A System of Physical Accounts Spanning Urban Development Through to the National Economy

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Keywords: Systems, physical accounts, sustainability

EXTENDED ABSTRACT

With the growing recognition that a majority of the worlds population is living, or soon will be, in urban areas there has been a substantial growth in sustainability research being focused on cities and urban areas. These regions are perhaps rightly regarded as the engine houses of modern and developing economies. However, this focus comes with the risk that we artificially set boundaries around the domain of interest without first identifying and examining the key sustainability issues.

This paper describes a series of research studies and a set of simulation tools that establish the necessity for maintaining research capability spanning national and global scales. It includes Stocks and Flows accounts that simulate interactions between demography, land-use, water use and basic industry for Melbourne in detail and the state of Victoria; and comparison with the national physical economy accounts in the Australian Stocks and Flows Framework. This material provides a data-rich basis for examining the issue of inappropriate geographical or sectoral boundaries when dealing with sustainability.

The analysis based on the Australian Stocks and Flows Framework shows how the resource and environmental situation may worsen in future. A number of specific challenges have been highlighted: supplying enough oil or alternative fuel for transport; growth in demands on water resources; averting further degradation of agricultural land and fish stocks; pressures on the labour force in an aging population; constraints on introducing clean technology due to infrastructure inertia; and the difficulty of achieving safe levels of GHG emissions.

The challenges will be made all the more difficult since they are linked. More detailed analysis of scenarios at the city level illustrated how such resource and environmental issues arise at finer scales.

1. INTRODUCTION

As a colleague puts it simply “there are no sustainable parts of unsustainable wholes” (pers comm. 2007). From a systems perspective, it is illogical if a sub-system—say, a city or a particular sector of the economy—is examined for its sustainability without appropriate recognition of issues beyond the sub-system boundary. Nevertheless, this approach is often applied using the argument that it is more pragmatic in terms of data collection and analysis, and that the analyses correspond to the same scale as the oversighting local management authorities so that policy development and implementation will be enhanced. These reasons may be attractive, but are inappropriate if the key sustainability issues are external to the sub-system but impact on it. This is more likely to be the case in the modern economy, where resources are drawn from distant places and wastes/emissions dispersed beyond boundaries. Similarly, economic sectors and settlements are highly interconnected.

Boundaries can be drawn in many ways, not just geographically. There are temporal boundaries, both past and future—inferences from past trends can be quite different depending on the characteristic time of the factor being analysed, and potential future pathways may diverge only when viewed over a sufficiently long timeframe. Analysing specific sectors of the economy is another way of drawing an artificial boundary. So too is omitting one or more of social, economic and environmental perspective, or leaving out groups of people that may be affected.

Naturally, the challenge facing practitioners in sustainability research is how to cover enough of the system without losing too much detail or connection with appropriate areas of influence. This paper describes the use of a set of tools and example applications that aspire to a systems approach on sustainability. The tools are briefly outlined in section 2, including the philosophical basis for modelling just the physical domain so that a participatory research approach is encouraged.

Selected examples from analysis using these tools at different geographical scales and in different sectors are used in section 3 to illustrate the importance of taking a big picture view. It starts at city level and elevates to state and then national analysis; some impacts or interactions across sectors are progressively following.

2. STOCKS AND FLOWS SIMULATIONS

The tools and analysis in this paper are generally based on Stocks and Flows Frameworks (SFF). They deal with multi-scale geography and intergenerational time frames. They cover all sectors of the economy and all environmental compartments. The tools are designed with the explicit recognition of the importance of the social and economic domain. They do this by deliberately simulating only the physical domain, but having many exogenous variables relating to social or economic behaviour, and technological progress. This is part of a “Design Approach” (Gault 1987) to analysing sustainability illustrated in Figure 1.

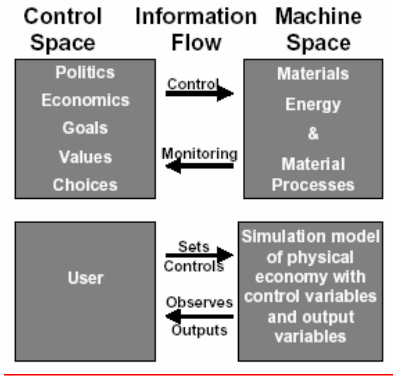

Figure 1. The principle of the Design Approach that separates physical processes to be simulated in “machine space” from behavioural processes that are engaged in “control space”. Based on (Gault, 1987).

