Supplementary Information – Literature table

Document details				Case study details		ES suitability			Investigation themes				Model complexity			
Authors	Year	Title	Citations	Case study location	Metabolic flows	Provisioning services	Regulating services	Cultural services	Temporal detail	Spatial detail	Multi-level	Cross-scale integration	Life cycle thinking	Systems thinking/ system dynamics	Network analysis	Emergy analysis
Pauleit, S.; Duhme, F.	2000	Assessing the environmental performance of land cover types for urban planning	254	50km2 grid cell in Munich, Germany	Energy, water, carbon dioxide	✓	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗
Huang, S. L.; Chen, C. W.	2005	Theory of urban energetics and mechanisms of urban development	91	Taipei area	Emergy (seJ)	✗	✗	✗	✓	✓	✗	✓	✗	✗	✗	✓
Zhang, Y.; Yang, Z.; Yu, X.	2006	Measurement and evaluation of interactions in complex urban ecosystem	60	6 Chinese cities: Beijing, Shanghai, Tianjin, Chongqing, Guangzhou, Shenzhen	Socioeconomic & ecological indices	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗
Forkes, J.	2007	Nitrogen balance for the urban food metabolism of Toronto, Canada	70	Toronto, Canada	Nitrogen	✓	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗
Kennedy, C.; Cuddihy, J.; Engel-Yan, J.	2007	The changing metabolism of cities	491	Brussels, Sydney (2), Tokyo, Hong Kong (2), Toronto (2), Vienna, London, Cape Town	Water, sulphur dioxide, nitrogen oxides, volatile organic compounds, & particulate matter	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
VandeWeghe, J. R.; Kennedy, C.	2007	A Spatial Analysis of Residential Greenhouse Gas Emissions in the Toronto Census Metropolitan Area	100	Toronto, Canada	Carbon dioxide	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗
Lookingbill, T. R.; Kaushal, S. S.; Elmore, A. J.; Gardner, R.; Eshleman, K. N.; Hilderbrand, R. H.; Morgan, R. P.; Boynton, W.	2009	Altered ecological flows blur boundaries in urbanizing watersheds	20	Potomac river watershed, Chesapeake bay USA	Nitrogen & water	✗	✓	✗	✓	✓	✓	✗	✗	✓	✗	✗

R.; Palmer, M. A.; Dennison, W. C.																
Zhang, Y.; Yang, Z.; Fath, B. D.; Li, S.	2010	Ecological network analysis of an urban energy metabolic system: Model development, and a case study of four Chinese cities	73	Beijing	Energy	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
Zhang, Y.; Yang, Z.; Liu, G.; Yu, X.	2011	Emergy analysis of the urban metabolism of Beijing	61	4 Chinese cities: Beijing, Tianjin, Chongqing, Shanghai	Emergy (seJ)	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✓
Chen, S.; Chen, B.	2012	Network environ perspective for urban metabolism and carbon emissions: A case study of Vienna, Austria	132	Vienna, Austria	Carbon dioxide	✗	✓	✗	✗	✗	✗	✓	✓	✗	✓	✗
Li, S.; Zhang, Y.; Yang, Z.; Liu, H.; Zhang, J.	2012	Ecological relationship analysis of the urban metabolic system of Beijing, China	50	Beijing	Energy, materials, mutualism index	✗	✗	✗	✓	✗	✗	✗	✗	✗	✓	✗
Villarroel Walker, R.; Beck, M. B.	2012	Understanding the metabolism of urban-rural ecosystems: A multi-sectoral systems analysis	20	Upper Chattahoochee Watershed, USA	Carbon, nitrogen, phosphorous, & water	✓	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗
Chrysoulakis, N.; Lopes, M.; San José, R.; Grimmond, C. S. B.; Jones, M. B.; Magliulo, V.; Klostermann, J. E. M.; Synnefa, A.; Mitraka, Z.; Castro, E. A.; González, A.; Vogt, R.; Vesala, T.; Spano, D.; Pigeon, G.; Freer-Smith, P.; Staszewski, T.; Hodges, N.; Mills, G.; Cartalis, C.	2013	Sustainable urban metabolism as a link between bio-physical sciences and urban planning: The BRIDGE project	63	5 cities in Europe: Helsinki, Athens, London, Firenze, Giliwice	Energy, water, carbon (especially), & socio-economic indicators	✓	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗
Leduc, W. R. W. A.; Van Kann, F. M. G.	2013	Spatial planning based on urban energy harvesting toward productive urban regions	26	Kerkrade, city in Netherlands	Energy	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
Mörtberg, U.; Haas, J.; Zetterberg, A.; Franklin, J. P.; Jonsson, D.; Deal, B.	2013	Urban ecosystems and sustainable urban development-analysing and assessing interacting systems in the Stockholm region	18	Stockholm county	Biodiversity/ habitat fragmentation	✗	✓	✗	✓	✓	✓	✗	✗	✓	✓	✗

