

# Urban Metabolism and the Circular Economy, The Capital Approach

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**Abstract:** As global human population continues to increase society is shifting toward more concentrated urbanisation. Urban settlements require adequate, appropriate infrastructure and accommodation to satisfy the increasing population needs. A circular economy is an inclusive approach relying on integrated systems that feedback into the production process. Humanity has reached a position where we must utilise the stock of natural capital more efficiently to ensure that replenishment of stock can occur. An appreciation of the circular economy is required to ensure that the stock and flows of capital can meet the metabolic rate of urbanism. The circular economy provides an opportunity to transition from the linear economy to satisfy sustainable development objectives.

**Keywords:** Capital, Circular Economy, Stocks, Flows

## Introduction

The primary function of our cities is to ensure that an adequate level of well-being is provided for all occupants throughout their lifetimes.

As the increase in human population continues, we are simultaneously experiencing a steady shift of the global population towards cities. This concentration of human occupation within the urban environment is increasing the pressure on the ability for cities to meet the needs of their occupants. Cities are increasingly expected to provide adequate housing, workspace, leisure facilities, education programs, transport and infrastructure, in a functional, safe and secure environment.

This urban pressure is manifested in three forms:

- developing the built environment stock to satisfy the growing population needs;
- providing the flow of adequate services including reliable energy, clean water, materials and infrastructure to allow the urban system to function and operate to meet needs and requirements of the population;
- ensuring the built environment is maintained to a level to meet the utility needs of the changing demographic profile.

These three requirements constitute the stock of the urban fabric and the flows of essential services.

### **Urban Metabolism**

The concept of urban metabolism was introduced by Abel Wolman in 1965. In the paper ‘The Metabolism of Cities’, Wolman identifies:

“three metabolic problems that have become more acute as cities have grown larger. These three problems are the provision of an adequate water supply, the effective disposal of sewerage and the control of air pollution (Wolman, 1965 p179).”

Since that time the global population has more than doubled and has transitioned away from rural areas toward urban settlements. The three identified urban metabolic problems are still relevant to today’s society, but many other components may now be added as essential to a functioning city. The provision of reliable energy, information and communication technology, and effective transportation systems may be seen as first world urbanisation issues, but they are becoming increasingly important and demanded by global urban inhabitants.

Urban metabolism is measured as a response to the population pressure on the urban fabric and is calculated as “the magnitude, rate and size of the flows, required to respond to the demands of the urban environment (Roggema, 2019).” The urban metabolic rate increases as a result of a growing population, the increasing and changing demand for resources and processes required to keep a city functioning for the benefit of the community inhabitants.

### **The Linear Economy**

The first sequel to the *Limits to Growth*, ‘Beyond the Limits’ (Meadows *et al*, 1992), stated:

“The earth is finite. Growth of anything physical, including the human population and its cars and buildings and smokestacks, cannot continue forever. But the important limits to growth are not limits to population, cars, buildings, or smokestacks, at least not directly. They are limits to *throughput* – to the flows of energy and materials needed to keep people, cars, buildings and smokestacks functioning.”

“The human population and economy depend upon constant flows of air, water, food, raw materials, and fossil fuels from the earth. The limits to growth are limits to the ability of the planetary *sources* to provide those streams of materials and energy, and limits to the ability of the planetary *sinks* to absorb the pollution and waste.” (Meadows *et al*, 1992)

From the commencement of the industrial revolution and throughout the twentieth century, the global economy has primarily functioned on a linear basis. This process was manageable, although not desirable, as natural capital stocks were seemingly in abundance and the ecosystems were generally capable of servicing, absorbing and regenerating to allow a functioning environment to serve the needs of the expanding human population. When the human population reached 5.5 billion in the 1990’s it was estimated that some of the natural systems operating under a linear approach, were at capacity (Meadows *et al*, 1992). Past this point, the regenerative flow capability of these natural

ecosystems was failing to keep pace with demand and pressures imposed by human occupation and production processes.

## **The Circular Economy**

“The circular economy is an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed as both process and output, to maximize ecosystem functioning and human well-being (Murray *et al*, 2015 p369).”

Creating a circular economy is necessary to meet the growing demand pressures created by the increasing urban metabolic rate. For the circular economy to be effective, a regenerative process that optimises the utility value of inputs, through the efficient distribution of outputs while eradicating negative impacts, is desirable. A balanced approach which optimises resource utilisation within boundaries and limitations is required.

