



ELSEVIER

Landscape and Urban Planning 44 (1999) 219–226

LANDSCAPE
AND
URBAN PLANNING

www.elsevier.com/locate/estoc

Sustainability and cities: extending the metabolism model

Peter W.G. Newman¹

Professor of City Policy, Murdoch University, Perth, WA 6160, Australia

Received 21 September 1998; accepted 19 February 1999

Abstract

The use of the metabolism concept, expanded to include aspects of livability, is applied to cities to demonstrate the practical meaning of sustainability. Its application in industrial ecology, urban ecology, urban demonstration projects, business plans and city comparisons are used to illustrate its potential. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Sustainability; Cities; Metabolism; Livability; Ecosystem; Indicators

1. Introduction

Sustainability has been defined through the United Nations as a global process of development that minimises environmental resources and reduces the impact on environmental sinks using processes that simultaneously improve the economy and the quality of life (UN World Commission on Environment and Development, 1987). This paper tries to show how a simple model developed for the Australian State of the Environment reporting process (Newman et al., 1996) can be used to give some substance to the application of sustainability to cities. Data from the Australian applications and some other case studies are provided to illustrate how the model works.

2. Application of sustainability to cities

The principles of sustainability can be applied to cities through the guidance on how this can be done

was not very clear in Agenda 21 or other United Nations documents (Keating, 1993). It is probably true to say that the major environmental battles of the past were fought outside cities but that awareness of the need to include cities in the global sustainability agenda, is now universally recognised by environmentalists, governments and industry. The Organisation for Economic and Cultural Development, the European Community and even the World Bank now have sustainable cities programs. In 1994 the Global Forum on Cities and Sustainable Development heard from 50 cities (Mitlin and Satterthwaite, 1994) and in 1996 the UN held Habitat II, the Second United Nations Conference on Human Settlements in Istanbul. At the ‘City Summit’ the nations of the world reported on progress in achieving sustainability in their cities (UN Centre for Human Settlements, 1996).

Anders (1991), in a global review of the sustainable cities movement, pointed out:

“The sustainable cities movement seems united in its perception that the state of the environment demands action and that cities are an appropriate forum in which to act”. (p. 17)

¹Tel.: +61-8-9360-6913; fax: +61-8-9360-6421
E-mail address: newman@central.murdoch.edu.au

Others such as Yanarella and Levine (1992) suggest that all sustainability initiatives should be centred around strategies for designing, redesigning and building sustainable cities. From a global perspective, they suggest that cities shape the world and that we will never begin to implement the sustainability process unless we can relate it to cities.

3. An emerging framework – the city as an ecosystem

Throughout this century the city has been conceived by sociologists, planners and engineers as a “bazaar, a seat of political chaos, an infernal machine, a circuit, and more hopefully, as a community, the human creation par excellence” (Brugmann and Hersh (1991), cited in Roseland (1992)).

One of the strongest themes running through the literature on urban sustainability is that if we are to solve our environmental problems we need to view the city as an ecosystem. As Tjallingii (1993) puts it:

“The city is (now) conceived as a dynamic and complex ecosystem. This is not a metaphor, but a concept of a real city. The social, economic and cultural systems cannot escape the rules of abiotic and biotic nature. Guidelines for action will have to be geared to these rules”. (p. 7)

Like all ecosystems, the city is a system, having inputs of energy and materials. The main environmental problems (and economic costs) are related to the growth of these inputs and managing the increased outputs. By looking at the city as a whole and by analysing the pathways along which energy and materials including pollutants move, it is possible to begin to conceive of management systems and technologies which allow for the reintegration of natural processes, increasing the efficiency of resource use, the recycling of wastes as valuable materials and the conservation of (and even production of) energy.

There may be on-going academic debate about what constitutes sustainability or an ecosystem approach (Slocombe, 1993), but what is clear is that many strategies and programs around the world have begun to apply such notions both for new development and redevelopment of existing areas.

