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Human Settlements arranged as Networks of Regenerative Villages with Nature-based Infrastructure Ecosystems

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Abstract

Civil infrastructures have historically been developed as highly centralised, extensive, and complicated systems. Electricity, water, buildings, transport networks, and communication systems are each delivered separately. Recent advancements in the development of energy micro-grids have opened the possibility of localised, intensive, and complex, nature-based infrastructure ecosystems. Designed at the scale of a village, such systems would integrate different types of infrastructure. For example, an energy micro-grid can provide electricity to buildings, power electric vehicles and cycle water through a precinct. In turn, the water system can store energy and irrigate a diverse, regenerative food system. Providing housing close to food production reduces transport costs, supply chain losses and packaging. The significant land area required for each village would result in a dispersal of populations, creating networks of villages, each with integrated infrastructure ecosystems. This challenges the orthodoxy in town planning and regional economics that accepts ever-increasing urbanisation. To synthesise ideas developed in different disciplines we adopt the epistemology of consilience. That is, a conclusion can be confirmed when different disciplines arrive at that same position. We show that literature in town planning, regional economics, ecological economics, and public health all support the argument for dispersal reached through civil engineering systems.

Keywords: town planning, infrastructure ecosystems, thermodynamics, regional economics, steady state economy

Introduction

Civil infrastructures have historically been developed as highly centralised, extensive, and complicated systems. Electricity infrastructure, water infrastructure, transport networks, and communication systems are each delivered separately by different providers, all operating under parallel and sometimes conflicting regulatory frameworks. Recent advancements in the development of energy micro-grids have opened the possibility of localised, intensive, complex, and integrated, nature-based infrastructure ecosystems.

Adopting a systems approach to the development of integrated civil infrastructures, this paper explores the possibility of infrastructure ecosystems, designed at the scale of a village or neighbourhood precinct, and then networked with similar villages to create a broader, interconnected network of communities within a bioregion and beyond.

The proposed infrastructure ecosystem will focus on those infrastructure categories that provide for essential and natural human needs and which may be intertwined with local ecosystems, creating a nature-based infrastructure ecosystem that offers food, water, energy, and shelter services. This aligns with, and builds on, the arguments of Whyte et al. (2020) in their development of 'A research agenda on systems approaches to infrastructure'. Their preferred approach is to regard infrastructure as a service, interpreting it in terms of services delivered rather than as physical assets. For example, a water reservoir can simultaneously provide water supply, energy storage, and aquaculture food services. This perspective is imperative 'at a time of systems shocks and climate emergency [where] it is no longer legitimate for engineers to focus solely on the built environment outside of a consideration of the natural environment...[instead we should] see the natural environment as all pervasive, where the built environment is inseparable from it and an adaptation of the natural environment to suit societal needs ... ' (Whyte et al. 2020, 226). Accordingly, in developing an infrastructure ecosystem the aim is to use technologies to enhance the capacity of natural ecosystems so that they can deliver the desired services and absorb waste from economic processes.

Adopting such a radically different approach to infrastructure development raises an important question related to urban densities. The significant land area required for water and food systems would mean that populations should be more dispersed rather than the current trend of urbanisation and centralisation. Countless reports have now cited the United Nation's 'World Urbanization Prospects' (2014), which claimed that the global urbanisation trend, having reached 54 percent of the world's population living in cities in 2014, will inevitably continue so that by 2050, 66 percent will live in cities. Is such a model practical in dense urban environments? Given the suggested benefits of agglomeration economies – the agglomeration of people and businesses in urban centres – why would we attempt to reverse this flow and disperse populations?

Epistemology

This tension between centralisation and decentralisation of populations arises in two fields of research – town planning and economic geography. Yet neither engages with the civil engineering systems (CES) perspective described above. A further research discipline, environmental economics, examines economic systems from the perspective of the laws of thermodynamics, providing a direct connection with CES. The challenge in this paper is to critically analyse and synthesise these different bodies of knowledge, with respect to whether the dispersal of populations into networks of villages with integrated infrastructure ecosystems is preferable to the current trajectory of urbanisation and centralisation.

A significant epistemological problem arises when attempting to integrate knowledge and conclusions drawn from different disciplines. How do we know which is true if different disciplines arrive at different conclusions? Indeed, our problem is that in both town planning and economic geography the dominant orthodoxy is that economic progress and positive development is a consequence of centralisation. How can we argue for decentralisation with any credibility?

American biologist Edward O. Wilson argues for the fundamental unity of all knowledge. That is, that the clearest view of Truth is perceived when different knowledge systems converge towards a common conclusion. Wilson called this 'consilience', literally a 'jumping together' or the 'linking of facts and fact-based theory across disciplines to create a common groundwork of explanation' (Wilson 1998, 8).

We argue for a distributed network of village-scale infrastructure ecosystems as a foundational framework to solve a range of social, environmental, and economic problems and that centralisation, urbanisation and disconnection from nature have been the cause of these problems. In making this case, we argue that what is true when the economic objective is for a few to extract maximum profits is different to what is true when the economic objective is to enhance natural ecosystems so that they provide for everyone's needs and wants at minimum cost. We also acknowledge that the proposed approach is only possible now because of the availability of new internet and renewable energy technologies, so what was held as true in the past may not be true going forward.

