

Supplementary Information for Seven Tools to Manage Complex Coupled Human and Natural Systems: A Sustainability Toolbox

Zhongming Lu^{*†}, Osvaldo A. Broesicke^{*‡}, Junchen Yan[‡], Michael E. Chang[‡], Ming Xu[¶],
§, Sybil Derrible^{||}, James R. Mihelcic[#], Ben Schwegler^{††}, John C. Crittenden[‡]

[†] Division of Environment and Sustainability, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China

[‡] Brook Byers Institute for Sustainable Systems (BBISS), School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332, USA

[¶] School of Environment and Sustainability, University of Michigan, Ann Arbor, MI 48109-1041, USA

[§] Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI 48109-2125, USA

^{||} Complex and Sustainable Urban Networks (CSUN) Laboratory, 2095 Engineering Research, Facility, University of Illinois at Chicago, Chicago, IL 60607-7023, USA

[#] Department of Civil and Environmental Engineering, University of South Florida, Tampa, FL 33620, USA

^{††} Center for Integrated Facility Engineering, Stanford University, Stanford, CA 94305, USA

***Main Corresponding Author** (obroesicke3@gatech.edu, T: 001-404-894-7895, Address: 828 West Peachtree Street, Suite 320, Atlanta, Georgia 30332, USA)

***Secondary Corresponding Author** (zhongminglu@usk.hk, T: (852) 3469 2398, Address: Division of Environment and Sustainability, HKUST, Clear Water Bay, Kowloon, Hong Kong.

1 Table of Contents

2 Supplementary Figures and Tables..... S3

3 Table S1. Topic keywords for each of the seven identified tools (listed under the

4 topics column). S3

5 Table S2. Topic keywords for each of the twenty-three identified research themes.

6 S4

7 Figure S1. Distribution of published research articles within each tool category. ... S5

8 Figure S2. Correlations among proportions of research themes in one research

9 article S6

10 Table S3. The total occurrence frequency of sustainable tool category and

11 sustainability research category within the 12,526 abstracts. S8

12 Table S4. List of sustainability tools within each category. S9

13 Note S1: Topic modeling code formulation S11

14 Note S2: Topic modeling code in Python S12

15 Supplementary references..... S13

16
17

18 *Note: All supplementary tables and figures are presented in order of appearance in the
19 manuscript.

20 **Supplementary Figures and Tables**

21 ***Table S1. Topic keywords for each of the seven identified tools (listed under the topics column).***

Category	ID	Topics	Stems of Keywords
Tools	1	Design for sustainability	design engin process sustain architectur optim approach stage integr solut method paper
	2	Modeling of complexity	model simul dynam predict data use scenario optim integr develop flow growth
	3	Framework for using sustainability indicators	indic sustain assess develop index measur framework evalu use perform method set
	4	Life cycle sustainability assessment	cycl life lca assess impact materi product cost methodolog lcc use inventori
	5	Sustainability governance	environment impact econom assess environ eco pollut eia issu protect account ecolog
	6	Decision support	decis criteria support multi decision mak evalu make method risk process select
	7	Engagement	project social communiti research develop local knowledg innov stakehold sustain manag participatori

