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Perspective

Metabolic Aspects of Rural Life and Settlement Coexistence in China

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Abstract: Among realms of settlement coexistences, *desakota* areas or *Township-Village-Enterprises* in China stand out as relatively conservative of material and other resources, including embodied energy. Chencun Village in the Shunde District of Guangdong Province is an agriculturally productive example of such a settlement covering some 131 hectares in area and hosting some 6,000 inhabitants, including villagers and migrant so-called "floating" households. Formerly a center of sericulture, the village now produces flowers and plants, alongside some factory operations making needed hardware in support of agriculture. From a metabolic perspective consisting of what Chencun is made of in material flows of stocks, including material extracted from the Geosphere, Biosphere, and Hydrosphere resulting in building materials, buildings, and land-uses, alongside of collected waste and recycling, the village's environmental performance is comparatively better than many other forms of settlement coexistence. Measured by stock-flow models represented by Sankey Diagrams, Chencun registers slightly lower than an average of 4.0 MJ/Kg/Yr. or about 106 metric tons of building material per year, below that of more compact and even peripheral modes of settlement. Water use, though very present due to agricultural production takes place in a non-water-stressed part of China and benefits from graywater recycling. Energy use is likewise relatively restrained due to the small amount of transportation and the largely compact and stay-at-home pattern of desakota life. Further, such desakota forms of settlement should be preserved as more environmentally suitable than denser and more profligate forms of settlement in emerging Metropolitan Regions of China like the Greater Bay Area.

Keywords: Metabolism, rural life, desakota areas, stock flows, Sankey diagrams, environmental performance

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1. Introduction

Since the onset of the Anthropocene era, global urbanization has placed increasing pressure on natural resources and ecosystems (Doussard et al., 2024; Gao & O'Neill, 2020; Zhong et al., 2023). Within this framework, the concept of urban-rural metabolism assumes a crucial role in deepening our comprehension of the intricate and dynamic relationships among various elements of human settlements and the environment. Urban-rural metabolism, as an interdisciplinary notion, facilitates an examination of how resources within settlements are utilized and waste is generated, alongside the accompanying societal, economic, and environmental challenges. Moreover, it endeavors to delineate how settlements utilize, transform, and discharge flows of materials, energy, and water (Baccini & Bruner, 2012). The concept of settlement metabolism was initially proposed by Abel Wolman as far back as 1965, and since then, there has been a growing inclination towards viewing urban metabolisms as interconnected and cyclical processes, prioritizing resource efficiency over linear models (Lucertini & Musco, 2020; Wang, 2022). This article aims to analyze Chencun Village in the Shunde District of Guangdong, China, as a representative case study of a desakota area. The objective is to present findings regarding water, energy, and material flows, while also providing a comprehensive overview of the case study area's spatial and demographic characteristics, its position within cities, and the physical attributes of the settlement, including building types, land use patterns, infrastructure, and open spaces.

By 2006 and 2007 or thereabouts the world's population of about 6.7 billion people crossed a threshold of 50 percent urban to 50 percent rural inhabitants by locale, rising to around 56 percent urban in 2023. During this transition, the urban population of China rose from a paltry 13 percent in 1950 to slightly above 56 percent. By 2050 these proportions seem likely to change globally to around 68 percent urban and 32 percent rural (Ritchie, et al., 2024). Presently there are at least four kinds of settlement coexistence. They are "compact central city areas", "dispersed city and peripheral areas" sometimes referred to as being suburban, "organic and informal settlements", and "desakota" areas, particularly in east and southeast Asia. More specifically in the Chinese context desakota settlements or "township-village enterprises" form a significant part of otherwise rural areas. Although becoming more generally urban, as already noted, the number of rural townships remains slightly above 10.000 in number in 2020, though down lower than some 25,000 in 1979. Indeed, this divergence of smaller towns to more normal urban city pathways has been relatively late in coming to China, dating from as recently as 2000 (Kan & Chen, 2021).

The term "*desakota*" is from the Indonesian "*desa*" meaning village and "*kota*" meaning town and was coined by Terry McGee in the 1990s (McGee, 1991). Also, roughly synonymous with "Township-Village Enterprises" in the Chinese context, they have typically happened in Asia and were located at least initially outside peri-urban zones away from convenient daily commuting and often adjacent to arterial roads. Generally, they were and are characterized by relatively high population densities and adjacent intense agricultural development. They differ from rural areas per se because of their more urban living conditions. In China, they occurred primarily during the Reform Period of the 1980s and mostly in coastal areas such as Guangdong Province and they included enterprises usually sponsored by townships and villages. They also often accommodated substantial numbers of migrant workers and so-called "floating populations". This usually comprised a rentier situation where villagers gained rental income from migrants working nearby in factories or within onsite village enterprises. Over time many of these settlements have become almost literally absorbed into burgeoning urban development, such as in Guangzhou and Shenzhen (Rowe, et al., 2022).