Several SFF have been created and applied to sustainability issues. The two main frameworks are described briefly below, since the focus here is on illustrating the boundary issues of sustainability; detail on the frameworks is provided elsewhere.

2.1. Australian Stocks and Flows Framework (ASFF)

The Australian Stocks and Flows Framework (ASFF) is a highly disaggregate simulation that keeps track of all physically significant stocks and flows in the Australian socio-economic system (Poldy 2000). Stocks are the quantities of physical items, such as land, livestock, people, buildings, etc., and are expressed in numbers or their appropriate SI units. Flows represent the rates of change of stocks resulting from physical processes, such as the (net) additions of agricultural land, immigration and birth rates, etc.

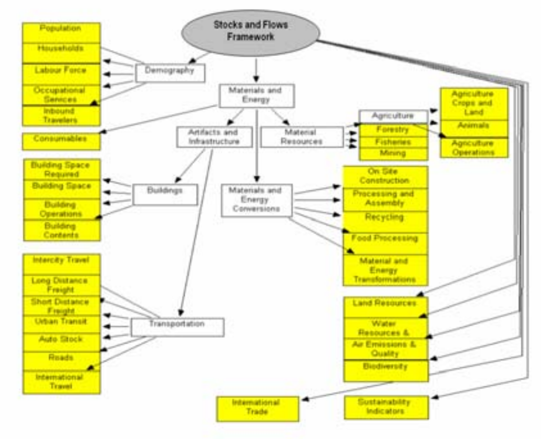

Figure 2. Schematic diagram showing the modules of the ASFF covering the sectors of the economy and environmental compartments.

ASFF covers the complete economy, including service aspects, but incorporates only the physically significant elements of each sector. At the centre of the framework is an input-output model for the transformation of basic materials and energy types. Elsewhere, there are physical accounting relationships that represent the key processes, such as converting the requirement for transport of goods into the size of the freight transport fleet and the fuel requirement. The result is that all the variables representing physical stocks and flows obey the thermodynamic constraints of conservation of mass and energy.

Geographically, ASFF covers continental Australia. Within specific sectors of the framework different geographic resolutions are used. The temporal extent of ASFF is long-term: scenarios over the future are calculated to 2100, and the model is also run over an historical period of 1940–2000 to reproduce many observed data sets.

2.2. Victorian Regional Stocks and Flows Framework (VRSFF)

Figure 3. Land-use cells of the VRSFF, with greater detail in areas with realistic urban development potential.

The Victorian Regional Stocks and Flows Framework (VRSFF) used in this study was originally conceived to help land use planners follow through the less obvious cross sectoral effects their development decisions may have (West 2005). The original focus on land use planning and demography regimes for Melbourne was subsequently extended spatially, to cover the whole of Victoria, and sectorally to include electricity generation and a general treatment of basic industries. A separate but linked framework, VRSFF Water, was developed in parallel to provide detailed accounting for water requirement and supply in Victoria under different development scenarios (Turner 2007a).

There are several major components to the VRSFF and these are inter-related. Demography is a key driver of economy and its requirements. Directly associated is the housing of the population and urban form which constitutes the major part of the land-use component in the VRSFF; other parts of the built environment include employment and education space. Detail on other non-urban land-uses is available from the complementary national framework, ASFF. The Victorian consumption of materials and energy was derived from the ASFF using Victorian data components where available or scaled data. These flows drive the physical Input-Output calculation of the basic industry sector in the VRSFF, with particular attention paid to electricity generation capacity. A number of data connections are subsequently made from the above components to the water account of the VRSFF, since demography, land-use and electricity production influence water demand and supply.

3. ANALYSIS AND INDICATIVE RESULTS

This section presents a selection of results from the application of the SFF described above. The presentation begins at the level of smallest spatial extent, the city, and moves up to the state of Victoria and subsequently national analysis. The intention here is to illustrate the importance of examining sustainability at whole-of-system scales. Though there are evidently more cross-boundary issues or examples, it is beyond the scope of this paper to cover them comprehensively.

3.1. City level analysis

The analysis here uses the VRSFF for scenarios involving Melbourne.

By using the urban development module of the VRSFF we have simulated two very different scenarios. One involves continued expansion of the area of Melbourne due to low-density housing. The second constrains development to within government policy aspirations of an Urban Growth Boundary (UGB). This scenario employs high-density (and some medium density) dwellings, in both Greenfield sites and in selected areas of redevelopment.