4. The extended metabolism model

How does a city define its goals in a way that enables it to be more sustainable? How do you make a systematic approach that begins to fulfil the global and local sustainability agenda? The approach adopted here is based on the experience of the Human Settlements Panel in the Australian State of the Environment Reporting process (see Newman et al., 1996) and on the experience of making a Sustainability Plan for Philadelphia with the graduate students at the University of Pennsylvania in 1995 and 1997, as well as awareness of the World Bank/UN Habitat project on developing sustainability indicators for cities (World Bank, 1994).

It is possible to define the goal of sustainability in a city as the reduction of the city’s use of natural resources and production of wastes while simultaneously improving its livability, so that it can better fit within the capacities of the local, regional and global ecosystems.

This is set out in Fig. 1 in a model that is called the ‘Extended Metabolism Model of the City’. Metabolism is a biological systems way of looking at the resource inputs and waste outputs of settlements. This approach has been developed by a few academics over the past 30 years, though it has rarely if ever been used in policy development for city planning (Wolman,

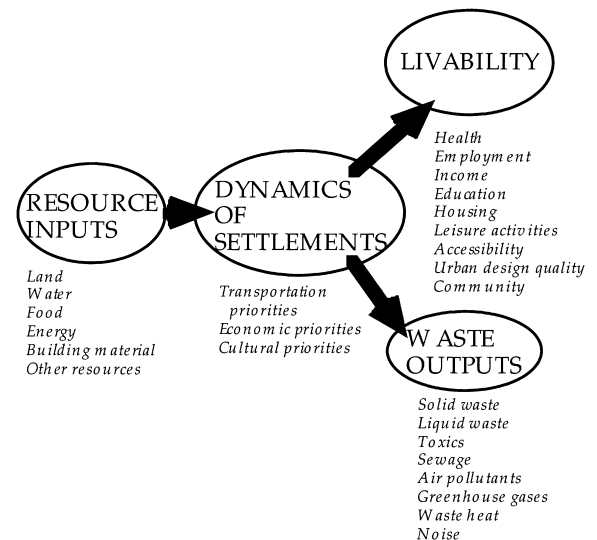


Fig. 1. Extended metabolism model of human settlements.

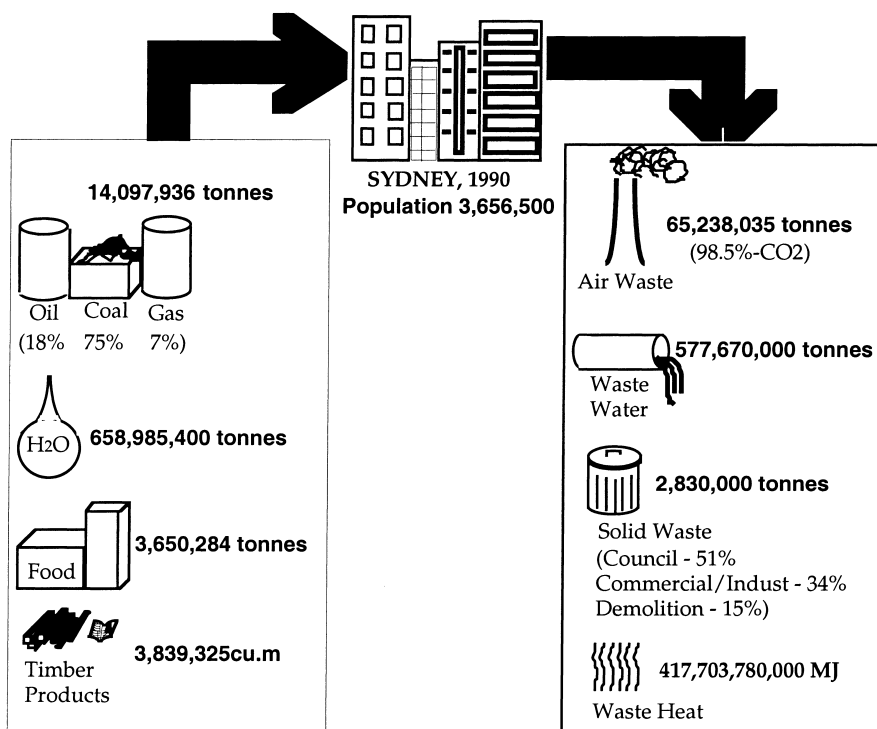
1965; Boyden et al., 1981; Girardet, 1992). Fig. 1 sets out how this basic metabolism concept has been extended to include the dynamics of settlements and livability in these settlements. It was developed as the basis of the approach adopted by the Australian State of the Environment Report (Newman et al., 1996).