2. Materials and Methods

2.1. Context

An example of such a settlement coexistence and an urban-rural lifestyle can be found in Chencun Village in the Shunde District of Foshan in Guangdong Province as illustrated in Figure 1. Referred to as *Shuntak* in Cantonese, this district is a county-level city with an urban area of 806 square kilometers and a population of 2.5 million inhabitants. Renowned for various forms of agriculture from the late Ming through the Qing dynasties, it was a center of sericulture and silk production. In fact, the current Chencun Village remains agriculturally productive with a footprint covering much of 60 percent of the overall site with fresh flowers and trees, as depicted in Figure 2. Indeed, the proportional value of agricultural production in China, judging from 2016 data is the highest rate in the world depicted in Figure 3 (Adapted from Ritchie & Rosado, 2023). Also, as shown in Figure 4, the village, covering an area of 131 hectares, takes on a dispersed but contiguous overall planar form, mainly of residences often associated with district level roadways. Adjacent spaces are given over to plant and tree growing, with a large flower market located on Weixin Lou, a major arterial road cutting through the village from east to west. The population of the village is comprised of some 5,000 residents and a "floating population" of another 1,000 or so inhabitants, all across 1,781 residential units. Mostly these inhabitants are housed in three-and four-story dwellings, as depicted in Figure 5, with ground floors occupied by garages or commercial enterprises, particularly along major streets. Generally, the resident community is well off economically and also incorporates some small factory operations making needed hardware, alongside a primary school.

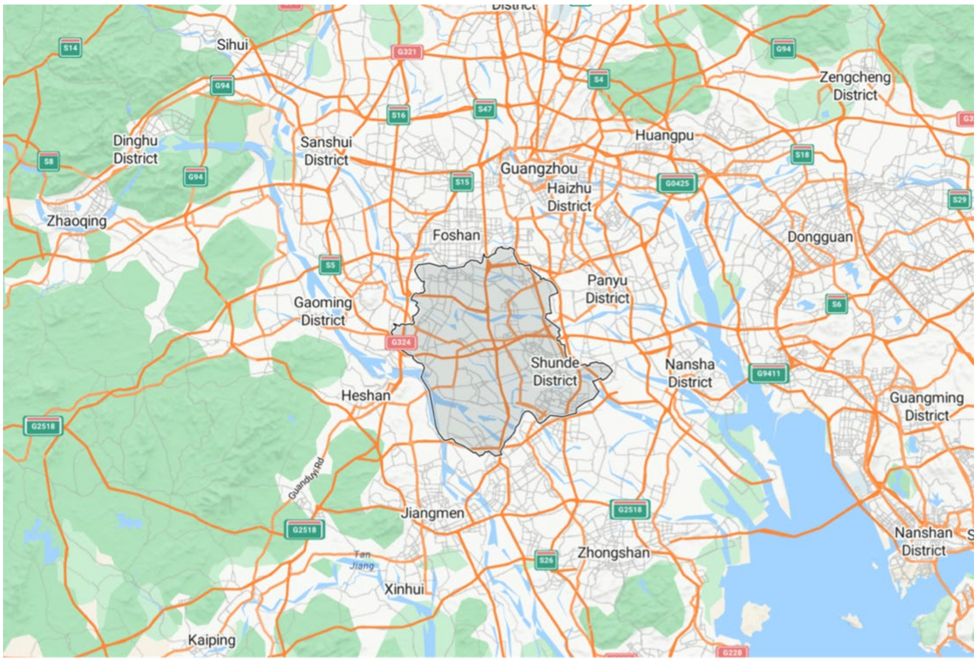

Figure 1. The Shunde District in the Context of Guangzhou and Guangdong Province, China.

Figure 2. Agricultural Production in Chencun Village, China.