The process modelling behind these concepts date back to the 1970's based on the system dynamics, World3 modelling from the Limits to Growth team of researchers headed by Dennis Meadows (Meadows D H *et al*, 1972). The five key areas central to the *Limits to Growth World3* model were exponential population growth, agricultural production, industrial production, natural resources and pollution. The *Limits to Growth* modelling highlighted the linear and circular flows of human habitation through system dynamic processing of data associated with the five identified areas. The analysis considered feedback loops and predicted time lags, indicating degeneration and the estimated regeneration capacity of natural systems and the ability of these systems to cope with increasing human population pressure (Meadows, 1972).

When *Limits to Growth* was published in 1972, the global human population had grown to an unprecedented 3.7 billion. In the past four decades global human population has now doubled to 7.4 billion. This increasing population level, combined with a shift toward urbanisation compounds the demand for appropriate accommodation and suitable infrastructure to supply services including the adequate provision of energy, clean water, effective transportation methods and supply chains for material goods and food. This compounding effect is manifested in the increasing rate or velocity of urban metabolism. The circular economy is an appropriate method to respond to the increasing rate of urban metabolism.

## **Asset Based Capital Approach**

A consideration of the stocks and flows of capital is necessary for the circular economy to be effective. Environmental economist, David Pearce outlined an asset-based approach that combined capital from four interrelated perspectives (Pearce *et al*, 1993). The four capital stocks outlined were **natural, human, manmade, and social.**

### Natural Capital

Natural capital stock covers a wide spectrum of environmental assets, including soil fertility, forests, fisheries, fossil fuels in the form of oil, gas and coal, the ozone layer and biological chemicals. (Pearce *et al*, 1994).”

The flows of natural capital can be further expanded to include ecosystems services: the capacity to assimilate waste, photosynthesis, evapotranspiration, renewable energy, the water, carbon, nitrogen and sulphur cycles and the ecological systems that allow cohabitation of all species.

### Human Capital

The stock of human capital includes the human population and the level of education and skills. The flows are the number of births and deaths, the demographic aging profile and the utilisation of knowledge, skills and labour.

### Man Made Capital

The stock of man-made capital constitutes the existing built environment and produced goods. The flows of man-made capital are through the manufacturing process. The built environment flows consist of the processing and utilisation of materials through the development process and the use of energy and materials in the operation of premises including repairs and maintenance.

### Social Capital

Social capital considers public health, access to education, non-discriminatory employment opportunities, public safety (law and order), privacy, freedom of association, indigenous rights, non-corrupt and equitable systems of governance (Gleeson-White, 2014)

The social capital stock is created as a result of the other capitals. Social capital can evolve from human capital flows. Social capital can improve as a consequence of man-made capital stock. Social capital can be impacted by natural capital stocks. As Jane Jacobs articulated in *'The Death and Life of the Great American Cities'*:

“development for the sake of development can sometimes have negative social consequences, whereas investment in improving the existing social fabric that has positive attributes can produce even greater positive outcomes (Jacobs, 1967).”

As Jacobs highlighted, heritage, culture and community, all are important social capital benefits.

The circular economy from a processing perspective is “virtually silent on the social dimension (Murray *et al*, 2013 p376)”, where the social capital perspective is central to sustainable development outcomes. This can be explained by the circular economy taking a quantitative analytical approach, whereas many social capital outcomes may be considered more qualitative.

Societal well-being is a consequence of the flows of human and man-made capital, which provide inputs to serve social capital, but social capital can only exist within a thriving natural capital environment.

Social capital preservation is the dominant theme in *'Our Common Future'* (Brundtland, 1987), concept for sustainable development: -

“Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without comprising the ability of future generations to meet their own needs.

Sustainable development requires meeting the basic needs of all and extending to all the opportunity to fulfil their aspirations for a better life (Brundtland, 1987 p8).”

The theory behind sustainable development is determined by ensuring social capital stocks are enhanced over time.

“The concept of sustainable development suggests that a development path is sustainable if and only if the stock of overall capital assets remains constant or rises over time. To be on a sustainable development path, then, a nation must be living within its means, which in this context means not decreasing its overall capital assets.” (Pearce *et al*, 1993 p84)

### **Capital Stocks and Flows**

It is essential to understand that natural capital systems operate as a complex arrangement of circular flows that provide eco-system services essential to support all species. The difference between natural capital and the other forms of capital is natural capital does not require human activity to build or maintain its stock. Natural Capital is a fundamental requirement for the development of the other capitals (Costanza et al, 2017) when interacted with human capital and man-made capital.