In this model it is possible to specify the physical and biological basis of the city, as well as its human basis. The physical and biological processes of converting resources into useful products and wastes is like the human body's metabolic processes or that of an ecosystem. They are based on the laws of thermodynamics which show that anything which comes into a biological system must pass through and that the amount of waste is therefore dependent on the amount of resources required. A balance sheet of inputs and outputs can be created. It also means that we can manage the wastes produced, but they require energy

in order to turn them into anything useful and ultimately all materials will eventually end up as waste. For example, all carbon products will eventually end up as CO₂ and this is not possible to recycle any further without enormous energy inputs that in themselves have associated wastes. This is the entropy factor in metabolism.

What this means, is that the best way to ensure that there are reductions in impact, is to reduce the resource inputs. This approach to resource management is implicitly understood by scientists but is not inherent to an economist's approach which sees only 'open cycles' whenever human ingenuity and technology are applied to natural resources. However, a city is a physical and biological system. Fig. 2 and Table 1 apply the metabolism concept to Sydney.

The metabolic flows for Sydney in 1970 and 1990 are summarised in Table 1; they show that apart from a few air quality parameters there has been an increase



Notes:
 Waste water data do not include stormwater
 Timber products and food data derived from national per capita data

Fig. 2. Resource inputs consumed and waste outputs discharged from Sydney, 1990. Source: Newman et al., 1996.

Table 1
Trends in certain per capita material flows in Sydney, 1970 and 1990; source: Newman et al. (1996)

	Population	
	Sydney 1970 2 790 000	Sydney 1990 3 656 500
<i>Resources inputs</i>		
Energy/capita	88 589 MJ/capita	114 236 MJ/capita
Domestic	10%	9%
Commercial	11%	6%
Industrial	44%	47%
Transport	35%	38%
Food/capita (intake)	0.23 tonnes/capita	0.22 tonnes/capita
Water/capita	144 tonnes/capita	180 tonnes/capita
Domestic	36%	44%
Commercial	5%	9%
Industrial	20%	13%
Agricultural/gardens	24%	16%
Miscellaneous	15%	18%
<i>Waste outputs</i>		
Solid waste/capita	0.59 tonnes/capita	0.77 tonnes/capita
Sewage/capita	108 tonnes/capita	128 tonnes/capita
Hazardous waste		0.04 tonnes/capita
Air waste/capita	7.6 tonnes/capita	9.3 tonnes/capita
CO ₂	7.1 tonnes/capita	9.1 tonnes/capita
CO	204.9 kg/capita	177.8 kg/capita
SO _x	20.5 kg/capita	4.5 kg/capita
NO _x	19.8 kg/capita	18.1 kg/capita
HC _x	63.1 kg/capita	42.3 kg/capita
Particulates	30.6 kg/capita	4.7 kg/capita
Total waste output	324 million tonnes	505 million tonnes

in per capita resource inputs and waste outputs. The reduction in hydrocarbons is because they are more completely burnt in modern automobile engines – but this just means that there's more CO₂ produced. If CO₂ is to be reduced, there needs to be more fundamental change, such as reducing the need to travel so much (Newman and Kenworthy, 1999).

The metabolism approach to cities is a purely biological view, but cities are much more than a mechanism for processing resources and producing wastes, they are about creating human opportunity. Thus Fig. 1 sets out how this basic metabolism concept has been extended to include livability in these settlements so that the economic and social aspects of sustainability are integrated with the environmental.

This approach now becomes more of a human ecosystem approach, as suggested by Tjallingii and others above.

Some typical sustainability indicators for cities covering metabolic flows and livability are outlined in Table 2. Livability is about the human requirement for social amenity, health and well being and includes both individual and community well-being. Livability is about the human environment though it can never be separated from the natural environment. Sustainability for a city is thus not only the reduction in metabolic flows (resource inputs and waste outputs), it must also be about increasing human livability (social amenity and health).