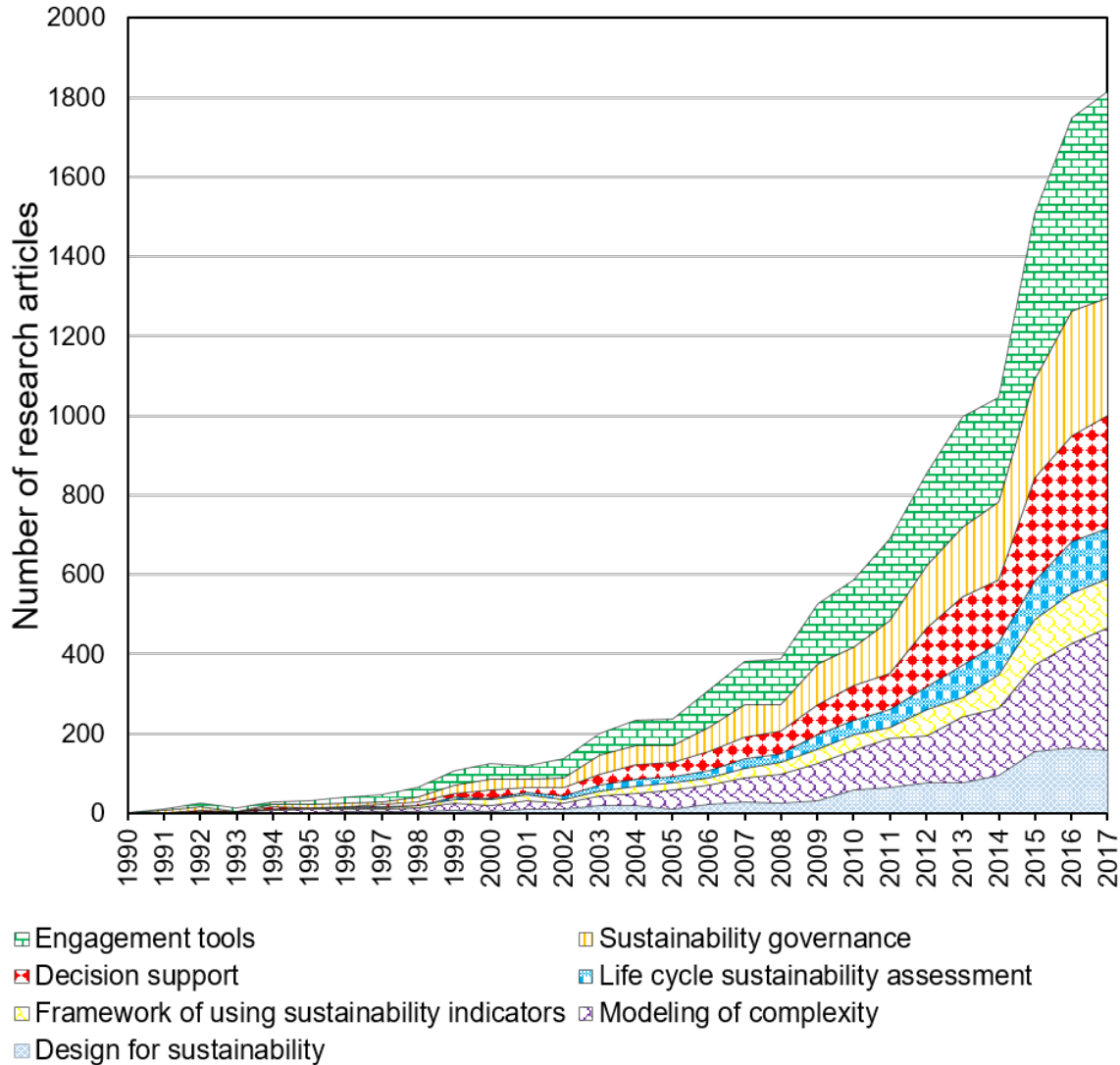
22

23 **Table S2. Topic keywords for each of the twenty-three identified research themes.**

24 The concurrence frequency of sustainability research categories is shown in Supplementary Figure 2.

Category	ID	Topics	Stems of Keywords
Research Themes	8	Sustainable products	product process industri chemic manufactur technolog materi engin develop new effici green
	9	Development of economy&society	polici govern develop countri econom nation european public sustain market economi sector
	10	Climate mitigation	climat chang risk adapt vulner scenario impact futur flood resili assess global
	11	Regional planning	plan coastal develop spatial strateg integr region process sea implement transport manag
	12	Sustainable business	compani busi corpor csr report manag perform sustain industri practic social firm
	13	Biological conservation	landscap conserv speci area biodivers tourism habitat protect plant ecolog cultur popul
	14	Sustainable buildings	build green construct perform rate leed bim materi project residenti assess thermal
	15	Emission control	emiss transport carbon footprint ghg co2 gas greenhous cost fuel road travel
	16	Water resource management	water basin resourc river irrig manag suppli demand qualiti hydrolog use catchment
	17	Energy efficiency&renewables	energi effici renew consumpt electr power heat solar save exergi sourc energy
	18	Sustainable agriculture	crop farm agricultur farmer irrig weed yield product rotat food fertil practic
	19	Cities and infrastructures	urban citi area space metabol growth smart infrastructur develop green neighborhood environ
	20	Sustainability education	educ student learn univers teach school teacher cours sustain higher engin curriculum
	21	Ecosystem services	ecosystem servic ecolog manag human natur provis integr es function resourc restor
	22	Sustainable logistics	chain suppli food product supplier valu consum perform logist sustain global secur
	23	Waste management	wast manag solid recycl treatment municip materi dispos msw landfil recoveri inciner
	24	Public health	health program care public intervent risk data patient improv diseas qualiti communiti
	25	Land management	land use agricultur chang area spatial cover region map watersh degrad gis
	26	Fishery resource management	fisheri fish manag marin speci stock catch coastal mpas protect popul harvest
	27	Forest management	forest manag forestri stand tree harvest timber wood certif sfm biomass silvicultur
	28	Sustainable machinery	machin cut manufactur surfac process wear optim consumpt dri paramet fluid materi
	29	Soil quality management	soil eros fertil qualiti nutrient organ properti site manag treatment sediment degrad
	30	Underground water management	groundwat aquif recharg area resourc manag irrig flow hydrogeolog pump map coastal

25



26

27 **Figure S1. Distribution of published research articles within each tool category.**