“These four general types of capital are all required in complex combinations to produce any human benefits. Ecosystem services thus refer to the relative contribution of natural capital to the production of various human benefits, in interaction with the other forms of capital. These services do not simply flow to human well-being without these crucial interactions. (Costanza *et al*, 2017 pp4-5).”

Humanity cannot survive without adequate life supporting natural capital stocks, produced by positive natural capital flows. Essential human life supporting attributes of natural capital stock include the air we breathe, the availability of fresh drinking water, soil and the nutrients required for plant growth. Each of the other forms of capital are reliant to some extent on natural capital stock and the natural systems regenerative flows. Natural capital is exploited by the other capitals to a position whereby the regenerative capacity of natural capital through ecosystems services is insufficient to keep pace with human production demands and urban metabolism.

Both urban metabolism and the circular economy are based around the concept of stocks and flows. Once the stock of the capitals has been identified, it is critical to understand the flows of these capitals.

“The critical aspect is to understand the stock, flows and impacts when incorporating natural capital into the capital equation. Stocks may be both sources and sinks of natural resources, while flows may be both inputs and outputs that increase or decrease stocks (Meadows, 1998).

Moreover, stocks and flows of resources are also characterised by different regeneration rates (Wall, 2002), which determine whether resources are referred to as renewable or non-renewable. (Costanza and Daly, 1992) (Mancini *et al* 2017 p125).”

Each of the capitals cannot be treated in isolation, but rather a cross capital approach is required to ensure that optimal performance or outputs are achieved within the boundary limitations.

The atmospheric cycle is one example of where man-made linear flows, the emission of carbon dioxide into the atmosphere has now reduced the natural stock holding capacity, by exceeding the flow rate capability of the atmosphere to absorb carbon emissions. The concentration of carbon dioxide in the atmosphere has already surpassed 410 parts per million (ppm), (Mauna Loa Observatory, 2019)<sup>1</sup> where 350ppm is the recommended position to avoid global warming and the effects of climate change.

- Fossil fuels remain the primary fuel source to provide energy for transport, the operation of building services, heating and cooling systems and the energy for the production process of materials for construction.
- Carbon dioxide is emitted by the burning of fossil fuels.
- Carbon dioxide accumulates in the atmosphere.
- The absorption rate of carbon dioxide out of the atmosphere is slow, with the lag or processing time estimated to be up to 100 years.
- The atmosphere and oceans act as sinks, but as they have reached their optimal processing capacity, the outcome of this oversupply of carbon dioxide manifests into the predicted consequences of global warming, resulting in increased frequency of drastic weather events, increased ocean warming, ocean acidification and rising sea levels.

These outcomes have potential severe existential consequences to humanity, but we continue to emit into a system that has passed its effective processing capacity.

From an urban metabolism approach, we should ensure that development and occupation of cities limit the output of carbon emissions to decrease the impacts and consequences of climate change and associated risks. This requires a shift to renewable energy as a substitute to carbon emitting fossil fuels, to a level that meets the energy demand of the population and reduces carbon emissions to levels that can be effectively absorbed into the atmosphere and oceans without negative consequences.

An effective circular economy should be designed to ensure that the projected outcomes contribute to the replenishment of the stock of capital and meet the rate of urban metabolism. From a circular economy perspective, systems should be developed and integrated to ensure that carbon dioxide emissions are reprocessed prior to entering the atmosphere.

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<sup>1</sup> According to <https://www.co2.earth> , The Mauna Loa Observatory, Hawaii, recorded atmospheric concentrations of carbon dioxide in April 2019 at 413.52 ppm.

## **Boundaries**

How can we be sustainable if the human population is already using 1.7 planets worth of resources and waste absorption capacity (Global Footprint Network, 2019) and depleting the stock of natural capital to a position where the ecosystems services are incapable of providing adequate regenerative flows?

Linear processes primarily utilise stock(s) as inputs, create waste during the production process and dump the residue. This approach fails to provide the feedback loops to allow systems to regenerate effectively. As we have now reached capacity in some systems and deteriorated natural capital stockholdings, a linear approach is no longer a satisfactory approach.

If we have passed the regenerative capacity limits of natural capital and are now depleting natural capital stock, a virtuous circle response must be adopted with the aim toward preserving and enhancing natural capital to provide positive social outcomes.