Garcia-Montiel, D. C.; Verdejo-Ortiz, J. C.; Santiago-Bartolomei, R.; Vila-Ruiz, C. P.; Santiago, L.; Melendez-Ackerman, E.	2014	Food sources and accessibility and waste disposal patterns across an urban tropical watershed: Implications for the flow of materials and energy	12	6 residential study plots (Average household) in Puerto Rico	Water, food, waste, energy	✓	✓	✗	✗	✓	✗	✓	✗	✗	✗	✗
Lin, T.; Gibson, V.; Cui, S.; Yu, C. P.; Chen, S.; Ye, Z.; Zhu, Y. G.	2014	Managing urban nutrient biogeochemistry for sustainable urbanization	27	Xiamen, China	Nitrogen & phosphorous	✗	✓	✗	✓	✗	✓	✗	✗	✓	✗	✗
Yang, D.; Kao, W. T. M.; Zhang, G.; Zhang, N.	2014	Evaluating spatiotemporal differences and sustainability of Xiamen urban metabolism using emergy synthesis	29	Xiamen, China	Emergy (seJ) indices	✓	✗	✗	✓	✓	✓	✓	✗	✗	✗	✓
Zhang, L.; Liu, G.; Qin, Y.	2014	Multi-scale integrated assessment of urban energy use and CO2 emissions	3	Beijing, China	Energy & carbon dioxide	✗	✓	✗	✗	✗	✓	✓	✓	✗	✗	✗
Zhang, Y.; Liu, H.; Chen, B.; Zheng, H.; Li, Y.	2014	Analysis of urban metabolic processes based on input-output method: Model development and a case study for Beijing	3	Beijing, China	Consumption intensity	✓	✓	✗	✓	✗	✗	✗	✓	✗	✓	✗
Zhang, Y.; Zheng, H.; Fath, B. D.; Liu, H.; Yang, Z.; Liu, G.; Su, M.	2014	Ecological network analysis of an urban metabolic system based on input-output tables: Model development and case study for Beijing	44	Beijing, China	Ecological hierarchy index	✗	✗	✗	✓	✗	✗	✗	✓	✗	✓	✗
Conke, L. S.; Ferreira, T. L.	2015	Urban metabolism: Measuring the city's contribution to sustainable development	20	Curitiba, Brazil	Materials, energy, water	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗
Cui, S.; Xu, S.; Huang, W.; Bai, X.; Huang, Y.; Li, G.	2015	Changing urban phosphorus metabolism: Evidence from Longyan City, China	4	Longyan city, China	Phosphorous	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✗
Huang, Q.; Zheng, X.; Hu, Y.	2015	Analysis of land-use emergy indicators based on urban metabolism: A case study for Beijing	7	Beijing, China	Emergy (seJ)	✓	✓	✗	✓	✗	✗	✓	✗	✗	✗	✓
Fragkou, M. C.; Vicent, T.; Gabarrell, X.	2016	An ecosystemic approach for assessing the urban water self-sufficiency potential: lessons from the Mediterranean	3	Barcelona, Spain	Water	✓	✗	✗	✓	✓	✓	✓	✗	✗	✗	✗
Lei, K.; Liu, L.; Hu, D.; Lou, I.	2016	Mass, energy, and emergy analysis of the metabolism of Macao	13	Macao, China	Mass, energy, emergy	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓