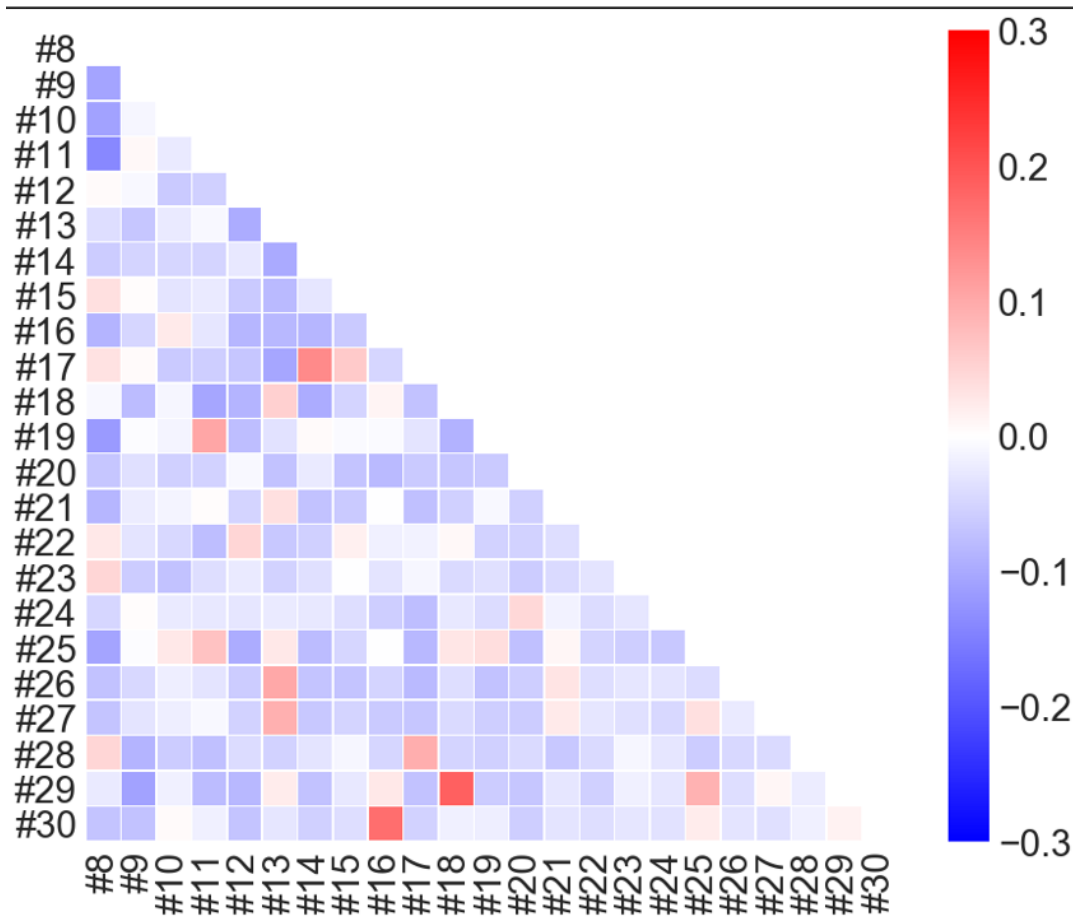
28 The values depict the total number of research articles and reviews in Web of Science
 29 whose abstracts contain the topics of (“sustainability” OR “sustainable”) AND “tool”
 30 (data accessed 2017.12.31)

31

32

33

ID	Topics	ID	Topics
8	Sustainable products	20	Sustainability education
9	Development of economy & society	21	Ecosystem services
10	Climate mitigation	22	Sustainable logistics
11	Regional planning	23	Waste management
12	Sustainable business	24	Public health
13	Biological conservation	25	Land management
14	Sustainable buildings	26	Fishery resource management
15	Emission control	27	Forest management
16	Water resource management	28	Sustainable machinery
17	Energy efficiency & renewables	29	Soil quality management
18	Sustainable agriculture	30	Underground water management
19	Cities and infrastructures		



34

35 **Figure S2. Correlations among proportions of research themes in one research**
 36 **article**

37 The numbers on the x-axis and y-axis correspond to the ID of the identified research
 38 themes. The color map represents correlation coefficients that explain the relative
 39 concurrence of the two themes in the same article.

40 Supplementary Figure 2 shows that some tool development studies aim to address
41 multiple sustainable issues. For instance, research themes of “Sustainable agriculture”
42 and “Soil quality management” are correlated as well as “Sustainable buildings” and
43 “Energy efficiency & renewable”. Tools were developed to address the challenges that
44 cover both research themes. However, most tool development studies we examined
45 only aims to address one particular sustainable issue. The current tool development
46 remains problem-oriented. That means one tool for one problem, which limits the scope
47 for solution investigation. We need to provide a toolbox cloud that individuals can
48 customize their system understanding of the causes and drivers of particular
49 sustainable challenges and identify solutions that can create synergic benefits not
50 limited to the particular issue of interest.