Structure

This paper is therefore structured in five parts. Part 1 examines trends in the development of civil infrastructure, which, due to efficiency benefits, point to the arrangement of human settlements as a network of villages or precincts each with nature-based infrastructure ecosystems. In Part 2 we examine two threads in the town planning literature. Firstly, we consider the debates that contrast the organic and the mechanical city, to see how nature-based infrastructure has previously been considered. We then examine the tension between managing growth by increasing the population of existing settlements versus creating new settlements – the new town or garden city model. This reflects the tension between centralisation and decentralisation of populations.

As the case for decentralisation is inconsistent with the trend over recent centuries towards urbanisation, Part 3 will examine the literature in economic geography, which considers this tension through a simplified two region model. The model assumes two urban centres surrounded by agriculture, and analyses population movement by reference to two so-called equilibrium conditions: (1) the two regions remain the same size (representing decentralisation or even distribution of populations), and (2) people agglomerate in one region (representing centralisation). Much of this literature makes the case that agglomeration is inevitable because it is more economically beneficial to manufacturers. We argue that this argument is flawed, that it ignores disadvantages for other segments of society, assumes away environmental degradation and fails to account for the externalisation of transport costs. Most importantly, we show that centralisation is not an equilibrium condition but depends on constant growth. To stabilise environmental degradation and maximise economic efficiency it is necessary to strive for an equilibrium condition. This brings us to Part 4 and the literature in environmental economics that applies the laws of thermodynamics to economic systems and proposes a steady-state economy.

In Part 5 will build on the case for the unity of knowledge, by showing how even literature in the field of public health, where it intersects with land use planning, also points towards a human settlement theory that is based in eco-system theory, where human activity and the built environment are integrated into the natural bioregion. This links human health with environmental health.

Part 1 Creating an infrastructure ecosystem

In this section we examine trends in the development of civil infrastructure – energy, transport, water, and food systems – which, due to the advent of renewable energy micro-grids, can now be physically integrated to create nature-enhancing infrastructure ecosystems.

The energy transition

The transition from fossil fuel energy sources – coal, oil, and gas – to renewable energy harvested from the environment is now generally accepted as inevitable. The low cost, minimal maintenance character of these technologies, together with their relatively small size and scalability, means that renewable energy generation and storage may be installed almost anywhere by anyone. As a result, the mode of energy production is transitioning from a one-directional system, with a few providers, to a two-directional system with many producers, most of whom are also consumers. This shift, from a centralised to a distributed energy system, challenges the logic of markets that have traditionally been understood as places where contracts are made between producers and consumers – separate players with different interests. The term ‘prosumer’, meaning ‘production by consumers’, is increasingly used to express this idea.

Another important difference is that traditional energy systems require inputs of fuel and labour to produce energy, whereas renewable energy has no such inputs. Energy is produced at close to zero marginal cost. After the capital cost is paid to install the system, operating costs tend towards zero, with some maintenance needed to maximise efficiency and minimise depreciation costs.

All these characteristics of renewable energy technologies enable the emergence of a different economic model. Whereas the fossil fuel energy producers seek to maximise their return on capital investment, consumers who install their own energy systems are seeking to minimise living or operating costs. The incentive of the former is to keep electricity prices high, whereas for the latter, the incentive is to keep these as low as possible. Communities responsible for delivering and managing the supply of energy would necessarily seek to minimise the demand, minimise waste and maximise efficiency. An illustrative example is a new housing precinct developed in Cape Paterson, Victoria. Homes in this precinct significantly exceed the minimum energy efficiency rating of 6 stars (NatHERS rating system), all include solar panels for energy generation, and some are now including batteries for storage. In an evaluation carried out by RMIT University (Moore et al. 2020) it was found that on average, homes draw 88percent less electricity from the grid than the average 6 star rated home.

The transport transition

Building on this logic of a community-scale micro grid designed to minimise the energy costs for end users, it would be sensible to design the system to also power a fleet of shared electric vehicles. Sharing vehicles would reduce the overall capital cost for everyone, while using only electric vehicles eliminates the substantial fuel costs. Indeed, as Seba (2014) notes, electric cars have fewer parts and with no internal combustion, the overall maintenance costs are significantly lower.

The creation of a compact built environment with a diverse range of living, work and entertainment activities would mean that walking could reduce the need for vehicular transport altogether. Alternatively, such environments would make less impactful forms of transport such as bicycles and electric golf carts more feasible.

Finally, the widespread acceptance of virtual meetings and working from home, due to the COVID-19 lockdowns, has substantially relocated the workplace from Central Business Districts to anywhere with internet connection. Transport networks may no longer be designed and scaled to cope with morning and evening work commutes, thus allowing us to re-imagine the organisation of cities and opening the possibility of more dispersed cities (Kotkin 2020) or as Barns (2020) suggests:

> *Like the radical suburban experiments of a bygone era, this public health crisis may yet allow for renewed kinds of making and connecting in previously dormant suburbs and neglected peripheral spaces. It may not be a "flight to the suburbs" in a retrograde sense, but a casting off of rigid modes of separation between home and work, industry and nature, as expressed in city forms. Australia's suburbs may yet be well-suited to a coming era of biophilic urbanism, one that embraces "green infrastructure", regenerative agriculture and productive allotments of either low or high-density urban farms.*

The water transition

For at least 30 years, engineers and others in the water management industry have recognised the superiority of natural ecosystems for managing water when compared with dams, pipes, and concrete channels. This approach is generally referred to in the industry as Water Sensitive Urban Design (WSUD), water sensitive cities, or cities as water catchments.