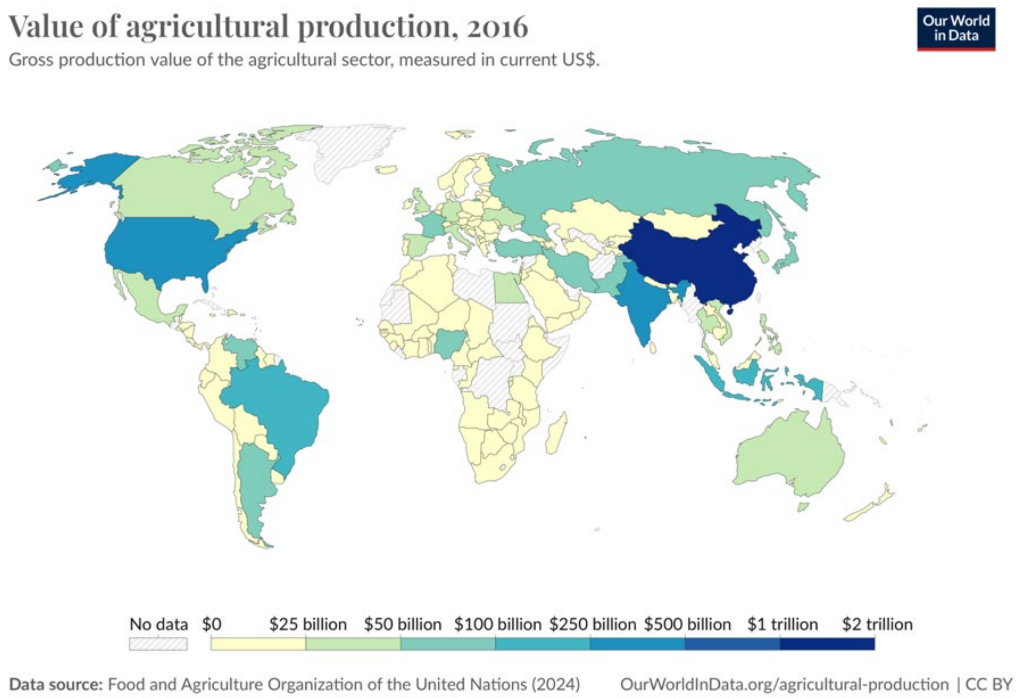

Figure 3. Worldwide Average of Agricultural Production, 2016. Adapted from "Agricultural Production" by Ritchie H. & Rosado P., 2023, Our World in Data. Data originally sourced from the Food and Agriculture Organization of the United Nations (FAO).

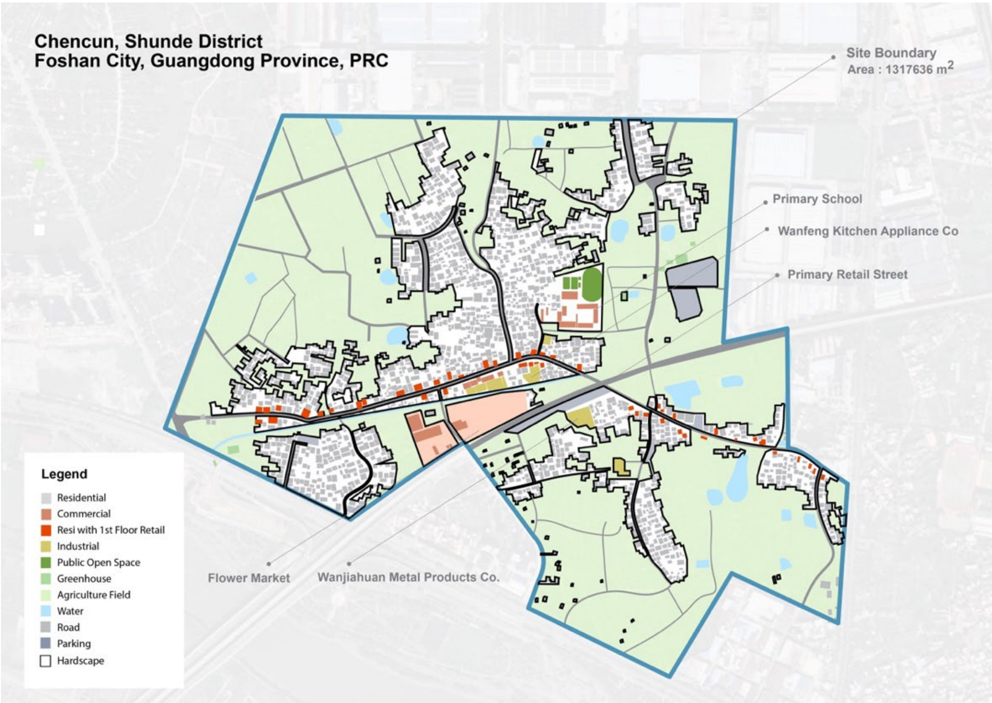

Figure 4. The Layout of Chencun Village, China.

Figure 5. Residential Buildings in Chencun Village, China.

2.2. Model Framing

With the apparent onset of the Anthropocene Era, concern for the metabolism of various kinds of settlement has risen appreciably. This metabolic aspect is manifest in the material from which the settlement is made and how these materials are refurbished and eventually disposed of and recycled, as well as stock flows of water and energy involved. In keeping with much earlier metabolic depictions of life dating back to the 16th century and earlier, research resulting in both conservation of mass and energy principles by the 18th century, more current accounts were mooted in 1965 by Abel Wolman (Wolman, 1965). Then links between the material character of the natural world and domains like the "Geosphere", "Biosphere" and "Hydrosphere" could be forged with activities of the "Technosphere", together with the residuals of spatial settlement production in the form of waste management and recycling potential. This could also be accomplished in a manner that directly reflected temporal variations on processes like deterioration and obsolescence (Baccini & Bruner, 2012). At root metabolism was bound up with the depiction, modeling, and analysis of flows of materials, water, and energy associated with human settlement. In addition, these flows could be conveniently represented through Sankey Diagrams, named after the pioneering work of Captain Sankey in 1898 in explaining the operation of the steam engine (Schmidt, 2008). Read from left to right, the flows of stocks emerge from natural domains and are manufactured into building materials and then deployed within settlement development and finally discarded and/or recycled. The proprietary software SankeyMATIC allows for relatively easy plotting of Sankey diagrams, though with the drawback of not representing circularity easily that needed to be overcome through obsolescence equations.