51

52 **Table S3. The total occurrence frequency of sustainable tool category and sustainability research category within**
 53 **the 12,526 abstracts.**

Sustainability Tool Category \ Sustainability Research Category	Design for sustainability	Modeling complexity	Sustainability indicators	Lifecycle Sustainability Assessment	Decision Support	Sustain. Govern.	Stakeholder Engagement	Total
Sustainable products	330	250	101	270	291	479	368	2089
Development of economy & society	53	179	153	41	199	346	642	1613
Climate mitigation	64	245	63	37	238	161	408	1216
Regional planning	55	165	85	28	257	207	414	1211
Sustainable business	83	159	89	50	172	237	404	1194
Biological conservation	55	202	83	28	132	179	436	1115
Sustainable buildings	178	107	45	94	130	166	232	952
Emission control	77	186	42	142	113	224	157	941
Water resource management	25	294	56	28	169	126	226	924
Energy efficiency & renewables	121	185	43	100	155	174	125	903
Sustainable agriculture	25	189	78	33	130	152	214	821
Cities & infrastructure	74	118	74	24	130	104	267	791
Sustainability education	105	71	42	18	64	110	363	773
Ecosystem services	45	112	62	21	84	126	256	706
Sustainable logistics	40	86	32	64	93	136	158	609
Waste management	41	53	34	86	82	150	83	529
Public health	29	51	50	20	80	59	227	516
Land management	13	115	31	14	96	92	153	514
Fishery resource management	16	120	31	20	49	70	127	433
Forest management	5	92	40	7	53	43	125	365
Sustainable machinery	50	80	16	33	47	59	25	310
Soil quality management	10	118	28	8	42	48	42	296
Underground water management	5	109	7	3	49	19	25	217
Total	1499	3286	1285	1169	2855	3467	5477	19038

54

55

56

57 **Table S4. List of sustainability tools within each category.**

Category	Tools	References
Design for Sustainability	12 Principles of Green Design	1
	12 Principles of Infrastructure Ecology	2
	Biomimicry	3
	Building Research Establishment Environmental Assessment Method (BREEAM)	4
	Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL)	5
	ENVISION	6
	Ergonomics	7
	Leadership in Energy Efficient Design (LEED)	8
	Level(s)	9
Modeling Complexity	Agent-Based Modeling	10–13
	Computable General Equilibrium Modeling	14
	Machine Learning	15,16
	Participatory Modeling	17,18
	System-dynamic Modeling	19
Sustainability Indicators	Ecological Footprint	20
	Ecosystem Services	21,22
	Environmental Sustainability Index (ESI)	23
	Genuine Progress Indicator (GPI)	24
	Gini Coefficient	25–27
	Happy Planet Index (HPI)	28
	Human Development Index (HDI)	29
	Palma Ratio	30,31
Ecological Economics	32–35	
Life Cycle Sustainability Assessment	Hypothetical Extraction Model (HEM)	36
	Input-Output Analysis	37
	Life Cycle Assessment (LCA)	38
	Life Cycle Costing (LCC)	38
	Life Cycle Inventory (LCI)	38,39
	Material Flow Analysis	37
	Social Life Cycle Assessment (SLCA)	40
Parametric Life Cycle Assessment (PLCA)	41	

58

59

60 **Table S4 (continued). List of sustainability tools within each category.**

Category	Tools	References
Decision Support	Multidisciplinary Design Optimization (MDO)	42–46
	Analytic Hierarchy Process (AHP)	47–49
	Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	50
	ELimination Et Choix Traduisant la REalité (ELECTRE)	48
	Fuzzy Logic	51
Sustainability Governance	Ecological Footprint Analysis	52,53
	Emergy Analysis	54–56
	Environmental Impact Assessment (EIA)	57
	Environmental Impact Cost-Benefit	58
	Montreal Protocol	59
	Policy Tools (e.g., taxes, cap-and-trade, governmental accounting, etc.)	60–62
Engagement	Crowdsourcing	63
	Expectations	64
	Latent Class Choice Analysis	65
	Semantic Analysis	66
	Topic Modeling	67,68
	Types of Engagement	69–71

61

62 Supplementary Table 4 is not a complete list of sustainability tools. Rather, the list contains sources where readers can
 63 take a deeper dive into many of the tools discussed in the paper. Many more sustainability tools within each category are
 64 available and under development.

65 **Note S1: Topic modeling code formulation**

66 We, the authors, did not create any new algorithm or system structure. The topic
67 modeling code implemented in the analysis uses the Nonnegative Matrix Factorization
68 (NMF)⁷² method via the Python Scikit-learn package⁷³. A detailed description of the
69 Scikit-learn package is available at <https://github.com/scikit-learn/scikit-learn> and
70 includes system requirements, installation instructions, demonstrations and examples,
71 and operation instructions.