For the circular economy to be effective, the process must provide positive benefits across all the capitals and therefore be considered to operate in a virtuous manner. If all the flows are positive, adding to the stock holding of all the capitals without diminishing or exploiting one for the benefit of the other, then it could be said that this is a sustainable approach.

One problem with the circular economy is that some approaches may plan for virtuous outcomes, but when all the capitals are considered there may be vicious circles embedded within the system resulting in a negative flow from a capital. For this situation to be sustainable, it is a matter of quantifying the positive and negative responses within the system to determine the true value proposition, ensuring that a gross positive outcome is achieved over the long term.

## **Urban Metabolism - Sydney Urban Planning**

Sydney is the most populous city in Australia, with a current population of approximately 5 million. The commercial business district of the city is located alongside the banks of Sydney Harbour near the coastline of the Pacific Ocean. The geographical boundaries of the metropolitan area are largely contained by the natural geography of the Pacific Ocean to the east, national parks to the north and south coastal regions and Blue Mountains to the west. The urban expansion of the city therefore spreads from the city centre predominately west outwards 50kms to the base of the Blue Mountains escarpment.

The Sydney basin is 12,367square kilometres, including the national parks. The urban area is currently 4,064 square kilometres with an urban density of 1,237 persons per square km. (City of Sydney 2019).

The climate of the City of Sydney is classified as subtropical. As the city is located alongside the harbour and situated near the coast, the city itself does not suffer from the characteristics of the urban heat island effect to a level detrimental to human habitation. The air temperature along the densely populated coastal suburbs and inland to approximately 8kms remain mild within the subtropical/temperate zone throughout the year. These suburbs are cooled by circulating sea breezes and coastal weather systems.



**Figure 1 Greater Sydney Metropolitan area**

Post-World War II urban expansion has generally been to the west of the city with the population geographically centred around the western Sydney centre of Parramatta, approximately 20kms from the coast. Residential expansion continues to spread further inland into the Sydney basin to the north

west, west and south west. The climate and temperature in these areas is significantly different to the coastal areas, as cooling sea breezes don't penetrate this far inland.

Most of the recent urban population growth has spread further west with the provision of available land, allowing the development of large suburban homes on small allotments. These sprawling suburbs lack appropriate infrastructure in the form of public transport. Motorways have been developed throughout this area to cope with the increased motor vehicle use. This area of western Sydney accommodates over half the metropolitan residential population of Sydney, in-excess of 2million people and has been planned for a further 3million over the forthcoming decades.

To accommodate this population growth, Sydney has experienced the continued clearing of native bush and agricultural land for suburban settlement within the western Sydney basin. Major city centres have been developed in Parramatta and Blacktown in the west, Liverpool and Campbelltown in the south west.

The New South Wales State Government Planning Department has undertaken numerous detailed urban planning strategies to accommodate growth for Sydney over the forthcoming decades. The latest urban expansion masterplan 'A Metropolis of Three Cities - The Greater Sydney Region Plan (Greater Sydney Commission, 2019)' considers a planning strategy for Greater Western Sydney to provide upgraded and investment in new infrastructure including a second airport, new employment centres and the provision of new residential accommodation. It is a detailed urban development plan providing a strategy for growth and development for the western Sydney urban area, based on the economic grounds of consolidated urban development with proposed employment centres.

## **The Vicious Circle**

### Western Sydney Urban Planning

- Increased urbanisation of this metropolitan region results in a reduction of the rural landscape, resulting in a reduction of low-level vegetation and the tree canopy.
- New suburbs are created through subdividing broadacre land.
- Roads are constructed with black asphalt bitumen.
- Homes have been built on small allotments with predominately black or dark roof tiles with narrow eaves and poor shading.
- Little residual space for landscaping and any established tree canopy.

The existing suburbs are now suffering from the suburban heat island effects, due to the reduction of green space replaced with black or dark fabricated surfaces. As these suburbs are located inland, they do not benefit from any coastal sea breezes.

- Average annual temperatures continue to rise and remain hotter for longer periods.
- The further inland, the higher the temperature increases.

- Dwellings are ineffectively designed to benefit from passive solar shading and natural breezes and therefore require cooling from air conditioning systems.
- There has been a slow take up of photo voltaic electricity cells, requiring electricity generated predominately from coal fired power stations.
- Where these dwellings are poorly orientated and are constructed with inappropriate materials for the environment, they require increasingly more energy for cooling.
- The cost per unit of energy continues to increase.
- Lower land values and low-cost building materials indicate that houses are “more affordable” but unsuited to a changing climate.
- Increasing building operating expenses and additional transportation costs equates to increasingly unaffordable living expenses.