2.3. Data Sources and Interface

Data for the modeling exercises in this article covered at least seven broad categories. They were spatial and population data, construction data, transportation data, information regarding specific stocks of material, data about waste management and recycling, as well as about water and energy use. The types of sources involved were primarily governmental agencies though proprietary sources for particular kinds of materials are also available and relatively reliable. Overall, there were three kinds of data. The first used direct field observation and measurement. This usually concerned information about site uses, some population characteristics, and areas of coverage, Second, there was data specific to a particular locale and within the purview of that locale. For China use was made of available "open data" as well as standardized data sets for built-up areas of the county (Liu et al., 2015; Jiang et al., 2021). Third, there was data relying on proxies drawn from wider surrounding areas such as the city-wide scale. Rarely, if ever, data sources went beyond these levels of spatial resolution. Rough proportions among each of these three categories were around five to ten percent from direct observation, some twenty-five percent from local sources, and the remainder involving broader proxies. All data, however, was clearly classified as to source, documented, and replicable.

Within each of the three types of stock-flow model depicted in this article, special interfaces have been developed, particularly for facilitation of data input using Excel (v.16.77), each employing a comparable framework and accounting method influenced by material flow analysis (MFA). To create a model of the metabolism of the avenue, mass conservation principle was used where the mass of inputs in a process equals the mass of outputs, plus a storage term (Doussard et al., 2024). m represents mass, along with equivalent units for energy and water, while time derivatives are indicated by dots. p and q denote the summation over input and output terms, respectively.

$$\sum_p \dot{m}_{input} = \sum_q \dot{m}_{output} + \dot{m}_{storage}$$

In the water model, for instance, these include information about the site and occupying population, residential, commercial, and public, as well as industrial and agricultural activities, along with green spaces. For the energy model interfaces apply again to site information and population characteristics, commercial, industrial, agricultural, and transport characteristics. For the material models, categories include site and population, construction of buildings and infrastructure, green spaces, production from agriculture and industry, activities and goods consumption, transport characteristics like various fleets, and waste, including recycling, composting, mining, and waste disposal as depicted in figure 6.

Data	Input
Population	
Number of residents	
Number of households	
Construction	
Buildings	
Floor area collective housing haussmanian buildings and equivalent (m2)	
Building footprint housing haussmanian buildings and equivalent (m2)	
Number of collective housing haussmanian buildings and equivalent	
Floor area collective housing post-1920 buildings (m2)	
Floor area commercial and public haussmanian buildings and equivalent (m2)	
Building footprint commercial and public haussmanian buildings and equivalent (m2)	
Number of commercial and public haussmanian buildings and equivalent	
Floor area commercial and public post-1920 buildings (m2)	
Floor area industrial post-1920 building (m2)	
Floor area agriculture pre-1920 building (m2)	
Building footprint agriculture pre-1920 building (m2)	
Number of agriculture pre 1920 buildings	
Floor area agriculture post-1920 building (m2)	
Life cycle collective housing haussmanian buildings and equivalent (y)	
Life cycle collective housing post-1920 buildings (y)	
Life cycle commercial haussmanian buildings and equivalent (y)	
Life cycle commercial and public post-1920 buildings (y)	
Life cycle industrial post-1920 building (y)	
Life cycle agriculture pre-1920 building (y)	
Life cycle agriculture post-1920 building (y)	
Infrastructure	
Asphalt roads (m2)	
Parking lots (m2)	
Railways rails length (m)	
Life cycle asphalt roads (y)	
Life cycle parking lots (y)	
Life cycle railways rails (y)	
Green Spaces	
Leisure land area herbaceous strata (m2)	
Leisure land area shrub strata (m2)	
Leisure number of trees	
Life cycle trees (y)	
Life cycle shrub strata (y)	
Life cycle herbaceous strata (y)	
Production	
Agriculture	
Production land area herbaceous strata (m2)	
Production land area shrub strata (m2)	
Production number of trees	
Number of bovines	
Number of pigs, sheeps and equivalent	
Number of chicken and equivalent	
Organic waste (%)	
Industrial	
Produced plant (t/y)	
Produced animal (t/y)	
Produced aluminum (t/y)	
Produced iron (t/y)	
Produced steel (t/y)	
Produced wood (t/y)	
Produced paper (t/y)	
Produced plastic (t/y)	
Produced glass (t/y)	
Produced ruber (t/y)	