Lin, T.; Wang, J.; Bai, X.; Zhang, G.; Li, X.; Ge, R.; Ye, H.	2016	Quantifying and managing food-sourced nutrient metabolism in Chinese cities	5	Xiamen, China	Carbo, nitrogen, phosphorous	✓	✓	✗	✓	✗	✗	✗	✗	✓	✗	✗
Lu, Y.; Geng, Y.; Qian, Y.; Han, W.; McDowall, W.; Bleischwitz, R.	2016	Changes of human time and land use pattern in one mega city's urban metabolism: a multi-scale integrated analysis of Shanghai	14	Shanghai, China	Human time & Land Use	✗	✗	✗	✓	✓	✗	✓	✗	✗	✗	✗
Metzger, A. E.; McHale, M. R.; Hess, G. R.; Steelman, T. A.	2016	Same time, same place: analyzing temporal and spatial trends in urban metabolism using proximate counties in the North Carolina Triangle	1	3 cities in North Carolina, USA: Durham, Orange, and Wake counties	Water, food, energy, wastes	✓	✓	✗	✓	✗	✓	✗	✗	✗	✗	✗
Sun, L.; Dong, H.; Geng, Y.; Li, Z.; Liu, Z.; Fujita, T.; Ohnishi, S.; Fujii, M.	2016	Uncovering driving forces on urban metabolism - A case of Shenyang	28	Shenyang, China	Emergy (seJ)	✗	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓
Zhang, Y.; Lu, H.; Fath, B. D.; Zheng, H.	2016	Modelling urban nitrogen metabolic processes based on ecological network analysis: A case of study in Beijing, China	10	Beijing, China	Nitrogen	✓	✓	✗	✓	✗	✗	✗	✗	✗	✓	✗
Dal Bo Zanon, B.; Roeffen, B.; Czapiewska, K. M.; de Graaf-Van Dinther, R. E.; Mooij, P. R.	2017	Potential of floating production for delta and coastal cities	3	2 floating production units (Rotterdam, Netherlands, & Metro Manila, Philippines)	Nitrogen & phosphorous	✓	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗
Firmansyah, I.; Spiller, M.; de Ruijter, F. J.; Carsjens, G. J.; Zeeman, G.	2017	Assessment of nitrogen and phosphorus flows in agricultural and urban systems in a small island under limited data availability	7	St. Eustatius, Caribbean	Nitrogen & phosphorous	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗
Liu, W.; Chang, A. C.; Chen, W.; Zhou, W.; Feng, Q.	2017	A framework for the urban eco-metabolism model - Linking metabolic processes to spatial patterns	3	Wangchunyuan community, Beijing	Water	✓	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗
Wang, X.; Wu, S.; Li, S.	2017	Urban metabolism of three cities in Jing-Jin-Ji urban agglomeration, China: Using the MuSIASEM approach	3	3 Chinese cities: Beijing, Tianjin, Tangshan in the Jing-Jin-Ji urban agglomeration	Energy & labour	✗	✗	✗	✓	✗	✓	✓	✗	✗	✗	✗

Han, W.; Geng, Y.; Lu, Y.; Wilson, J.; Sun, L.; Satoshi, O.; Geldron, A.; Qian, Y.	2018	Urban metabolism of megacities: A comparative analysis of Shanghai, Tokyo, London and Paris to inform low carbon and sustainable development pathways	1	Shanghai, Tokyo, London, Paris	Energy, economic labour productivity, human activity	✗	✗	✗	✓	✗	✗	✓	✗	✗	✗	✗
Tan, L. M.; Arbabi, H.; Li, Q.; Sheng, Y.; Densley Tingley, D.; Mayfield, M.; Coca, D.	2018	Ecological network analysis on intra-city metabolism of functional urban areas in England and Wales	1	35 FUAs in England and Wales	Relationship indicators	✗	✗	✗	✓	✓	✗	✗	✗	✗	✓	✗
Thomson, G.; Newman, P.	2018	Urban fabrics and urban metabolism – from sustainable to regenerative cities	4	Perth, WA, Australia	Food, fuel, energy	✗	✓	✗	✗	✓	✗	✗	✗	✗	✗	✗
Viglia, S.; Civitillo, D. F.; Cacciapuoti, G.; Ulgiati, S.	2018	Indicators of environmental loading and sustainability of urban systems. An emergy-based environmental footprint	8	Roma, Napoli, Ischia, Massa Lubrense, Vico Equense, in Italy (5 cases)	Emergy (seJ)	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✓
Wen, Z.; Bai, W.; Zhang, W.; Chen, C.; Fei, F.; Chen, B.; Huang, Y.	2018	Environmental impact analysis of nitrogen cross-media metabolism: A case study of municipal solid waste treatment system in China	1	Municipal waste treatments aggregated across China	Ammonia, ammonium, & nitrogen oxides	✗	✓	✗	✗	✗	✗	✗	✓	✗	✗	✗
Wu, Y.; Que, W.; Liu, Y. G.; Li, J.; Cao, L.; Liu, S. B.; Zeng, G. M.; Zhang, J.	2018	Efficiency estimation of urban metabolism via Emergy, DEA of time-series	1	Changsha city, China	Emergy (seJ)	✗	✗	✗	✓	✗	✗	✓	✗	✗	✗	✗
Zhang, Y.; Lu, W.; Wing-Yan Tam, V.; Feng, Y.	2018	From urban metabolism to industrial ecosystem metabolism: A study of construction in Shanghai from 2004 to 2014	0	Shanghai (construction sector only)	Materials, energy, water, labour	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✗