Designing water sensitive cities is about integrating water systems planning with land use planning. Much research has been carried out, many case studies have been show- cased and a raft of tools and products have been developed and incorporated into development controls. WSUD is now considered best practice for stormwater management, at least for new precinct-scale developments.

A leading example is Lochiel Park in Adelaide (Figure 1), completed in December 2015. A project by the state-owned Renewal SA, it has achieved substantial savings in water demand from the grid:

> *Water efficiency measures include rainwater for re-use as hot water and … recycled stormwater for toilets, washing machines and irrigation contribute reaching a target of 78% saving of potable water (against the 2004 average). (Renewal SA website)*

Such significant reductions in demand for potable water serve to illustrate just how wasteful our current single-use water management systems are. This is without integrating the energy system to cycle cleaned water back to an upper reservoir and recycle it through the site again.

Figure 1 Lochiel Park masterplan showing constructed reservoir and wetlands (Source: Renewal SA)

The technology and expertise to design cities in a far more water efficient manner is available. Yet, as the Lochiel Park masterplan in Figure 1 shows, on-site water management requires significant land area for constructed reservoirs and wetlands. This suggests that human settlements should be substantially less dense than current urban environments, or more dispersed in the landscape. That is, more like a distributed network of settlements rather than dense and centralised urban settlements.

The technology and expertise to deliver an alternative nature-based water infrastructure system is available. A substantial reduction in demand for potable water from centralised supplies can potentially be achieved if cities are designed as a network of precincts that each capture, store, clean and recycle their own water. For maximum efficiency, therefore, water infrastructure should transition from large-scale dams, extensive channel and pipe networks, and sewerage infrastructure, towards localised models. It is more difficult to retrofit existing suburbs, but we can, at least, not continue to make the same mistakes with new greenfield precincts. Rural towns will be less difficult to retrofit where they have their own water supply and are surrounded by rural land.

We have already shown that a renewable energy micro-grid can provide electricity for homes and other buildings as well as for a fleet of shared electric vehicles, golf carts and e-bikes. It can also be used to pump and cycle water through a precinct creating a water micro-grid. Water would be harvested, stored in reservoirs, distributed, cleaned in a constructed wetland, and recirculated through a precinct. Moving water can be converted into energy, while stored water can be a store of heat or potential energy.

The integration of energy and water infrastructure increases the complexity of the infrastructure system but also increases the efficiency of both the energy and water systems compared to the development of these separately.

The food transition

By adding a diverse, regenerative food system, including aquaculture in the reservoirs, we could legitimately describe our infrastructure as an ecosystem. The proximity of housing to food systems reduces packaging, as well as transport and supply chain costs and losses. Food waste can be converted into a biofuel for energy or composted to create soil that, in turn, can store and clean water.

Food systems researchers (Bellotti 2017, Parfitt et al, 2010) acknowledge that approximately one-third of food produced is wasted. Food systems are heavily reliant on non- renewable energy sources (Pelletier et al. 2011), with significantly lower energy return on energy invested (EROI = food joules/ fossil fuel joules) in regions with higher fossil fuel use (Bajan et al. 2021). Schramski et al. (2011) summarise some of the more comprehensive studies that examine the energy requirements of the entire food system and while estimates vary widely, the most comprehensive study found that in the United States, 7.4 calories of fossil fuels are required for every calorie of food consumed (EROI = 1/7.4). They conclude that as natural resources continue to be depleted, food systems must find a 'balanced relationship with local environments [to] sustain a large-scale food supply network that may be much less centralised'. A balanced relationship would be one where the EROI is at least equal to one (1).

Liaros (2021a) examines the food system through the lens of the proposed transition from a linear to a circular economy—the principles of a circular economy are (a) design out waste and pollution, (b) keep products and materials in use and (c) regenerate natural systems—and concludes that:

> *This analysis of the food system points to the need for a decentralised network of diverse, polyculture farms, each with integrated energy and water micro-grids, and managed at a local level. Co-locating food producers with food consumers… creates an integrated village system at the food-water-energy-housing nexus. Villages may then be networked to enable collaboration for sharing of rarer skills or the satisfaction of more complex needs and wants, forming a trading network of circular economy villages. It is therefore posited that the transition to a fully circular economy would require a paradigm shift—another agricultural revolution—the transition away from large-scale industrial agriculture to a decentralised network of circular food systems. (Liaros 2021a, p. 1193)*

In reviewing the trends in energy, transport, water, and food infrastructure systems it is evident that these different bodies of knowledge converge towards a common conclusion. So how would this case for a distributed network of circular economy villages be viewed in the town planning literature?

Part 2 Town planning literature and key debates

As a fundamental human need, the systems for producing and distributing food have always been critical in determining the shape and organisation of human settlements. The Agricultural Revolution – somewhat simplistically understood as the transition from nomadic, hunter-gatherer lifestyles, to a more settled lifestyle in more permanent human settlements – enabled the building of the earliest cities. The shape and organisation of human settlements changed again with the industrialisation of agricultural processes in recent centuries, together with technologies and processes for storing and transporting food over long distances, resulting in the creation of megacities, where people are far removed from food production. Whereas historically towns were located where there was access to food and water, today these are taken for granted. Town planning has become urban planning, concerned primarily with issues of congestion, pollution, managing competing private interests, regulating to protect the public interest, and supporting the growth of economic activity.