Livability indicators were produced for Sydney and other Australian settlements for the State of the Environment Report (Newman et al., 1996), but only for 1 year. Further studies can thus determine if these aspects of sustainability are improving or not.

5. Application of the extended metabolism model

The extended metabolism model can be applied at a range of levels and to a range of different human activities, for example:

- *Industrial areas* can examine their inputs of resources and outputs of waste while measuring their usual economic parameters and other matters such as worker health and safety. These data could then be used to see how mutually useful solutions could be found such as the recycling of one industry's waste as an important resource substitute for an adjacent industry. The Kalundborg area of Denmark has made an assessment of this kind (Tibbs, 1992). Ayres and Simonis (1994) have adopted a similar approach for industrial areas based on 'industrial metabolism'.
- *Households or neighbourhoods* can make an assessment of their metabolic flows and livability and together make attempts to do better with both. Examples of this approach in single developments are being labeled 'urban ecology' (Newman and Kenworthy, 1999).
- *Urban demonstration projects* can be assessed for their sustainability using the extended metabolism model. For example, we were asked to evaluate the

Table 2
Annual goals and indicators for sustainable city

<p>1. Energy and air quality</p> <ul style="list-style-type: none"> Reduce total energy use per capita Decrease energy used per dollar of output from industry Increase proportion of bridging fuels (natural gas) and renewal fuels (wind, solar, biofuels) Reduce total quantity of air pollutants per capita Reduce total green house gases (eg Kyoto goals of 'demonstrable progress' by 2005 and 5% reductions by 2008–12 from 1990 levels and then further reductions annually) Achieve zero days not meeting air quality health standard levels Reduce fleet average and new vehicle average fuel consumption Reduce number of vehicles failing emission standards Reduce number of households complaining of noise reducing <p>2. Water, materials and waste</p> <ul style="list-style-type: none"> Reduce total water use per capita Achieve zero days not meeting drinking water quality standards Increase proportion of sewage and industrial waste treated to reusable quality Decrease amount of sewage and industrial waste discharged to streams or ocean Reduce consumption of building materials per capita (including declining proportion of old growth timber to plantation timber) Reduce consumption of paper and packaging per capita Decrease amount of solid waste (including increasing recycle rates for all components) Increase amount of organic waste returning to soil and food production <p>3. Land, green spaces and biodiversity</p> <ul style="list-style-type: none"> Preserve agricultural land and bushland at the urban fringe Increase amount of green space in local or regional parks per capita, particularly in 'green belt' around city Increase amount of urban redevelopment to new development Increase number of specially zoned transit-oriented locations Increase density of population and employment in transit-oriented locations <p>4. Transportation</p> <ul style="list-style-type: none"> Reduce car use (vehicle kilometer traveled or vehicle miles traveled) per capita Increase transit, walk/bike and car pool and decrease sole car use Reduce average commute to and from work Increase relative average speed of transit to cars Increase service kms of transit relative to road provision Increase cost recovery on transit from fares Decrease parking spaces per 1000 workers in central business district Increase length of separated cycleway <p>5. Livability, human amenity and health</p> <ul style="list-style-type: none"> Decrease infant mortality per 1000 births Increase educational attainment (average years per adult) Increase local leisure opportunities Decrease transport fatalities per 100 population Decrease reported crimes per 1000 population Decrease deaths from urban violence Decrease proportion of substandard housing Increase length of pedestrian-friendly streets (based on specific indicators) in city and sub-centres Increase proportion of city/suburbs with urban design guidelines to assist communities in redevelopment Increase proportion of city allowing mixed use, higher density urban villages 	<hr/> <p>Australian Better Cities program which consists of 45 demonstrations of urban innovations. The approach adopted was to try to see the extent to</p>	<p>which each project was reducing resource inputs, lowering waste outputs and simultaneously improving the livability of the urban area (Diver</p>
--	--	---