Activities and Goods	
Food and Drinks	
Average consumption of plant based food per capita (kg/y)	
Average consumption of animal based food per capita (kg/y)	
Average consumption of water per capita (kg/y)	
Organic food waste (%)	
Packages	
Average consumption of plastic in packages per capita (kg/y)	
Average consumption of paper in packages per capita (kg/y)	
Average consumption of glass in packages per capita (kg/y)	
Furniture and Furnishing	
Average weight of plastic in furniture per capita (kg)	
Average weight of wood in furniture per capita (kg)	
Life cycle furniture and furnishing (y)	
Consumer and Institutional Products	
Average weight of plastic in consumer and institutional products per capita (kg)	
Average weight of paper in consumer and institutional products per capita (kg)	
Average weight of glass in consumer and institutional products per capita (kg)	
Life cycle plastic consumer and institutional products (y)	
Life cycle paper consumer and institutional products (y)	
Life cycle glass consumer and institutional products (y)	
Clothing	
Average weight of plant products in clothing per capita (kg)	
Average weight of animal products in clothing per capita (kg)	
Average weight of plastic in clothing per capita (kg)	
Average weight of other products in clothing per capita (kg)	
Life cycle of clothing (y)	
Appliances	
Average consumption of steel in major appliances per household (kg)	
Average consumption of plastic in major appliances per household (kg)	
Average consumption of aluminum in major appliances per household (kg)	
Life cycle of appliances (y)	
Transport	
Private Cars Fleet	
Number of cars	
Average weight of steel used per car (kg)	
Average weight of plastic used per car (kg)	
Average weight of aluminum used per car (kg)	
Average weight of rubber used per car (kg)	
Life cycle cars (y)	
Bus Fleet	
Number of buses	
Average weight of steel used per bus (t)	
Average weight of plastic used per bus (t)	
Average weight of aluminum used per bus (t)	
Average weight of rubber used per bus (t)	
Life cycle buses (y)	
Metro Fleet	
Number of metros	
Average weight of steel used per metro (t)	
Average weight of plastic used per metro (t)	
Average weight of aluminum used per metro (t)	
Average weight of rubber used per metro (t)	
Life cycle metros (y)	
Tram Fleet	
Number of trams	
Average weight of steel used per tram (t)	
Average weight of plastic used per tram (t)	
Average weight of aluminum used per tram (t)	
Average weight of rubber used per tram (t)	
Life cycle trams (y)	
Transition	
% of maintenance residential	
% of repurposed residential	
% of demolished residential	
% of maintenance commercial and public	
% of repurposed commercial and public	
% of demolished commercial and public	
% of maintenance industrial	
% of repurposed industrial	
% of demolished industrial	
% of maintenance agricultural	
% of repurposed agricultural	
% of demolished agricultural	
% of maintenance infrastructure	
% of demolished infrastructure	
% of waste produced in repurposed compared to stock	
Maintenance condition residential (H=1 ; M=0,9 ; L=0,8)	
Maintenance condition commercial and public (H=1 ; M=0,9 ; L=0,8)	
Maintenance condition industrial (H=1 ; M=0,9 ; L=0,8)	
Maintenance condition agriculture (H=1 ; M=0,9 ; L=0,8)	
Maintenance condition infrastructure (H=1 ; M=0,9 ; L=0,8)	

Waste	
Recycling rates (for mined and not mined)	
% paper	
% plastic	
% aluminum	
% iron	
% steel	
% limestone	
% concrete	
% asphalt	
% wood	
% glass	
% clothing	
% rubber	
Industrial collected waste rates	
% industrial waste from organic material (plant + animal)	
% industrial waste from aluminum	
% industrial waste from iron	
% industrial waste from steel	
% industrial waste from wood	
% industrial waste from paper	
% industrial waste from plastic	
% industrial waste from glass	
% industrial waste from ruber	
Composting rates	
% organic waste food	
% organic waste greenspaces	
% organic waste agriculture	
Incinerated rates after sorting	
% paper	
% plastic	
% aluminum	
% wood	
% clothing	
% rubber	
Landfill rates after sorting	
% paper	
% plastic	
% aluminum	
% steel	
% iron	
% concrete	
% limestone	
% asphalt	
% wood	
% clothing	
% rubber	
Export rates after sorting	
% steel	
% iron	
% concrete	
% limetone	
% asphalt	

Figure 6. Material Model Input Interface.