There are two key debates in the town planning literature that can illustrate how it may be possible to reconnect the planning for food and water systems with the planning of towns. The first relates to the competing visions of the organic and the mechanical city, the second relates to Ebenezer Howard's idea of planning for new garden cities.

The organic versus the mechanical city

As more and more human activities were mechanised, organised, and rationalised, the city began to be conceived as a machine. Le Corbusier's Ville Radieuse (Radiant City), originally proposed in 1930, epitomised this attitude. His response to the congestion and disorder of the urban environment was to raze it to the ground and rebuild it in an ordered, symmetrical, and standardised manner. Tower buildings would serve as vertical villages, allowing for more green space between the buildings. It is fascinating to note that by the time Le Corbusier proposed the Radiant City, physicists had already abandoned a mechanistic view of the world, replacing it with a more relativistic and relational view due to the acceptance of Albert Einstein's theories of special and general relativity.

Lewis Mumford was a principal critic of the mechanical city, arguing that it was hazardous to human wellbeing and that the space between buildings was not used as intended and effectively became a wasteland. Mumford (1961) advocated for a more organic approach to planning, and for buildings to be of human-scale, having a height of no more than one or two storeys. For Mumford the city is more than a collection of buildings; it is a living unity (Mumford 1922, 34) and its inhabitants should 'have a familiarity with their local environment and its resources' (Mumford 1922, 186). John Nolen, who was influenced by Mumford, promoted the development of regional cities that reconciled 'the struggle between men and machines, between natural and artificial tendencies, between biology and technology' (as cited in Stephenson 2018, 285). In his 1927 book New Towns for Old, Nolen argued for regional cities to reflect the topographical and climatic conditions of their locality. Stephenson (2018) identifies Lewis Mumford, John Nolen, and Sottish polymath Patrick Geddes (Mumford's mentor) as the key proponents of the city as a living organism – and critics of the dominant orthodoxy of the city as a machine. Stephenson (2018, 282) argues that the notion of sustainability took root in the work of Nolen and Mumford as their arguments for limiting the growth of cities evolved into the 'limits to growth' generally as it applies to sustainability. We agree with their argument that human settlements should be limited in scale, with 'urban, rural and natural landscapes ... meshed in synergistic fashion' (Stephenson 2018, 284).

Population growth should therefore be managed by building new organic settlements rather than growing the size of any one settlement.

Managing growth by building new settlements

Proposals for building new settlements rather than growing existing settlements arise at the very beginning of modern town planning in England. In 1899, Ebenezer Howard published the original version of the 1902 classic *Garden Cities of To-morrow* and established the Town and Country Planning Association to advocate for the development of Garden Cities. Acknowledging that rural areas were being depleted, Howard (1902) was also concerned with the many issues arising in industrial cities—including poverty, overcrowding, low wages, squalid conditions, general neglect, poorly ventilated and drained houses, and lack of connection with nature.

Figure 2 Ebenezer Howard's illustration arguing for growth through networking of towns

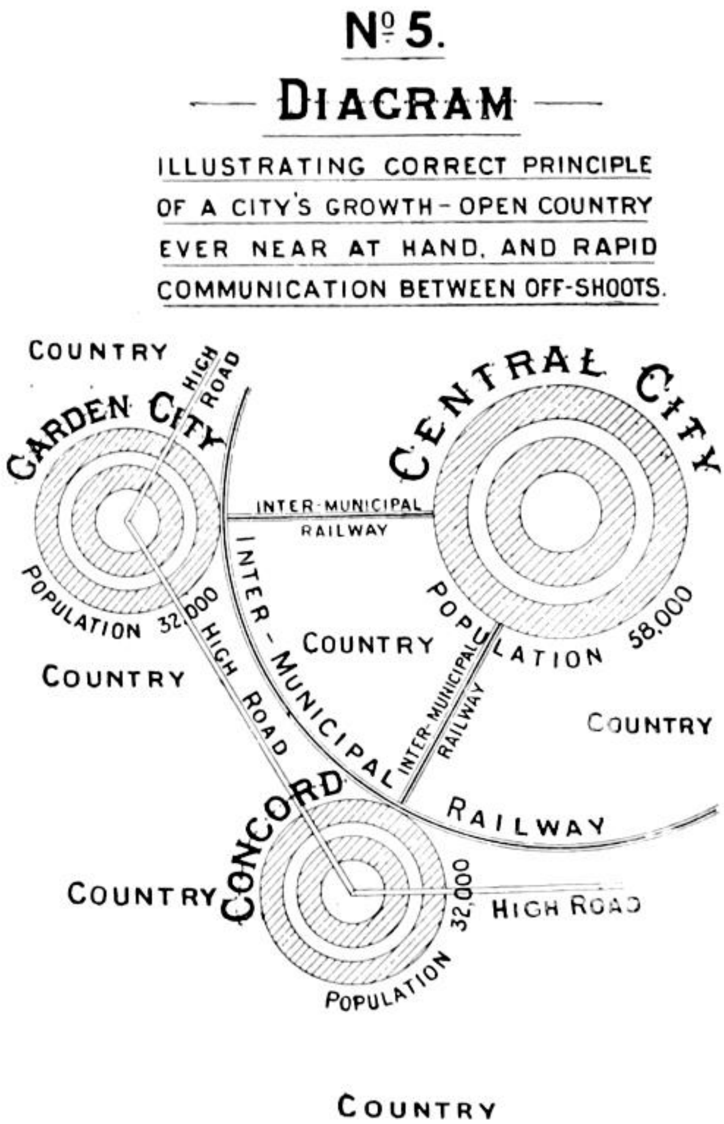


Figure 2 is a diagram by Howard illustrating what he describes as the correct principle of a city's growth—that is, to create a network of settlements rather than growing the central city. He envisaged a network of satellite settlements that he referred to as Garden Cities.