72 The topic modeling code was formulated following instructions provided by
73 DARIAH-DE⁷⁴. These instructions can be found at
74 https://liferay.de.dariah.eu/tatom/topic_model_python.html. Further information,
75 including system requirements, installation instructions, demonstrations, and sample
76 data, see the organization's GitHub at <https://github.com/ariddell/tatom/>.

77 Note S2: Topic modeling code in Python

```
78 #Python Code of Topic Modeling to Synthesise Research Topics
79
80 import os
81 import numpy as np
82 import sklearn.feature_extraction.text as text
83
84 CORPUS_PATH = '..\Abstract_stem'
85 filenames = sorted([os.path.join(CORPUS_PATH, fn) for fn in os.listdir(CORPUS_PATH)])
86
87 vectorizer =
88 text.TfidfVectorizer(input='filename', decode_error='ignore', stop_words='english',
89 max_df=0.95, min_df=5)
90 dtm = vectorizer.fit_transform(filenames).toarray()
91 vocab = np.array(vectorizer.get_feature_names())
92
93 from sklearn import decomposition
94 num_topics = 30
95 num_top_words = 12
96
97 clf = decomposition.NMF(n_components = num_topics, random_state = 1)
98 doctopic=clf.fit_transform(dtm)
99
100 topic_words = []
101 for topic in clf.components_:
102     word_idx = np.argsort(topic)[::-1][0:num_top_words]
103     topic_words.append([vocab[i] for i in word_idx])
104
105 doctopic = doctopic/np.sum(doctopic, axis=1, keepdims=True)
106
107 for t in range(len(topic_words)):
108     print ("Topic {}: {}".format(t, ' '.join(topic_words[t][:15])))
109
110
```

111 Supplementary references

- 112 (1) Anastas, P. T.; Zimmerman, J. B. Peer Reviewed: Design Through the 12 Principles of Green
113 Engineering. *Environ. Sci. Technol.* **2003**, *37* (5), 94A–101A.
- 114 (2) Pandit, A.; Minné, E. A.; Li, F.; Brown, H.; Jeong, H.; James, J. A. C.; Newell, J. P.; Weissburg, M.;
115 Chang, M. E.; Xu, M.; et al. Infrastructure ecology: an evolving paradigm for sustainable urban
116 development. *J. Clean. Prod.* **2017**, *163*, S19–S27.
- 117 (3) The Biomimicry Institute. The Biomimicry Institute: Building a new generation of sustainability
118 innovators <https://biomimicry.org/> (accessed Nov 19, 2018).
- 119 (4) BRE Global Ltd. What is BREEAM? <https://www.breeam.com/> (accessed Oct 10, 2018).
- 120 (5) BRE Global Ltd. CEEQUAL (2018) coming soon <http://www.ceequal.com/> (accessed Oct 10,
121 2018).
- 122 (6) ASCE. ENVISION <https://www.asce.org/envision/> (accessed Oct 10, 2018).
- 123 (7) Radjiyev, A.; Qiu, H.; Xiong, S.; Nam, K. H. Ergonomics and sustainable development in the past
124 two decades (1992–2011): Research trends and how ergonomics can contribute to sustainable
125 development. *Appl. Ergon.* **2015**.
- 126 (8) USGBC. LEED is green building <https://new.usgbc.org/leed> (accessed Oct 10, 2018).
- 127 (9) European Commission. Level(s) <http://ec.europa.eu/environment/eussd/buildings.htm> (accessed
128 Oct 1, 2018).
- 129 (10) MacAI, C. M.; North, M. J. Tutorial on agent-based modelling and simulation. *J. Simul.* **2010**.