The compact scenario manages to house Victorian population within the UGB out to 2100, with densities about 15 times higher than typical low-density development. Even though most of the development is in greenfield sites, about 350 dwellings in selected areas of Melbourne must be demolished each for many decades (Turner 2007b). The sprawl scenario results in 110 kha of additional land being required in 2050, relative to the compact scenario.

In terms of water supply to Melbourne, our analysis shows that the Thomson Reservoir which supplies the majority of water to Melbourne can be maintained (say at 50% capacity) for the remainder of the century even under a high climate change scenario (2 °C change by 2050) (Jones and Durack, 2005). However, this required increasing abstractions from the Thomson River, such that it ceases to flow by 2100 (Figure 4).

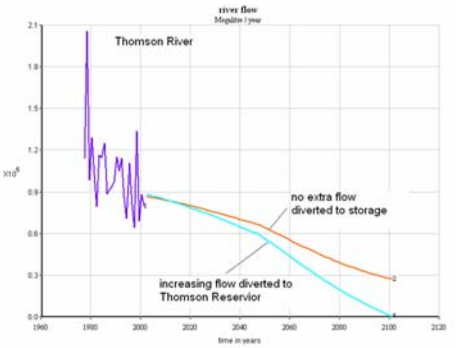

Figure 4. Flows in the Thomson River (a major source of Melbourne's water) under a "high" climate change scenario. The lower curve shows increasing abstractions to maintain Melbourne's water; the upper curve keeps the abstractions constant (though the Thomson Reservoir fails in 2040). From (Turner, 2007b).

In an alternative sub-scenario we explored the effects of keeping the river abstractions constant. While the river flow was higher (upper curve of Figure 4) than when the Reservoir was maintained, the flow still dropped considerably over the century due to climate change. Additionally, the Reservoir level remained adequate for a few decades, before falling precipitously to zero by about 2040.

These scenarios incorporated a wide range of Victorian government policies and options being canvassed. Several of these have significant influences on the water system for Melbourne. Our analysis shows that dense urban form can potentially relieve pressure on water supply, largely due to a reduction in outdoor water use (Kenway 2007). This is incorporated in the above results; consequently, further low-density development and watering behaviour would worse the situation for the Thomson River beyond that depicted in Figure 4. Annual variations in rainfall also exacerbate the situation, masking slow moving trends and advancing by several decades the point when critical environmental thresholds may be crossed.

In keeping with the cross-boundary focus of this paper we can ask: what is missing from the above city level analysis? Among many factors are: transport systems and the fuels supporting them, water resources in the rest of the state, and other climate change impacts (and responses). We pick up some of these, and other issues, in the following sections starting with a view of the state water resources.

3.2. State level analysis

The Thomson River discussed above is one of 29 major water catchments within Victoria. Adjacent to the Thomson River, to the south-east is the Latrobe Valley, which is significant because water here is used for cooling in the brown coal-based thermal power stations that supply much of Melbourne's and Victoria's electricity. Water consumption by electricity generation has increased substantially in line with past economic growth and associated electricity demand. Assuming that growth in electricity generation were to increase at long term rates or even somewhat less than this implies water consumption in the Latrobe Valley may increase by at least a factor of 2–3 or more. Our analysis showed that this could just be maintained to 2100 under a medium climate change scenario (1.5 °C change at 2050) if treated discharge water at Melbourne's Eastern Treatment Plant was transferred to the Latrobe.

The extra electricity required for such treatment and pumping is only a small fraction of a percentage of the overall state electricity demand. However, increase of energy use within the water sector of about 10–50% may occur by 2050, depending on urban water use (influenced by urban form and other factors) (Kenway, 2007). This is dwarfed by the 4–5 fold increase that could result if reverse osmosis desalination is employed to supply all new water demand. Still, this remains only a low percentage of total electricity demand and yields some benefits in river health by relieving pressure due to abstractions.

Further interactions between the water, energy and land systems are explored in (West 2007).

The water required for electricity generation described above is one form of indirect water consumption largely associated with Melbourne's function. Other indirect water consumption is associated with the production of food. Some of this is for food that is actually consumed in the city and some is associated with the food that is exported out of the state. The latter is related indirectly to the city because the export earns international currency as part of the trade balance allowing all Australians to purchase imports such as white goods and vehicles.