Howard also recognised that people should not be compelled to move out of the cities and sought a way for effectively "redistributing the population in a spontaneous and healthy manner". For Howard, life in the towns (cities) and in the country (rural areas) each possessed certain attractions, but the attractions of town life were, in his time, substantially stronger. To draw people out of the towns and back into the country, the new settlements must possess the best elements of both town life and country life—hence the idea of a 'Garden City' encouraged through 'Town and Country Planning'.

We concur with Howard's approach to growth through the creation of a network of settlements, each designed with the best elements of city and rural life, thus attracting people because of these design offerings. The one drawback is the somewhat mechanical appearance of Howard's Garden Cities, with the 'garden' referring to manicured parklands rather than food forests.

Garden cities of the 21st century should be organic settlements with urban, rural, and natural landscapes synergistically meshed, and designed as a living unity—a holistic integrated infrastructure ecosystem providing energy, water, food, and housing as a service. This infrastructure ecosystem would align with local geographic and climatic conditions and be designed to enhance natural ecosystems. The direct relationship between the land managers and local environment would create a reciprocal relationship whereby land managers would literally enjoy the fruits of their labour.

Part 3 New Economic Geography and the benefits of Agglomeration

While the literature in civil engineering systems and town planning both offer sound arguments for dispersed populations, this is inconsistent with the trend towards increasing urbanisation. Numerous reports and studies begin with the assumption that past trends can be unquestioningly projected into the future, often citing the United Nation's 'World Urbanisation Prospects' (2014). This report claimed that the global urbanisation trend, having reached 54 percent of the world's population living in cities in 2014, will inevitably continue so that by 2050, 66 percent will live in cities. There is an emerging contra view suggesting that the internet, as a decentralised network itself, is creating a more distributed urban form (Giuliano, Kang, and Yuan 2019), with the dispersal accelerated by opportunities remote work and other factors arising from the COVID-19 pandemic (Barns 2020; Kotkin 2020). This is supported by the Australian Bureau of Statistics (ABS 2022), although it's not yet clear whether this will become a long-term trend.

There is a collective acceptance of the narrative that the industrialisation of agriculture – which enables the creation of megacities – increased the efficiency of the food system. Yet the evidence outlined above, in our discussion of the food transition, suggests otherwise when the energy required, and waste created, through long supply chains is properly accounted. Could it be that the agglomeration of industrial production in cities—similarly purported to result in increased efficiency through economies of scale and the 'benefits of agglomeration'—is also a flawed argument?

A New Economic Geography and the two-region model

In October 2008, Paul Krugman was awarded The Sveriges Riksbank Prize in Economic Sciences for demonstrating mathematically why industries and people will naturally agglomerate in larger centres. "Economies of scale combined with reduced transport costs also help to explain why an increasingly larger share of the world population lives in cities" (RSAS, 2008). The apparent advantages of agglomeration, that is, the centralisation of businesses and people in major cities, is generally accepted almost as a natural law by mainstream economists.

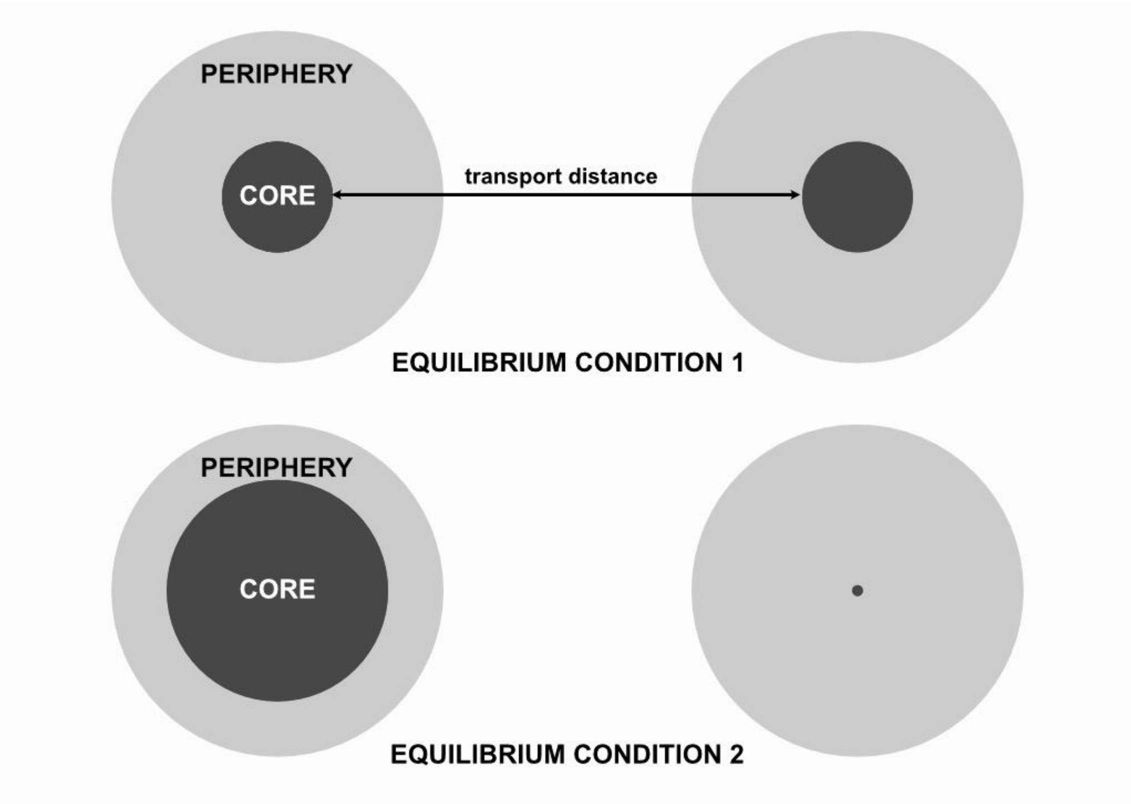
Outside mainstream economics the study of unequal regional development, including within cities, has been the subject of analysis for decades. For example, Agarwal, Giuliano, and Redfearn (2012, 433) argue that although the 'existence and persistence of cities provide prima facie evidence of agglomeration economies', large cities are invariably polycentric in character, composed of a network of sub-metropolitan centres.

