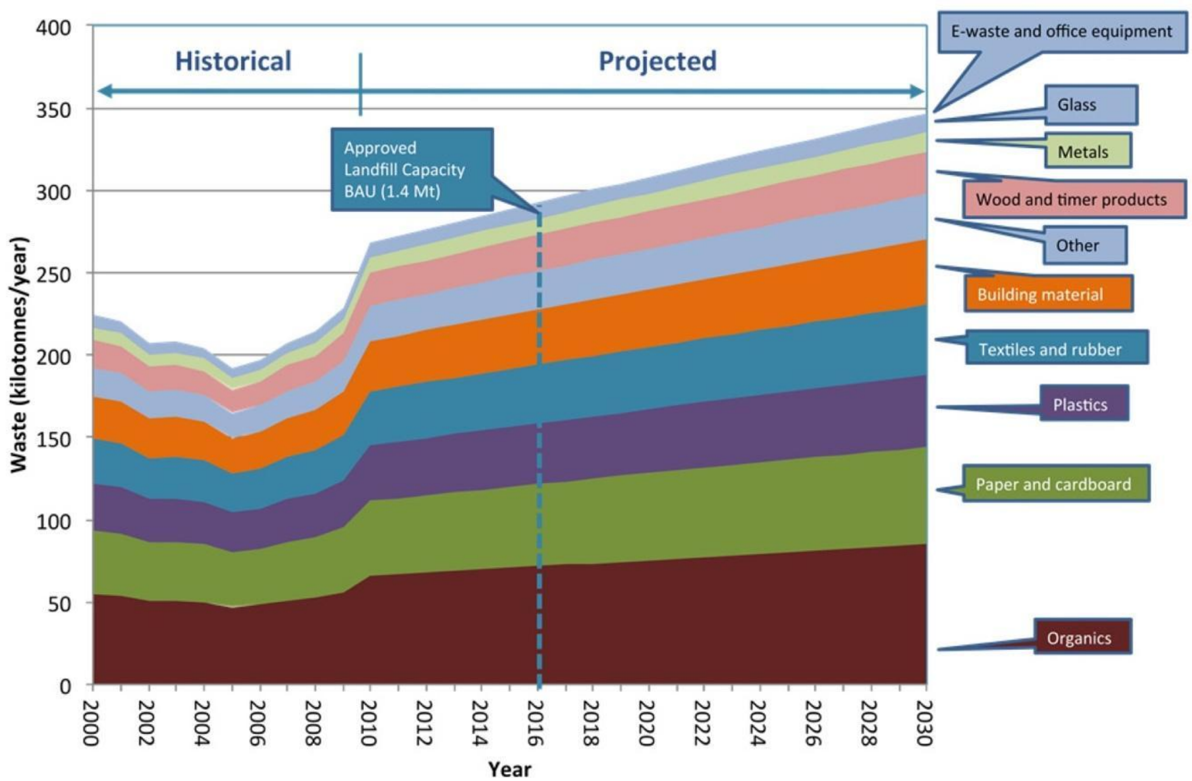

Figure 3: Historical and projected waste by sector in the ACT

The graph indicates, when the analysis was conducted, that under business as usual (BAU), the ACT would reach its approved landfill capacity of 1.4 million tons (Mt) by the year 2016 (approximately 5 years) if no action to reduce waste was taken. Thus highlighting the need to identify options for creating additional landfill capacity (supply-side options) or increasing landfill avoidance/diversion (demand-side options).

Figure 4 a supply curve, similarly shown in Case Study #1 and commonly used in IRP analysis, illustrates the cost per ton of landfill capacity supplied or waste avoided for the illustrative options considered. For the food waste campaign, waste smart, deposit and refund for containers, the waste capacity refers to the tons reduction achieved. For materials recovery facilities (MRF) and energy from waste, the waste capacity refers to the tons that can be handled by the option. Similar supply curves can be drawn for other individual years, reflecting different costs and volumes for points in time. The example only considers costs, as benefits were not available. Hence the demand-side options shown would actually look even more favorable compared to the supply-side options if benefits were incorporated in the analysis.