Table 3
Sustainability and construction

The Sydney 2000 Olympics are described as the 'Green Olympics' due to the Greenpeace winning design for the Olympic Village. In this Olympic Village there will be 100% renewable electricity (from roof top photo voltaics and wind power), energy efficient buildings, solar hot water, no poly vinyl chlorides or rain forest timber, a rail service connection, bicycle/pedestrian oriented layout and water and waste recycling systems (Bell et al., 1995). Karla Bell and Associates who were closely involved in the design have also designed a Swedish new town, Hammarby Sjostad, which was part of the failed 2004 Stockholm Olympics bid but which will still be built as a 'spearhead for ecological and environmentally friendly construction' (City of Stockholm, 1997)

The goals of the new town are a model of reduced metabolic flows:

Energy

- 100% renewable-based electricity and heating
- Energy use to not exceed 60 kwh/m² in 2005 and reducing to 50 kwh/m² by 2015

Transport

- 80% commuting by non automobile means
- 20% less traffic by 2005 and 40% less by 2015
- 15% vehicles using biofuels by 2005 and 25% by 2015
- 100% freight vehicles electric or low emission vehicles

Material flows

- 100% solid waste recycled
- 20% reduction in waste by 2005, 40% by 2015
- Water consumption reduced by 50% in 2005 and 60% by 2105
- Sewage used for energy extraction and nutrients for farm soil
- Stormwater used locally

Building materials

- No PVC or non-recyclable materials to be used
- No rain forest timbers to be used
- New building materials only 50% of construction by 2005 and only 10% by 2015
- No 'sick-building' chemicals in carpets and furniture glues

et al., 1996). An urban demonstration project in Jakarta was evaluated in terms of sustainability using the extended metabolism model (Arief, 1998).

Cities can even extend this evaluation process to events like the Olympic Games and all the facilities and infrastructure they require (see Table 3).

- *Individual businesses* can apply the extended metabolism model and create a sustainability plan. The first business to make a 'sustainability report' is Interface (Anderson, 1998) which is a large US company making flooring. They began a process in 1994 after the CEO had read Paul Hawken's 'The Ecology of Commerce' (Hawken, 1994) and chose to follow a Swedish set of principles called Natural Step (Greyson, 1995). Their process was similar to the metabolism model in that it examined resources ('what we take'), dynamics ('what we make') and

wastes ('what we waste'). It did not specify livability outcomes, though their report stressed that economic productivity improved as much from staff morale as from new technology. Four hundred separate sustainability initiatives were specified in the firm based on the work of 18 different teams.

- *City comparisons.* By comparing indicators for resource use, wastes and livability in different cities, it is possible to locate those cities (or parts or cities) that have something to contribute to policy debates on sustainability. Few cities have done full assessments of their resources, wastes and livability (Newman and Kenworthy, 1999). New Zealand cities were assessed using the extended metabolism model (Parliamentary Commission of the Environment, 1998) and found that the area requiring most attention was the growth in automobile dependence. Australian cities were studied

Table 4

Australian settlements and sustainability — based on 'State of The Environment, Australia 1996'

1. The larger the cities the more sustainable they are in terms of per capita use of resources (land, energy, water) and production of wastes (solid, liquid and gaseous) and in terms of livability indicators (income, education, housing, accessibility). The reason for this is the economies of scale and density which mean that they have more public transport and recycling and are generally more innovative with new technology (Newman and Kenworthy, 1999)
2. Larger cities are however more likely to reach capacity limits in terms of air sheds and water sheds. For large cities to continue to grow they will need to be even more innovative if they are to be sustainable
3. In geographic cross section across Australian cities there is an increase in metabolic flows and declines in livability indicators from core to inner to middle to outer to fringe suburbs. This pattern is related to the different urban development periods and most recently has been related to re-urbanisation by more wealthy residents and firms. This rapid re-urbanisation of more central areas appears to be related to processes of economic change in the new Information Age which may be helping cities to become less automobile dependent (Newman and Kenworthy, 1999)
4. Ex-urban and coastal settlements beyond the big cities are the least sustainable of all Australian development; they have large environmental impacts, high metabolic flows and low invability on all indicators. These areas are heavily automobile dependent and highlight how sustainability and transportation priorities are totally enmeshed
5. Remote aboriginal settlements have low metabolic flows and low livability (especially in regard to employment and health) but are the settlements where new small-scale eco-technologies are being trialed.

using this approach and showed the broad trends set out in Table 4.