Friedmann (1988, 94) notes that regional theory relies to a large extent on the core–periphery model originally formulated in the 1950s by François Perroux, Gunnar Myrdal and Albert O. Hirschman. Krugman (1991) adopts this core–periphery model to compare two regions with similar populations and to explain why industries and economic activities agglomerate in larger cities. In this model each region contains two kinds of production: manufacturing in the core and agriculture in the periphery.

Krugman identifies two equilibrium conditions as shown in Figure 3: (1) populations remain equally distributed, and (2) populations agglomerate in one of the two regions.

According to Krugman, the mathematics demonstrate that if the system tips only slightly away from the initial equilibrium condition where populations are evenly distributed, it will move inexorably to the agglomerating equilibrium. Krugman states that modelling shows that agglomeration, the clustering of manufacturing businesses together, yields *pecuniary* externality benefits for all the businesses in the cluster.

Figure 3 Two-region, core-periphery model & Krugman's two equilibrium conditions



That is, all the businesses benefit financially by being close to other businesses. The two-region model suggests that if the production and costs in the regions are the same, then nothing much happens but if there is a slight difference "population will start to concentrate … once started, this process will feed on itself." (Krugman, 1991, p. 487). Populations and businesses will both be drawn to one of the two cities, because, for businesses, the greater population represents a larger market for goods and a larger pool of workers. For people there are more opportunities for work and a greater availability of manufactured goods.

Flawed assumption related to agriculture

This all sounds very reasonable and is also consistent with the historical reality as described by Ebenezer Howard, of streams of people flowing into cities. Yet the model makes some crucial assumptions that need to be tested. The first is that:

> *Peasants produce agricultural goods… [and the] peasant population is assumed completely immobile between regions, with a given peasant supply … in each region. [this is contrasted with manufacturing workers who] may move between the regions. (Krugman, 1991, p. 488)*

The basis of this assumption is that there will always be some ‘peasant’ farmers producing food to support the manufacturing in the cities. This assumption takes both farmers and agricultural production processes entirely for granted and effectively assumes that farmers will continue to produce food for urban dwellers, irrespective of how little their produce is valued by the broader economic system. This criticism is underlined by a second assumption: that agriculture is a ‘constant returns sector tied to the land, and manufacturers, an increasing-returns sector that can be located in either region’ (Krugman 1991, 487). Constant returns in agriculture assumes no degradation of the land over time, no droughts or bushfires or floods, even when these have been caused by industrial processes, including industrialised agricultural processes.

Food production is a primary input to the manufacturing process as no manufacturing can continue without those involved in the manufacturing process being fed. Agricultural production must therefore be supported and managed in a manner that ensures its continuing economic viability. By focusing on pecuniary interests for manufacturers only, Krugman’s mathematical model simply describes mainstream economic thinking and practice, which prioritises profit over environmental and social impacts. Rather than explaining why people and business agglomerate in cities he is reinforcing the bias that causes that agglomeration.

Distributive inefficiencies due to externalisation of transport costs

Despite this criticism, Krugman’s model has significant value. The starting condition of the model is one in which the two regions are of the same scale. In this condition there is no flow of people from one region to the other and no agglomeration of industries. Krugman develops mathematical formulae to express the relationships between, amongst other things, the number of workers, pricing behaviour, relative wages, relative demand, and transportation costs. He concludes that when transport costs are high the system stays in this balanced equilibrium and the two regions remain the same size, while when trans- port costs are low the system tips out of equilibrium and people flow from one city to the other. Therefore, transportation costs are the principal variable that determines the final equilibrium condition.