Future residential subdivision will further reduce the green space within these suburbs.

- With increasing temperatures, tree leaf canopy transpiration and plant photosynthesis are negatively impacted.
- Increasing heat events with temperatures consistently over 35degree Celsius days are experienced throughout an extended summer period.
- This region is getting hotter and it is staying hotter for longer.
- The heat is being trapped overnight, therefore these suburbs don't experience adequate heat relief.
- Artificial cooling through air conditioning is required for longer periods.
- Increased energy use requires more burning of fossil fuels creating higher levels of green-house gas emissions, resulting in increased warming.
- High temperatures reduce green space growing ability along with a lack of available water for irrigation, creates heat stress on plants.
- More people require more cars, alongside a lack of appropriate public transport infrastructure. This creates traffic congestion and continuous demand for transport infrastructure improvements.
- More vehicles on the roads for longer periods creates more carbon emissions leading to global warming.
- Changing climatic conditions affects the supply of water. As the population increases the provision of water per person is diminished.

The City of Parramatta are conscious of this warming phenomenon and are installing heat monitors and sensors throughout the city as part of a smart city initiative, but this action does not mitigate the problem, it only identifies it. (City of Parramatta, 2018)

This development cycle has now reached a stage where the continued residential expansion of this region is now negatively impacting the natural capital stock and flows to a detrimental level of social well-being. The heat stress impact on this area is worsening.

The proposed urban development plan effectively ignores this issue and does not offer any solutions to this worsening situation. The problem is that the metabolic rate of the existing urban population is creating a compounding affect with urban heat retention and has broader global warming implications. This affect will be further compounded as the metabolic rate increases to meet the demands proposed population expansion.

The plan proports to consider a sustainable development approach but fundamentally it considers development from a linear economic approach. The plan fails to consider a holistic approach considering the four capitals, urban metabolism and the circular economy. Being based primarily on job creation and economic considerations, the plan fails to recognise the importance of natural capital and the environment being the critical capital component determining the consequential social outcomes.

We have available land, but do we have suitable or appropriate land for residential expansion? The impact of urbanisation is affecting the climatic conditions in this region to a position that is becoming unsuitable for human habitation.

This region is experiencing the effects of global warming now, which is impacting social well-being, health and safety, resource use and furthering the depletion of natural capital stocks. We have created a vicious circle though a linear urban planning approach, but little consideration has been had for the urban metabolism. This urban planning strategy fails, as it fails to meet the needs of society and negatively impacts natural capital stock holdings. The plan proposes to increase economic performance. When the capitals are taken into consideration, this plan does not enhance well-being, it negates it. It does not create wealth, it depletes it.

## **Conclusion**

When we consider that the stock of natural capital is now a non-negotiable asset, the endowment of natural capital stock must be protected. The operating paradigm for sustainable development must be within the functional ability of natural capital regenerative flows. We can no longer allow natural capital stocks to be used as a sink if the regenerative process fails to meet the absorption capacity as this will further deteriorate the stock of natural capital.

A linear economic approach is now redundant as a linear approach cannot satisfy the objectives of sustainable development and meet the needs of urban metabolism in a balanced and secure manner. A circular economy is necessary to enhance natural capital systems and provide appropriate social capital outcomes. We must transition to a circular economy to ensure continuous improvement and to increase our overall stock of capital assets. This will provide the opportunity for a sustainable outcome.

We still require an adequate resource base and systems to satisfy social needs through the supply of manmade products. A circular economy can assist in meeting the demands of urban metabolism, but

the rate of renewal and regeneration and use of critical resources must provide an overall virtuous response to the key limited areas.

With an increasing global population, changing demographic patterns and a shift toward urbanization, the urban metabolic rate continues to increase. The primary priority is to provide a process whereby we can continue to operate within natural capital limits to protect environmental reserves (stock) and renewal by ecological systems (flows), while satisfying social needs to enhance equitable prosperity. This needs to be achieved in addition to ensuring that the expanding human population needs are met through the provision of new capital works and the repair and maintenance of existing systems. If all these outcomes can be achieved through a virtuous circular economy approach, then we have satisfied the demands of urban metabolism in a sustainable manner.

### **Acknowledgements**

The author of this paper is a PhD candidate of the University of New South Wales (Sydney) and is a recipient of the Commonwealth of Australia's Research Training Program scholarship. I hereby acknowledge the support by the Australian Government Research Training Program Scholarship.

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