Cities can operate this model on many such levels, but most of all they need to be able to measure how they are doing overall as a city in reducing their metabolic flows whilst improving their human livability. Most cities will be able to point to a few innovations they are making in sustainability but until they can bring a full assessment of these matters together they will not be addressing the fundamentals of urban sustainability.

6. Conclusion

This paper has provided examples of how the extended metabolism model can be used to assess the sustainability of cities. The simultaneous achievement of reduced resources and wastes whilst improving livability provides a framework for guiding our cities into the future.

References

- Anders, R., 1991. The sustainable cities movement. Working paper no. 2, Institute for Resources and Security Studies, Cambridge, MA, USA.
- Anderson, R., 1998. Sustainability Report. Interface, New York.
- Arief, A., 1998. A sustainability assessment of squatter redevelopment on Jakarta. M. Phil. Thesis, Institute for Science and Technology Policy, Murdoch University, Perth, WA.
- Ayres, R.U., Simonis, U.E., 1994. Industrial Metabolism. United Nations University Press, Japan.
- Bell et al., 1995. Environmental guidelines for Sydney 2000, Sydney Organising Committee for Olympic Games, Sydney, Australia.
- Boyden, S. Millar, S Newcombe, K., O'Neill, B., 1981. The Ecology of a City and its People. ANU Press, Canberra.
- Brugmann, J., Hersh, R., 1991. Cities as ecosystems: opportunities for local government. ICLEI, Toronto.
- City of Stockholm, 1997. An environmental program for Hommarby Sjordad. City of Stockholm.
- Diver, G., Newman, P., Kenworthy, J., 1996. An evaluation of better cities: environmental component. Department of Environment, Sport and Territories, Canberra.
- Girardet, H., 1992. The Gaia Atlas of Cities. Gaia Books, London.
- Greyson, J., 1995. The Natural Step 1995 – A Collection of Articles. The Natural Step, Sausalito, CA.
- Hawken, P., 1994. The Ecology of Commerce: A Declaration of Sustainability. Harper Business, New York.
- Keating, M., 1993, The Earth Summit's Agenda for Change: A Plain Language version of Agenda and Three Other Rio Agreements, Center for Our Common Future, Geneva.
- Mitlin, D., Satterthwaite, D., 1994. Cities and sustainable development. Discussion paper for UN Global Forum, 1994, Manchester, IIED, London.
- Newman, P., Kenworthy, J., 1999. Sustainability and Cities: Overcoming Automobile Dependence. Island Press, Washington, DC.
- Newman, P.W.G. et al., 1996. Human settlements. In: Australian State of the Environment Report, Department of Environment, Sport and Territories, Canberra.
- Parliamentary Commission of the Environment, 1998. The Urban Environment. Parliamentary Commissioner, Wellington, New Zealand.

- Roseland, M., 1992. Towards sustainable communities. Canadian National Round Table on the Environment and the Economy, Ottawa.
- Slocombe, D.S., 1993. Environmental planning, ecosystem science and ecosystem approaches for integrating environment and development. *Environ. Manag.* 17(3), 289–303.
- Tibbs, H.B.C., 1992. Industrial ecology: An agenda for environmental management. *Pollution Prevention Review*, Spring.
- Tjallingii, S.P., 1993. *Ecopolis: Strategies for Ecologically Sound Urban Development*. Backhuys Publishers, Leiden.
- UN Centre for Human Settlements, 1996. *An Urbanising World: Global Review of Human Settlements 1996*. Habitat, Nairobi.
- UN World Commission on Environment and Development, 1987. *Our Common Future*, Oxford University Press, London.
- Wolman, A., 1965. The metabolism of the city. *Sci. Am.* 213, 179.
- World Bank, 1994. *World Development Report 1994*. Oxford University Press, New York.
- Yanarella, E.J., Levine, R.S., 1992. Does sustainable development lead to sustainability?. *Futures* 24(8), 759–774.