In other words, the efficiency of production cannot be divorced from the efficiency of distribution. Falling production costs due to industrialised mass production are counter-balanced by rising distribution costs as the distance between producer and consumer increases. Yet while falling production costs benefit manufacturers, they do not directly pay for the rising distributions costs – increased pollution and waste as well as the costs of road networks, port facilities and other infrastructure needed to transport goods. These are often paid for or subsidised by taxpayers. Therefore, while Krugman's model acknowledges that industries and people agglomerate in cities because of lower transport costs, he does not account for the fact that the benefits are privatised while the costs are externalised. This is a typical Tragedy of the Commons (Hardin 1968) scenario. Hardin recognised that we have created a system in which the benefits of economic growth accrue to businesses, while the costs of that growth accrue to the community in common: 'Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons' (Hardin 1968, 1244).

Centralisation not an equilibrium condition

Krugman (1991, p. 494) then tests "whether a situation in which all workers are concentrated in one region is an equilibrium". Manipulating another set of mathematical formulae, Krugman reaches the following conclusion:

> *With lower transportation costs, a higher manufacturing share, or stronger economies of scale, circular causation sets in, and manufacturing will concentrate in whichever region gets a head start. (Krugman, 1991, p. 497)*

This comment does not answer the question he intended to test. Circular causation and increasing concentration do not necessarily result in equilibrium – equilibrium is a dynamic state of balance. In the two-region model, the depletion of one region will indeed result in the growth of the other but this is only a model. The reality is quite different. The process of agglomeration would not suddenly stop when the adjoining village is depleted. Once commenced, the growth trajectory becomes insatiable, and the major centre would look for other growth opportunities by extracting people and resources from other regions. The continued growth within this major centre would generate increasing demand for goods, requiring constant recalibration of production and distribution systems. This, in turn requires more labour and resources resulting in a spiralling interplay between supply and demand. The agglomeration of populations in one centre is not an equilibrium condition as it is dependent on continued growth and activity, requiring continuing inputs of fossil fuel energy. The equilibrium condition that Krugman is seeking would best be described as one that is that is in thermodynamic, or energy equilibrium with earth systems, a dynamic but stable or steady-state condition.

The requirement for constant growth and ever-increasing economic activity is a central design construct of the present economic system. It results in ever larger cities with an insatiable desire for energy consumption, whether in the form of fossil fuels or human labour. There is no energy equilibrium to be found here, only growth in energy demand. The only equilibrium available in the two-region model is when both regions remain the same size. In this latter condition, each region harvests energy from the sun to power natural systems and economic activity in their locality. By eliminating the need for growth, energy demand is significantly reduced. Potentially energy demand can be reduced to the level of energy supplied by the sun and harvested for use. By matching energy supply to energy demand within the system, a renewable energy micro-grid – harvesting, storing, and distributing energy within the region – can help create a thermodynamically stable economic system.

As with previous sections, this confirms our proposition that a settlement pattern described as a network of similar sized townships is more energy efficient and sustainable over the long term than the prevailing assumption that populations will centralise and cities will continually grow.

Part 4 Ecological Economics and the Steady State Economy

Just as Lewis Mumford criticised the mechanical city and promoted a more organic city, so Nicholas Georgescu-Roegen (1971, 1) argued that mechanistic thinking was no longer a useful way to understand economics. Economies are dynamic systems based on the flow of energy; therefore, the laws of thermodynamics should be foundational to economic thinking. Indeed, as a set of natural laws, thermodynamics offer perhaps the only way (Wilson 1998, 9) to confirm or refute the consilience established in previous sections.

Georgescu-Roegen (1975, 351) notes that the first law of thermodynamics – the law of conservation of energy – is consistent with mechanical thinking. On its own it does not preclude perpetual motion or infinite economic growth. In contrast, the second law – the entropy law – speaks to the availability or unavailability of energy for human use. Available energy, contained for example in fossil fuels, may be converted into work and heat at which point it is no longer available. Georgescu-Roegen acknowledges that entropy is a human construct but for this reason it is of central importance to the design of a human economy.

Economic activity currently involves the extraction of useful fossil fuel energy from the earth's crust, which is then converted into products, plus heat that is dissipated in the earth's atmosphere and is no longer available for human use. The more economic activity, the faster will be the transfer of energy from the earth's crust to the atmosphere. Therefore, rather than maximising economic activity, the aim, as Herman Daly suggests (1973, 19), should be to minimise physical flows of production and consumption. Therefore, the sensible strategy for building a durable political economy is to minimise the energy input needed to achieve the necessary outcomes.

The steady state economy

Herman Daly builds upon this paradigm shift from mechanics to thermodynamics in the development of the concept of a steady state economy. Daly (1973, 5) indicates that the necessity for a paradigm shift arises from the conflict between the biophysical constraints of the planet and the current political economic demand for infinite economic growth and unconstrained use of materials and energy. This argument aligns with the general limits to growth thesis outlined in the modelling of Meadows et al. (1972).

Daly provides a succinct statement of the goal of a steady state economy as one that is able 'to sustain a constant, sufficient stock of real wealth and people for a long time' (Daly 2010, 21). Unfortunately, this raises at least two significant issues: (a) the population problem – how to stop population growth and maintain a constant population; and (b) what population can be sustained by the environment?

Both of these issues are almost impossible to address at the global or national scales of current economic thinking. Ecological limits are dependent on the geographic and climatic conditions of a locality. To apply this approach in a vast continent like

Australia, with its dramatic ecological variations, would be near impossible. One approach might be to divide the continent into its many bioregions and then determine the ecological carrying capacity of each.