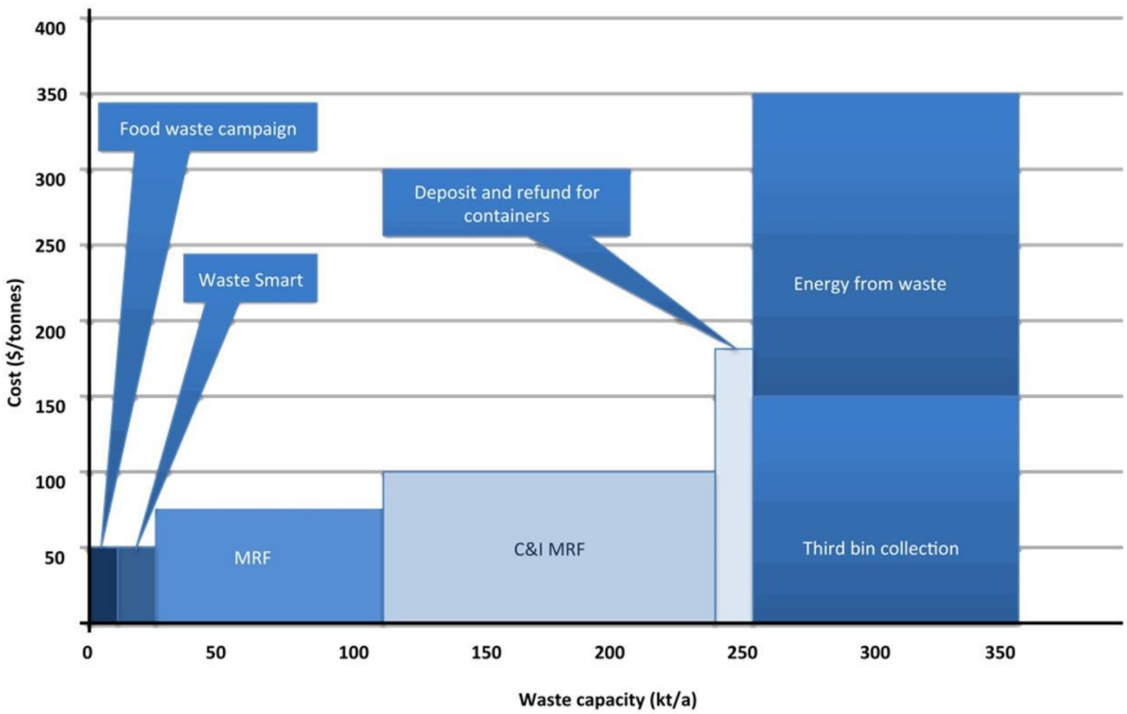

Figure 4: Waste supply curve for the ACT

The analysis illustrates the breaking down of demand into components (i.e. sectors) to help forecasting and options development. As with both water and energy, demand-side options are low cost, even without benefits, compared to supply-side options aiming to deal with greater levels of waste generation. The analysis conducted showed the potential benefits of using IRP for waste industry forecasting and options assessment and a way to assist stakeholders to consider the system more holistically including tradeoffs between various options using consistent boundaries.

Key to the use of IRP in planning waste management systems, and specifically organic waste, which often represents the largest component of municipal waste in Australia, will be consideration of the objectives of the planning exercise and service provision that defines these systems. In the ACT example the metric was the tons of waste avoided or supplied. However, in complex systems such as organic waste management as well as the service of waste removal, the system may need to consider services such as capture/reuse of nutrients or return of micronutrients and carbon to soils. It may also need to account for benefits such as potential kwh of energy generated or value of byproducts created if applying circular economy principles [29]. Thus illustrates the importance of system thinking concepts in complex industries such as the waste sector which is faced with multiple and sometimes competing objectives.

The Future

Many practical examples of IRP exist, with recent developments seeing a move to extend system boundaries for planning by integrating water, energy and waste and drawing on adaptive planning concepts to help address increasing uncertainty. The bulk of IRP examples available to date are representative of the combination of first wave/operations and second wave/strategic approaches of systems thinking, as utility systems have become more complex, in part due to the success of IRP in embracing soft path demand-side solutions. However, utility systems are becoming even more complex with other factors such as new emerging technologies, more diverse stakeholders and the impacts of climate change and sustainability needing to be addressed. With this increased complexity, consideration of the boundary of analysis and a broader set of criteria beyond economics for decision-making becomes even more important.

In addition, other considerations such as politics have become more pertinent. For example, in the mid 2000s during the height of the drought sophisticated systems modelling and participatory processes (based on IRP) were used to determine the Metro Water Plan in Sydney which identified dam trigger levels for when large scale desalination might be needed [30]. However, political considerations about the drought during an election period dominated, resulting in a decision to build a AUD 1.8 billion desalination plant before the agreed trigger levels were actually reached [31]. The plant was finally used for drought supply for the first time over a decade later. This example illustrates the need for IRP processes to embrace other concepts highlighted within third wave [1] or normative systems practice [22] (i.e. ethical outcomes and power dynamics at multiple levels). Actively including these concepts in IRP would also benefit application in new utility/essential service sectors such as waste, which can be highly fragmented and can demonstrate difficult power dynamics and competing objectives [32].

Further extension of the third wave or potential emerging fourth wave systems thinking [24] may also be helpful to IRP decision-making processes and specifically participants in such processes. As IRP typically relates to complex sustainability issues, improved systems thinking skills for those engaged in planning, such as those posed by Cabrera et al [33], are likely to be highly advantageous.

IRP has been used in the energy and water industries for decades and to a limited extent in other sectors such as transport [17] and waste [34]. However, whilst it is implicitly a systems approach there is a lack of formal connection to the systems thinking field.There are significant opportunities for IRP to: (1) create stronger links between the IRP practitioners and the systems thinking community; (2) use more formal systems thinking nomenclature; (3) explicitly use the combination of hard and soft systems concepts and methods/tools; and (4) embrace additional third (and potentially fourth) wave systems thinking concepts. This will both broaden the use of IRP, including within the systems thinking community, and strengthen the IRP approach, helping it achieve one of its primary objectives of developing more sustainable utility systems

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