- 130 (11) Lu, Z.; Noonan, D.; Crittenden, J. C.; Jeong, H.; Wang, D. Use of impact fees to incentivize low-
131 impact development and promote compact growth. *Environ. Sci. Technol.* **2013**, *47* (19), 10744–
132 10752.
- 133 (12) Zhang, W.; Guhathakurta, S.; Fang, J.; Zhang, G. Exploring the impact of shared autonomous
134 vehicles on urban parking demand: An agent-based simulation approach. *Sustain. Cities Soc.*
135 **2015**, *19*, 34–45.
- 136 (13) Joffre, O. M.; Bosma, R. H.; Ligtenberg, A.; Tri, V. P. D.; Ha, T. T. P.; Bregt, A. K. Combining
137 participatory approaches and an agent-based model for better planning shrimp aquaculture. *Agric.*
138 *Syst.* **2015**, *141*, 149–159.
- 139 (14) Yu, X.; Moreno-Cruz, J.; Crittenden, J. C. Regional energy rebound effect: The impact of
140 economy-wide and sector level energy efficiency improvement in Georgia, USA. *Energy Policy*
141 **2015**, *87*, 250–259.
- 142 (15) Lee, D.; Derrible, S.; Pereira, F. C. Comparison of Four Types of Artificial Neural Network and a
143 Multinomial Logit Model for Travel Mode Choice Modeling. *Transp. Res. Rec. J. Transp. Res.*
144 *Board* **2018**, 036119811879697.
- 145 (16) Lee, D.; Derrible, S. *Predicting Residential Water Consumption: Modeling Techniques and Data*
146 *Perspectives*; 2019.
- 147 (17) Allen, J.; Lu, K. Modeling and Prediction of Future Urban Growth in the Charleston Region of
148 South Carolina: a GIS-based Integrated Approach. *Conserv. Ecol.* **2003**, *8* (2).
- 149 (18) Voinov, A.; Jenni, K.; Gray, S.; Kolagani, N.; Glynn, P. D.; Bommel, P.; Prell, C.; Zellner, M.;
150 Paolisso, M.; Jordan, R.; et al. Tools and methods in participatory modeling: Selecting the right
151 tool for the job. *Environ. Model. Softw.* **2018**, *109*, 232–255.
- 152 (19) Elsworth, S.; Pierce, S. A.; Hamilton, S. H.; van Delden, H.; Haase, D.; Elmahdi, A.; Jakeman, A.
153 J. An overview of the system dynamics process for integrated modelling of socio-ecological
154 systems: Lessons on good modelling practice from five case studies. *Environ. Model. Softw.* **2017**.
- 155 (20) Wackernagel, M.; Schulz, N. B.; Deumling, D.; Linares, A. C.; Jenkins, M.; Kapos, V.; Monfreda,
156 C.; Loh, J.; Myers, N.; Norgaard, R.; et al. Tracking the ecological overshoot of the human
157 economy. *Proc. Natl. Acad. Sci.* **2002**, *99* (14), 9266–9271.
- 158 (21) Sun, X.; Crittenden, J. C.; Li, F.; Lu, Z.; Dou, X. Urban expansion simulation and the spatio-
159 temporal changes of ecosystem services, a case study in Atlanta Metropolitan area, USA. *Sci.*
160 *Total Environ.* **2018**, 622–623, 974–987.
- 161 (22) Sun, X.; Lu, Z.; Li, F.; Crittenden, J. C. Analyzing spatio-temporal changes and trade-offs to
162 support the supply of multiple ecosystem services in Beijing, China. *Ecol. Indic.* **2018**, *94*
163 (February), 117–129.
- 164 (23) Srebotnjak, T.; Esty, D. C. Measuring Up: Applying the Environmental Sustainability Index. *Yale J.*