Supplementary Information – Scoping review

Document details Citation	Citations[1]	Article type	Adaptation for UES assessment	Investigation themes			
				Temporal detail	Spatial detail	Multi-level	Cross-scale integration
Pincetl, Stephanie; Bunje, Paul; Holmes, Tisha Kennedy, Pincetl, and Bunje (2011)	102	PE	✓		✓		✓
Zhang (2013)	97	Re	✓	✓	✓		✓
Golubiewski (2012)	46	Re	✓	✓	✓	✓	✓
Stephanie Pincetl (2012)	42	Ar	✓	✓			✓
Zhang, Yang, and Yu (2015)	18	Re	✓	✓	✓	✓	✓
van Broekhoven and Vernay (2018)	1	Re	✓		✓	✓	
Kennedy et al. (2011)	290	Re		✓			✓
Beloin-Saint-Pierre et al. (2017)	9	Re		✓	✓	✓	✓
Céspedes Restrepo and Morales-Pinzón (2018)	5	Re					✓
Cui (2018)	0	Re			✓	✓	✓

Beloin-Saint-Pierre, D., Rugani, B., Lasvaux, S., Mailhac, A., Popovici, E., Sibiude, G., . . . Schiopu, N. (2017). A review of urban metabolism studies to identify key methodological choices for future harmonization and implementation. *Journal of Cleaner Production, 163*, S223-S240.

Céspedes Restrepo, J. D., & Morales-Pinzón, T. (2018). Urban metabolism and sustainability: Precedents, genesis and research perspectives. *Resources, Conservation and Recycling, 131*, 216-224. doi:10.1016/j.resconrec.2017.12.023

Cui, X. (2018). How can cities support sustainability: A bibliometric analysis of urban metabolism. *Ecological Indicators, 93*, 704-717. doi:10.1016/j.ecolind.2018.05.056

Golubiewski, N. (2012). Is there a metabolism of an urban ecosystem? An ecological critique. *Ambio, 41*(7), 751-764. doi:10.1007/s13280-011-0232-7

Kennedy, C., Pincetl, S., & Bunje, P. (2011). The study of urban metabolism and its applications to urban planning and design. *Environ Pollut, 159*(8-9), 1965-1973. doi:10.1016/j.envpol.2010.10.022

Pincetl, S. (2012). Nature, urban development and sustainability – What new elements are needed for a more comprehensive understanding? *Cities, 29*, S32-S37. doi:10.1016/j.cities.2012.06.009

van Broekhoven, S., & Vernay, A. L. (2018). Integrating functions for a sustainable urban system: A review of multifunctional land use and circular urban metabolism. *Sustainability (Switzerland), 10*(6). doi:10.3390/su10061875

Zhang, Y. (2013). Urban metabolism: a review of research methodologies. *Environmental pollution (Barking, Essex : 1987), 178*, 463-473.

Zhang, Y., Yang, Z., & Yu, X. (2015). Urban Metabolism: A Review of Current Knowledge and Directions for Future Study. *Environmental Science and Technology, 49*(19), 11247-11263. doi:10.1021/acs.est.5b03060

[1] SCOPUS citations as of 20th November 2018