The task could be dramatically simplified if the problem was reversed. Rather than asking what is the maximum population that can be sustained in a bioregion, we could ask: how much land is required to sustain a discrete village-scale population, of say, 200 people. As the goal of a steady state economy is to sustain a constant, sufficient stock of real wealth and people for a long time, the goal of our land development process would therefore be to create places that sustain a discrete population in their local environment for a long time. Indeed, we should ask: how do we build an infrastructure ecosystem to enhance the capacity of the land to support a given population. If the building blocks of the political economy are regenerative and designed as systems, then that will be the character of the larger economy, which would be structured as a network of villages.

The land enhancement would, of course, take the form of a renewable energy micro- grid that cycles water through the site, up to a reservoir, through the food system and the buildings and down to a wetland where it is cleaned before being cycled back to the top. As food is grown and waste is composted, the volume and health of soil increases, thus improving biodiversity while storing and slowing the flow of water. Over time, the stock of real wealth – natural capital – is increasing, while the population remains constant, ensuring that there is an abundance of food, water, energy, and shelter for that population.

It cannot be emphasised enough that further development involves replicating rather than growing the size of the village. Historically, as villages grew into towns and eventually to megacities the population exceeded the capacity of the land and supporting infrastructure. A land development strategy that replicates similar sized villages creates a distributed network of complementary city-states. Building many villages with discrete populations also ensures that the population problem is addressed and managed at each place in accordance with local conditions.

Part 5 The Unity of Knowledge, Public Health and Governance

In the previous sections we have shown how knowledge in one discipline can help resolve debates in other disciplines, increasing our certainty as more disciplines arrive at the same conclusion. To further increase certainty, we introduce the literature in the public health sphere that examines the impacts of land use planning on health and well-being. A literature review by Kent et al (2011) identified three key areas in which the built environment can support human health: (a) getting people active, (b) connecting and strengthening communities, and (c) providing healthy food options. The proposed walkable village environment with many accessible, shared facilities as well as a regenerative farm, would encourage both exercise and community collaboration in the production, processing and distribution of fresh food and other necessities.

In his exploration of future research directions at the intersection of health and spatial planning Barton (2009, S121) notes that:

> *current research is hampered by the inadequacy of human settlement theory. Each discipline provides its own perspective but they are not integrated. [The] next 40 years will see the development of an integrated theory of settlement function, form and evolution. It will be based in eco-system theory, linking human activity and well-being with development processes, the structure of the built environment and the natural bioregion.*

We believe that the human settlement theory provided here and in previous publications (Liaros 2019, 2021a, 2021b, 2021c) establishes an integrated approach that strives to improve not just human health, but also ecosystem health, social connection, and economic efficiency.

An important aspect of such a new system relates to governance and ongoing management. While space prohibits a detailed discussion here, readers are referred to Liaros (2021c, chapter 8) that explores how the principles of community governance of the commons developed by Elinor Ostrom may be applied to the management of the proposed local infrastructure ecosystems.

Conclusion

This paper described a conceptual model for planning, design, and development of the human habitat, which we describe as a network of circular economy villages. To create such a system, it is necessary to perceive a village, town, or precinct as a discrete, efficient, but open thermodynamic system that circulates energy and resources within, while minimising energy and resource losses. That is to say, the infrastructure, landscaping and built environment would be holistically designed to harvest as much natural energy as possible and minimise energy losses. Efficiency (energy output / energy input) is maximised by facilitating the natural, dynamic flow of energy within the village precinct, minimising entropy, while eliminating the need for fossil fuel inputs.

The evolution of various technologies that now enable the development of affordable, renewable energy micro-grids, is critical in the evolution of this development model. A renewable energy micro-grid can power a fleet of shared electric vehicles, while also circulating water within the precinct. Abundant water ensures a greater food productivity. The built environment, also part of the infrastructure ecosystem, should be passively designed to minimise energy demand.

Further potential integrations will inevitably emerge as nature-based infrastructure ecosystems are developed under different geographic and climatic conditions creating a diverse network of complex, adaptable and resilient systems.

This paper then showed that while the case for a dispersed network of villages, is sound from the perspective of civil engineering systems, it runs counter to accepted, pre- vailing logic in town planning and economic geography, which argue for centralisation of populations. We then showed that, in fact, there is a long-held view in the town planning literature for building new settlements as an alternative to growing the scale of existing settlements, and for creating a network of settlements rather than an amorphous agglomeration of people in one settlement. There is also a strong case in this literature for human settlements to be less mechanical or clinical, and more organic in character, integrated with food systems and natural landscapes.

Reviewing the literature in regional economics and ecological economics, the case for a distributed network of thermodynamically stable settlements strengthens significantly. As all these disciplines converge on the same conclusion, we can be certain that substantial environmental, social, economic and health benefits that can be derived if human settlement patterns are arranged into networks of villages supported by nature-enhancing infrastructure ecosystems.

Together with the adoption of this new vision for human settlements, it is necessary to develop an action plan for bringing the vision into reality. Key elements of this plan have been proposed, including design guidelines for Circular Economy Villages (Liaros 2021b) and a strategic planning process enabling the assessment and approval of such village developments by local authorities (Liaros 2019). While more research may be useful, perhaps the next steps should involve developing practical methods of financing and building pilot projects to test the concept on the ground.

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