3. Results and Discussion

The defining characteristics of the water stock-flow model for Chencun in cubic meters per year without recycling improvements is around two million with a distribution by water source of 33 percent from surface sources and 67 percent from stormwater harvesting reflecting the agriculture associated with the desakota community. The distribution of water use also reflects agriculture at fully 70 percent, followed by 20 percent in residential use and 3 percent on commercial and public use. In this particular case, very little or any use was made of gray water recycling. However, as depicted in Figure 7, with gray water recycling water use is improved by about 12 percent with 25.3 percent coming from surface supply and 62.5 percent from stormwater harvesting. Again, the defining characteristics of energy stock flows reflected the Chinese locale, with 75 percent from fossil fuels of which fully 52 percent was from coal with a further 16 percent of total energy from nuclear, and a paltry 2 percent was from other sources, most likely biomass. This could be readily improved from 4.4 percent renewables to 7.4 percent and a diminution of coal use to 50.8 percent as depicted in Figure 8. Again, agriculture was the major user accounting for 57 percent, followed by related industry at 20 percent, residential at 9 percent and commercial and public use at 3 percent.

Finally, 11 percent was ascribed to transportation again reflecting the rather compact and "stay-at-home" nature of desakota settlement. Improvements in water use could be found in higher levels of gray water use, though the relatively low levels of its primary source in residential use is a constraint. Further shifts towards renewable sources of energy should also be encouraged. Finally, the defining characteristics of material stock-flows in metric tons per year are shown in Figure 9 with fully 85 percent drawn from the Geosphere, 11 percent from the Biosphere, and 4 percent from the Hydrosphere. With regard to land use, most at 85 percent was in residential and agricultural industrial use, including considerable amounts of clay in the pot planting of plants and trees, followed by 6 percent or so in commercial use and 4 percent in transportation. Moderate obsolescence rates meant that 85 percent of material flows remained annually as stock, with some 6 percent ending as collected waste. Of this 78 percent was sorted, 19 percent was otherwise recycled, and 2 percent was composted. Moreover, of the sorted waste fully 89 percent was mined and re-used, a frugality not uncommon to desakota forms of settlement (Cossu & Williams, 2015).

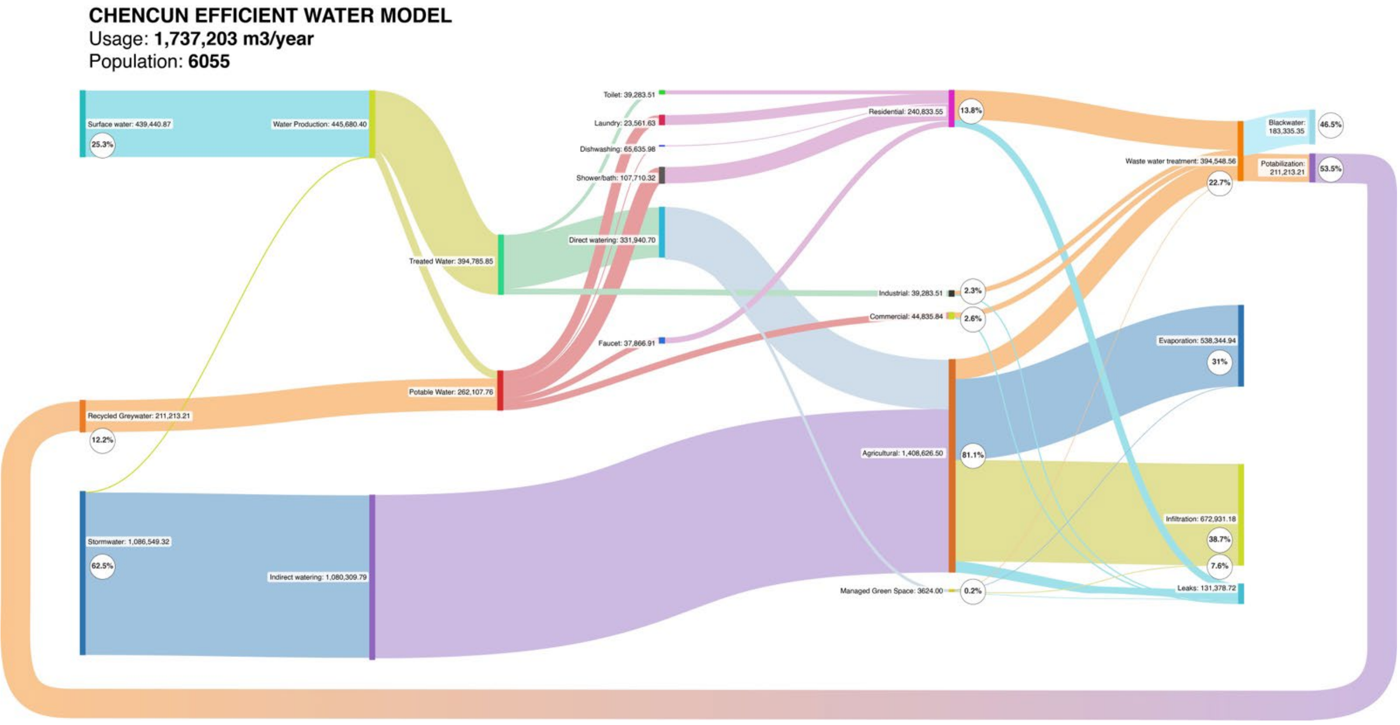

Figure 7. Sankey Diagram of Chencun Efficient Water Model.