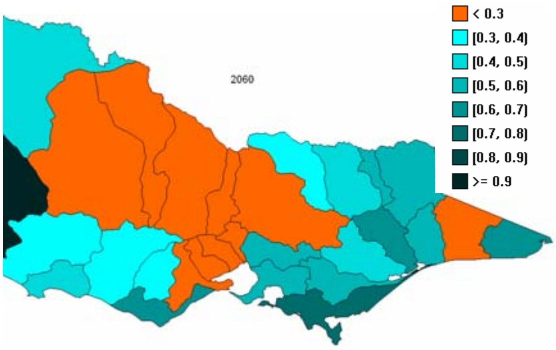

Figure 5. Relative river flow at 2060 in the water regions across Victoria, with respect to historical levels. Orange areas show relative flows below 30%. The scenario incorporates high climate change (in keeping with the present trajectory of CO2 emissions matching worse case IPCC scenarios). From (Turner, 2007b)

This analysis forces us to lift our perspective above that of the city and consider state and national issues, such as the water resource situation across Victoria. Figure 5 shows that, for example under high climate change scenario (increasingly likely), by about mid-century approximately 1/3 of the water basins have river flows that have dropped below 30% of historical levels (Turner, 2007b); the Thomson and Latrobe basins to the east of Melbourne are not among these. The threshold of 30% represents an indicative level at which river ecology may be seriously threatened (although this doesn't even factor in effects of variability). A medium climate change scenario sees the impact delayed by about 3 decades.

In addition to river health, there are implications for irrigated agriculture. Lake Eildon in central Victoria is one of the major water storages of Victoria, suppling water for irrigated pasture (dairy) and horticulture. Under medium climate change it can be maintained at about 50% capacity only by drawing heavily on river flows, which not only affected ecological systems but impacts on other water users along the Murray River. High climate change simulations indicate that Lake Eildon might run dry by 2080. In this case, the future of irrigated agriculture would be threatened with uncertain flow-on consequences. Even less severe conditions could be serious because they would impact on the viability of current proposals and projects to trade and transfer water from agricultural supplies to major metropolitan areas including Melbourne.

Some of the direct and indirect consequences above represent "tensions" in the SFF that remain as yet unresolved. Further scenario creation and analysis is required, ideally involving stakeholders affected. This process should also highlight that other impacts, such as other inflows of the Murray-Darling system in NSW and Queensland should be considered. Consequently, the analysis here has now risen above State level, and the following section explores sustainability issues at the national level.

3.3. National level analysis

This section is taken largely from the analysis of the "Future Dilemmas" (Foran and Poldy, 2002) and subsequent research reports, which was based on the use of ASFF (Lowe 2003, Dunlop and Turner, 2003). Continuing on from the previous section, we begin with the agriculture sector and the issue of land degradation.

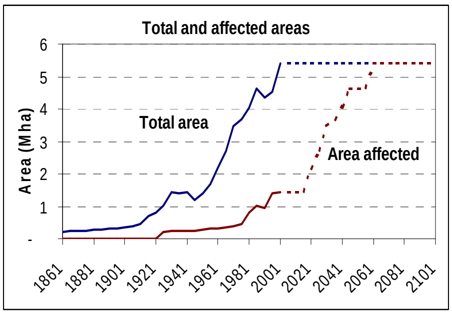

Figure 6. Agricultural land area (crop and sown pasture) in Midlands SD in WA, showing the proportion that has yield loss of at least 20%. The scenario data shows the implication of not introducing or retiring any of the land already in production. From (Dunlop and Turner, 2003).

Several types of degradation to agricultural land condition have contributed to losses in production. However, the aggregate production volume has not decreased due in part to the introduction of new land parcels. Viewed over a century and a half the growth in agricultural (crop and sown pasture) land has compounded at an average of approximately 2% pa (Dunlop and Turner, 2003). This physically cannot continue indefinitely; and for other reasons land-clearing is being halted. An implication is that the "aging" of the land in production will continue and impact seriously the productive capacity, as Figure 6 illustrates the 4–6 decade lag in Western Australia.

Other food production in Australia, namely our fisheries, is also under stress. Stocks and flows analysis indicates that the commercial domestic wild catch will not reach the peak volumes achieved in the 1990s, and would continue to decrease if attempts are made to maintain those historic catch rates (Lowe, 2003).