- 165 *Int. Aff.* **2005**, 1 (1), 156–168.
- 166 (24) Kubiszewski, I.; Costanza, R.; Franco, C.; Lawn, P.; Talberth, J.; Jackson, T.; Aylmer, C. Beyond
167 GDP: Measuring and achieving global genuine progress. *Ecol. Econ.* **2013**, 93, 57–68.
- 168 (25) Cidell, J. Concentration and decentralization: The new geography of freight distribution in US
169 metropolitan areas. *J. Transp. Geogr.* **2010**, 18 (3), 363–371.
- 170 (26) Yitzhaki, S.; Schechtman, E. More Than a Dozen Alternative Ways of Spelling Gini. In *The Gini*
171 *Methodology: A Primer on a Statistical Methodology*; 2013.
- 172 (27) Rey, S. J.; Smith, R. J. A spatial decomposition of the Gini coefficient. *Lett. Spat. Resour. Sci.*
173 **2013**.
- 174 (28) New Economics Foundation. *Happy Planet Index 2016: Methods Paper*; 2016.
- 175 (29) UNDP. *Human Development Indices and Indicators: 2018 Statistical Update*; New York, NY, 2018.
- 176 (30) Cobham, A.; Schlögl, L.; Sumner, A. Inequality and the Tails: The Palma Proposition and Ratio.
177 *Glob. Policy* **2016**.
- 178 (31) Cobham, A.; Sumner, A. Is inequality all about the tails?: The Palma measure of income
179 inequality. *Significance* **2014**.
- 180 (32) de Beer, P.; Friend, F. Environmental accounting: A management tool for enhancing corporate
181 environmental and economic performance. *Ecol. Econ.* **2006**, 58 (3), 548–560.
- 182 (33) Tol, R. S. . Equitable cost-benefit analysis of climate change policies. *Ecol. Econ.* **2001**, 36 (1),
183 71–85.
- 184 (34) Martinez-Alier, J. Ecological Economics. In *International Encyclopedia of the Social & Behavioral*
185 *Sciences: Second Edition*; 2015.
- 186 (35) Gómez-Baggethun, E.; de Groot, R.; Lomas, P. L.; Montes, C. The history of ecosystem services
187 in economic theory and practice: From early notions to markets and payment schemes. *Ecol.*
188 *Econ.* **2010**.
- 189 (36) Wang, Y.; Lai, N.; Mao, G.; Zuo, J.; Crittenden, J.; Jin, Y.; Moreno-Cruz, J. Air pollutant emissions
190 from economic sectors in China: A linkage analysis. *Ecol. Indic.* **2017**.
- 191 (37) Stadler, K.; Heeren, N.; Pauliuk, S. Industrial Ecology <https://github.com/IndEcol> (accessed Dec
192 12, 2018).
- 193 (38) Matthews, H. S.; Hendrickson, C. T.; Matthews, D. H. *Life Cycle Assessment: Quantitative*
194 *Approaches for Decisions That Matter*, Open acces.; 2014.
- 195 (39) Frischknecht, R.; Rebitzer, G. The ecoinvent database system: a comprehensive web-based LCA
196 database. *J. Clean. Prod.* **2005**, 13 (13–14), 1337–1343.
- 197 (40) United Nations Environment Programme. *Guidelines for social life cycle assessment of products*.
- 198 (41) Lee, D.-Y.; Thomas, V. M. Parametric modeling approach for economic and environmental life
199 cycle assessment of medium-duty truck electrification. *J. Clean. Prod.* **2017**, 142, 3300–3321.
- 200 (42) Martins, J. R. R. A.; Lambe, A. B. Multidisciplinary Design Optimization: A Survey of Architectures.
201 *AIAA J.* **2013**, 51 (9), 2049–2075.
- 202 (43) Best, R. E.; Flager, F.; Lepech, M. D. Modeling and optimization of building mix and energy supply
203 technology for urban districts. *Appl. Energy* **2015**, 159, 161–177.
- 204 (44) Swischuk, R.; Mainini, L.; Peherstorfer, B.; Willcox, K. Projection-based model reduction:
205 Formulations for physics-based machine learning. *Comput. Fluids* **2018**.
- 206 (45) Kumar, H. S.; Ashish, P.; Basant, Y. Ensemble Wavelet-Support Vector Machine Approach for
207 Prediction of Suspended Sediment Load Using Hydrometeorological Data. *J. Hydrol. Eng.* **2017**,
208 22 (7), 5017006.
- 209 (46) Lei, G.; Zhu, J.; Guo, Y. *Multidisciplinary Design Optimization Methods for Electrical Machines and*
210 *Drive Systems*; Springer Berlin Heidelberg: Berlin, 2016.
- 211 (47) Mahjouri, M.; Ishak, M. B.; Torabian, A.; Abd Manaf, L.; Halimoon, N.; Ghodusi, J. Optimal
212 selection of Iron and Steel wastewater treatment technology using integrated multi-criteria
213 decision-making techniques and fuzzy logic. *Process Saf. Environ. Prot.* **2017**, 107, 54–68.
- 214 (48) Curiel-Esparza, J.; Cuenca-Ruiz, M.; Martin-Utrillas, M.; Canto-Perello, J. Selecting a Sustainable
215 Disinfection Technique for Wastewater Reuse Projects. *Water* **2014**, 6 (9), 2732–2747.
- 216 (49) Rashidi, M.; Ghodrat, M.; Samali, B.; Kendall, B.; Zhang, C. Remedial Modelling of Steel Bridges
217 through Application of Analytical Hierarchy Process (AHP). *Appl. Sci.* **2017**, 7 (2), 168.
- 218 (50) Mousavi-Nasab, S. H.; Sotoudeh-Anvari, A. A comprehensive MCDM-based approach using
219 TOPSIS, COPRAS and DEA as an auxiliary tool for material selection problems. *Mater. Des.*
220 **2017**, 121, 237–253.