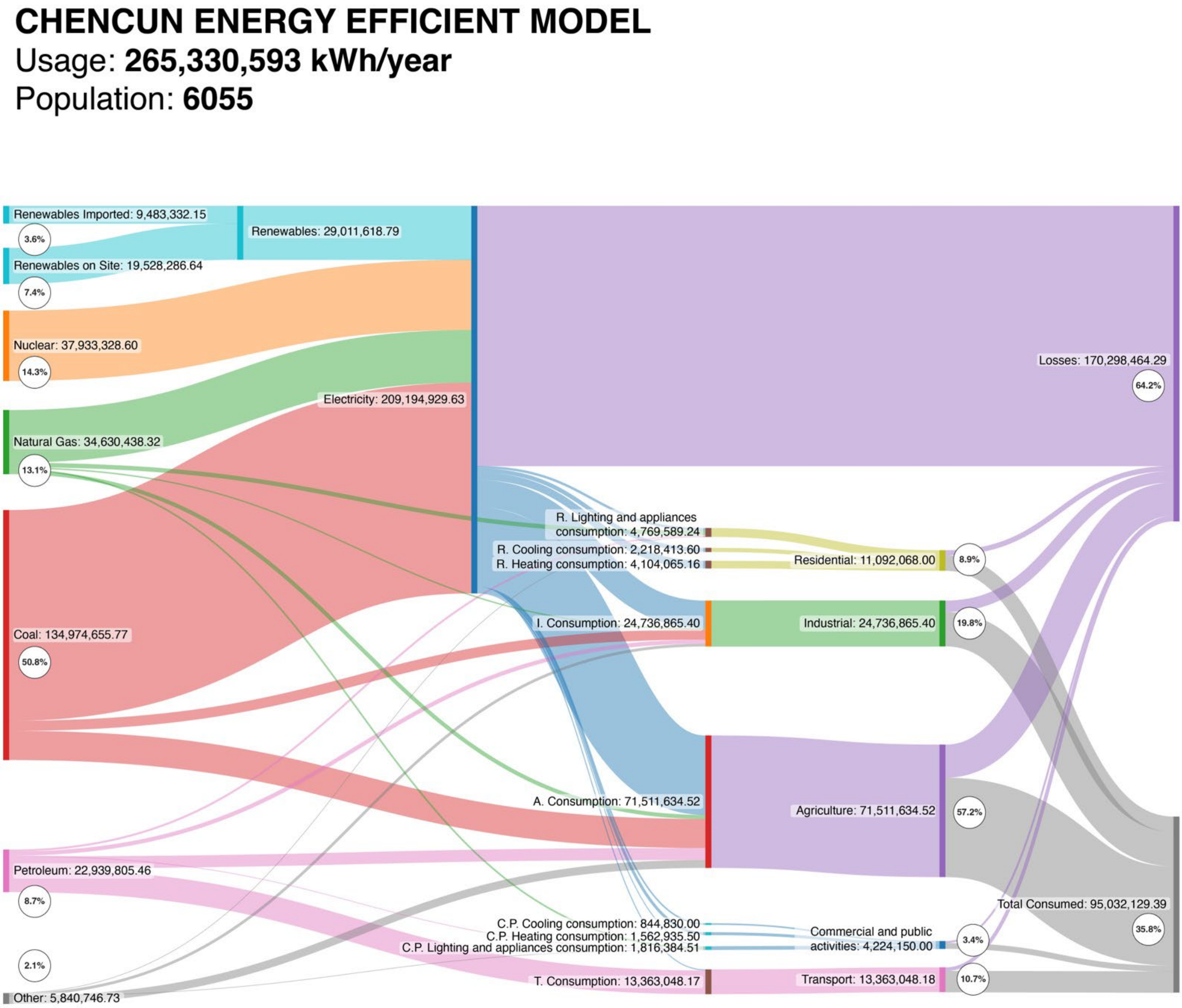

Figure 8. Sankey Diagram of Chencun Efficient Energy Model.