Among other factors, the agricultural and fisheries sectors (like the rest of the economy) also clearly depends on energy inputs, such as transport fuels. Over the last 3–4 decades Australia has produced more oil than it imports, but this situation is possibly changing at present, as shown in Figure 7. This has substantial implications depending on possible future alternatives for transport. Continuing to import oil would impact the foreign trade balance, particularly if global resources are increasingly hard to obtain. Australia could transition to using its domestic gas resource for some decades, depending on how much is also exported. Biofuels might be another option, competing with food production and use of water.

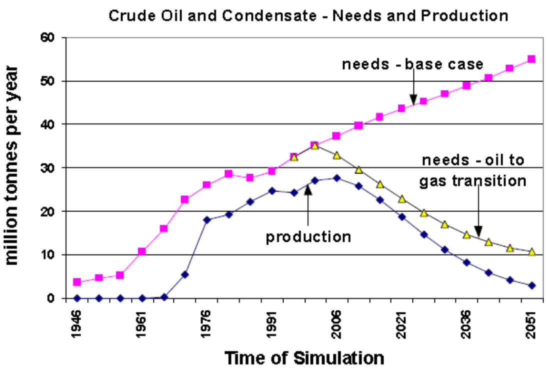

Figure 7. Australian oil production and total requirements for transport fuel. The scenario period shows a potential (50% probability) production decline, while requirements either continue to grow, or decrease if a transition to gas is made, for example. From (Foran and Poldy, 2002).

The skilled labour to achieve some of these changes is another input of the economy which cannot be taken for granted. Even in the absence of such "transition" demands, the aging of the Australian population will continue such that the proportion of young and old depending on the workforce will rise by some 20% or so irrespective of high immigration rates. This signals a challenge for the workforce, especially when combined with portents of obesity related health issues, and productivity increases to underpin further economic growth.

As for the workforce, aging of infrastructure and the rate of turnover should be factored into thinking on future options. This can be illustrated when considering trajectories for lowering greenhouse gas (GHG) emissions, as in Figure 8. The scenarios show that even if aggressive increases in efficiency are pursued (such as 3L/100km car fuel consumption, and 50% efficiency increase in buildings), the savings will not occur quickly enough or offset further grow in overall energy demand.

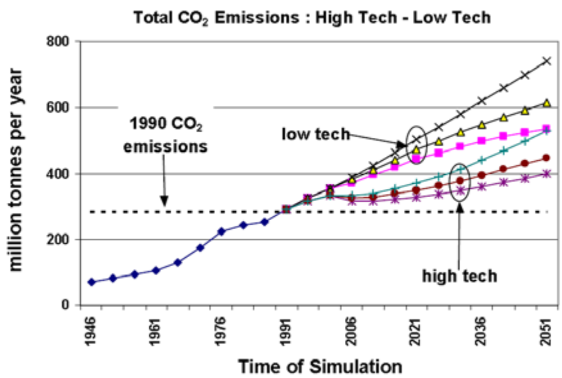

Figure 8. Emissions of CO2 from transport and stationary energy sources, for several population scenarios and alternative technological scearios. From (Foran and Poldy, 2002).

3.4. Other levels of analysis

This paper has not explored the global levels of analysis that would follow naturally from the national scale. The potential for this exists—for instance, whatIf Technologies offer a prototype global stocks and flows framework (the Global System Simulator, GSS) (whatIf_Technologies). Alternatively, we can refer to other models such as the World3 simulation behind the original Limits to Growth (Meadows 1972). Output from this model has recently been compared with historical data, increasing confidence in the 'business-as-usual' scenario (Turner, 2007a).

The analysis could be extended further into the economic and social domain (assuming it is appropriate to draw a distinction between these over the long time scales relevant to sustainability). As outlined early in this paper, the modelling approach we have employed explicitly recognises the connection with social/economic domains. To date however, interactions between our physical/environmental simulations and social/economic inputs have been regrettably somewhat limited though there are indications that this is improving (see for example, (Baynes 2007)).

4. CONCLUSIONS

This paper has demonstrated the use of Stocks and Flows Frameworks for whole-of-system sustainability analysis. The examples given illustrate cross-boundary interactions, both geographically spanning city, state and national levels, and drawing connections across sectors. Similarly, long-timeframes draw attention to intergenerational issues, appropriate perspectives on trends, and inclusion of stock dynamics.

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