- 221 (51) Zadeh, L. A. The concept of a linguistic variable and its application to approximate reasoning—I.
222 *Inf. Sci. (Ny)*. **1975**, 8 (3), 199–249.
- 223 (52) Hoekstra, A. Y. Human appropriation of natural capital: A comparison of ecological footprint and
224 water footprint analysis. *Ecol. Econ.* **2009**.
- 225 (53) Beloin-Saint-Pierre, D.; Rugani, B.; Lasvaux, S.; Mailhac, A.; Popovici, E.; Sibiude, G.; Benetto, E.;
226 Schiopu, N. A review of urban metabolism studies to identify key methodological choices for future
227 harmonization and implementation. *J. Clean. Prod.* **2017**, 163, S223–S240.
- 228 (54) Amaral, L. P.; Martins, N.; Gouveia, J. B. A review of emergy theory, its application and latest
229 developments. *Renewable and Sustainable Energy Reviews*. 2016.
- 230 (55) Ingwersen, W. W. Emergy as a Life Cycle Impact Assessment Indicator: A Gold Mining Case
231 Study. *J. Ind. Ecol.* **2011**.
- 232 (56) Lifset, R.; Graedel, T. E. Industrial Ecology. In *International Encyclopedia of the Social &*
233 *Behavioral Sciences: Second Edition*; 2015.
- 234 (57) Banhalimi-Zakar, Z.; Larsen, S. V. How strategic environmental assessment can inform lenders
235 about potential environmental risks. *Impact Assess. Proj. Apprais.* **2015**, 33 (1), 68–72.
- 236 (58) Stratus Consulting. *A Triple Bottom Line Assessment of Traditional and Green Infrastructure*
237 *Options for Controlling CSO Events in Philadelphia's Watersheds, Final Report*, Philadelphia,
238 2009.
- 239 (59) United Nations Development Programme. Montreal Protocol
240 [http://www.undp.org/content/undp/en/home/sustainable-development/environment-and-natural-](http://www.undp.org/content/undp/en/home/sustainable-development/environment-and-natural-capital/montreal-protocol.html)
241 [capital/montreal-protocol.html](http://www.undp.org/content/undp/en/home/sustainable-development/environment-and-natural-capital/montreal-protocol.html) (accessed Oct 10, 2018).
- 242 (60) Brown, M. A.; Sovacool, B. K. *Climate Change and Global Energy Security: Technology and*
243 *Policy Options*; MIT Press: Cambridge, MA, 2011.
- 244 (61) Sovacool, B. K.; Brown, M. A.; Valentine, S. V. *Fact and Fiction in Global Energy Policy: 15*
245 *Contentious Questions*; John Hopkins University Press: Baltimore, MD, 2016.
- 246 (62) Brown, M. A.; Wang, Y. *Green Savings: How Policies and Markets Drive Energy Efficiency*; ABC-
247 CLIO, LLC: Santa Barbara, CA, 2015.
- 248 (63) Mueller, J.; Lu, H.; Chirkin, A.; Klein, B.; Schmitt, G. Citizen Design Science: A strategy for crowd-
249 creative urban design. *Cities* **2018**.
- 250 (64) National Research Council. *Analysis of Global Change Assessments*; National Academies Press:
251 Washington, D.C., 2007.
- 252 (65) Lu, Z.; Southworth, F.; Crittenden, J.; Dunham-Jones, E. Market potential for smart growth
253 neighbourhoods in the USA: A latent class analysis on heterogeneous preference and choice.
254 *Urban Stud.* **2015**, 52 (16), 3001–3017.
- 255 (66) Hofmann, T. Unsupervised learning by probabilistic Latent Semantic Analysis. *Mach. Learn.* **2001**.
- 256 (67) Lu, Z.; Du, R.; Dunham-jones, E.; Park, H.; Crittenden, J. Data-enabled public preferences inform
257 integration of autonomous vehicles with transit-oriented development in Atlanta. *Cities* **2017**, 63,
258 118–127.
- 259 (68) Meerow, S.; Newell, J. P. Resilience and Complexity: A Bibliometric Review and Prospects for
260 Industrial Ecology. *J. Ind. Ecol.* **2015**, 19 (2), 236–251.
- 261 (69) Arnstein, S. R. A Ladder Of Citizen Participation. *J. Am. Inst. Plann.* **1969**, 35 (4), 216–224.
- 262 (70) Stewart, K. Write the Rules and Win: Understanding Citizen Participation Game Dynamics. *Public*
263 *Adm. Rev.* **2007**, 67 (6), 1067–1076.
- 264 (71) Vereijssen, J.; Srinivasan, M. S.; Dirks, S.; Fielke, S.; Jongmans, C.; Agnew, N.; Klerkx, L.;
265 Pinxterhuis, I.; Moore, J.; Edwards, P.; et al. Addressing complex challenges using a co-innovation
266 approach: Lessons from five case studies in the New Zealand primary sector. *Outlook Agric.* **2017**,
267 46 (2), 108–116.
- 268 (72) Kuang, D.; Park, H. Fast rank-2 nonnegative matrix factorization for hierarchical document
269 clustering. In *Proceedings of the 19th ACM SIGKDD international conference on Knowledge*
270 *discovery and data mining - KDD '13*; KDD '13; ACM Press: New York, New York, USA, NY, USA,
271 2013; p 739.
- 272 (73) Pedregosa, F.; Varoquaux, G.; Gramfort, A.; Michel, V.; Thirion, B.; Grisel, O.; Blondel, M.;
273 Prettenhofer, P.; Weiss, R.; Dubourg, V.; et al. Scikit-learn: Machine Learning in Python. *J. Mach.*
274 *Learn. Res.* **2011**, 12, 2825–2830.
- 275 (74) DARIAH-DE. DARIAH-DE: Digital research infrastructure for humanities and cultural sciences
276 <https://de.dariah.eu/en/startseite> (accessed Aug 15, 2017).