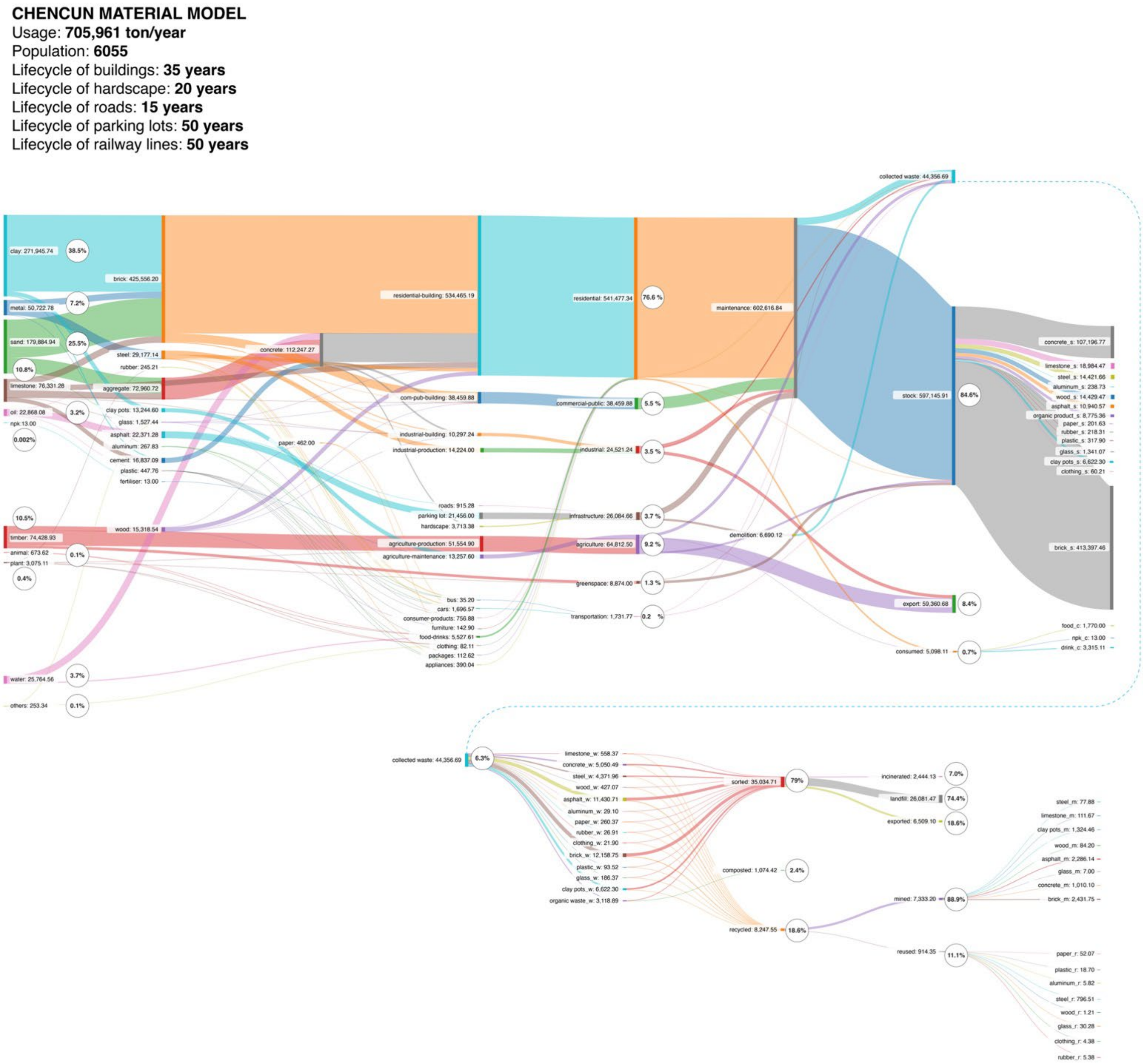

Figure 9. Sankey Diagram of Chencun Materials Model.

Compared to other forms of settlement coexistence, desakota areas perform relatively well metabolically and certainly in comparison to less agriculturally developed territories. Setting aside "informal settlement" and their relatively impoverished circumstances, Chencun's material use is conservative at around 106 metric tons per inhabitant, compared to Paris' compact inner area development at 117 and the US suburban or peripheral developments wasteful 246 tons per inhabitant. Similarly, applying standard multipliers for embodied energy in MJ/kg/yr. and embodied carbon on KgCo2/kg/yr. averages again show Chencun to be on the low side among other forms of settlement coexistence at around 4.0 or slightly less MJ/kg/yr. compared to Parisian compact forms at around 4.1 and the American peripheral development at 5.8 MJ/kg/yr. Clearly differing obsolescence rates come into play as well, with buildings in the compact example at something like 100 years compared to American peripheral development pegged at around 60 or so years, and somewhat less for Chencun at around 35 to 50 years. Roadway infrastructure by contrast is usually relatively stable at around 15 to 20 years, at least in this modeling analysis. To reiterate, all told Chencun and its desakota style of settlement is relatively conservative from a metabolic perspective. To the extent that improvements might be made they seem to lie in water and waste management, as well as more use of energy renewables as noted earlier. Also, the pursuit of circular functions in

Chencun from the present “cradle-to-grave” configuration to something like, for instance, McDonough and Braungant’s “cradle-to-cradle” biometric mimicking could be attempted further and even for the purpose of becoming a safer stopgap to more rampant compact and peripheral forms of development within China’s emerging Metropolitan Urban Regions (McDonough & Braungart, 2002; Rowe et al., 2022).

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