A spatial agent based model for simulating and optimizing networked eco-industrial systems

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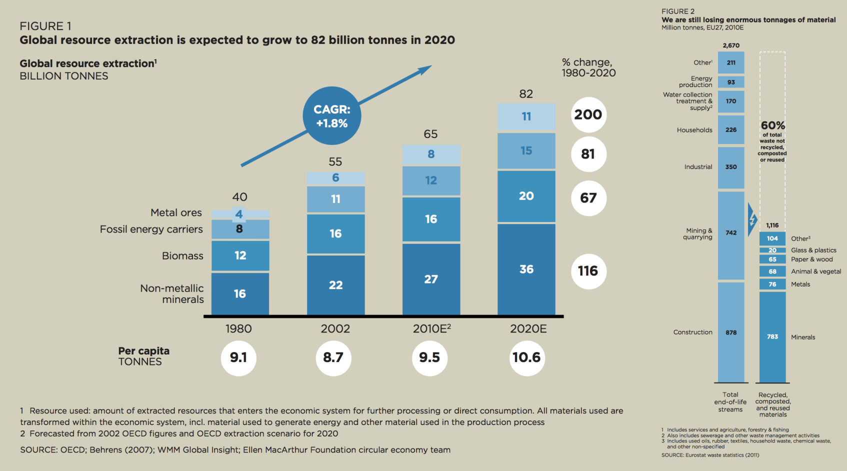
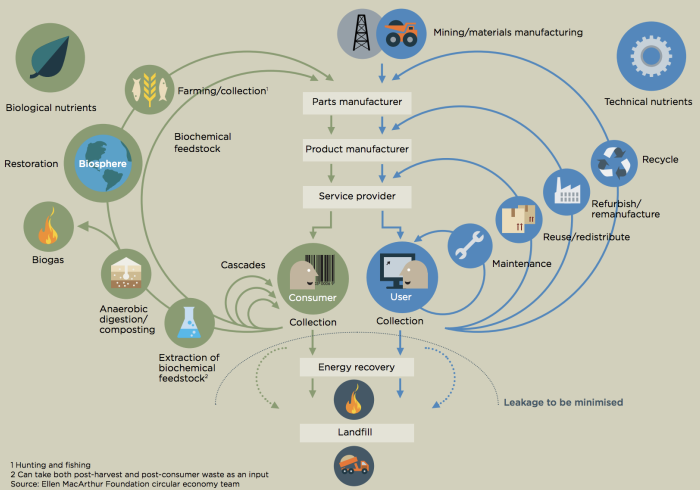
An unsustainable use of resources



MacArthur, E. (2013). Towards the circular economy. Journal of Industrial Ecology, 2, 23-44.

Towards a circular economy

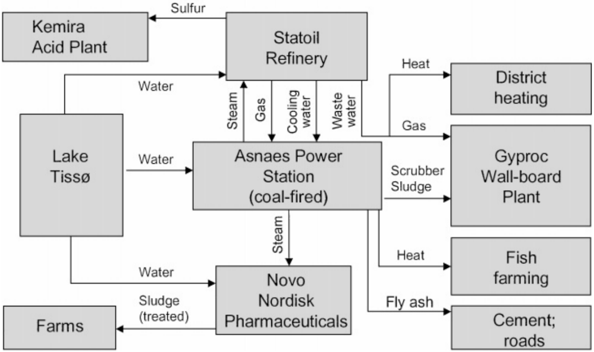
FIGURE 6 **The circular economy—an industrial system that is restorative by design**



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input
Source: Ellen MacArthur Foundation circular economy team

[MacArthur, 2013]

Industrial symbiosis as an approach to cycle by-products and energy between industries [Chertow, 2000], such as in eco-industrial parks [Gibbs and Deutz, 2007]



Chertow, M. R. (2000). Industrial symbiosis: literature and taxonomy. Annual review of energy and the environment, 25(1), 313-337.

Industrial symbiosis and spatial structure

Systems perspective necessary to understand and optimize industrial symbiosis processes [Chertow and Ehrenfeld, 2012]

Spatial structure of the system plays a crucial role [Desrochers, 2001]

Agent-based modeling as a privileged modeling approach but never applied at regional scales from an urban system perspective [Kraines and Wallace, 2006]

An agent-based model for industrial symbiosis

→ A simple agent-based model to study the effects of geographical proximity on industrial symbiosis network, and the role of cluster policies.

→ Integrates geography, ecology and economy concepts, from a generative social science perspective.

→ Can be applied to understand the interplay between different processes, and to optimize policies for a circular economy

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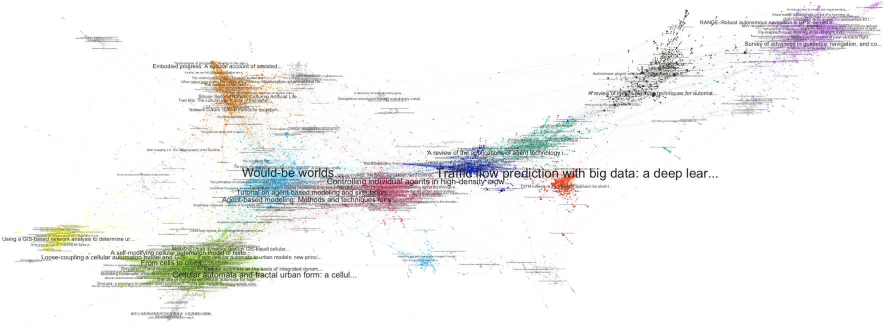
Artificial life and generative models

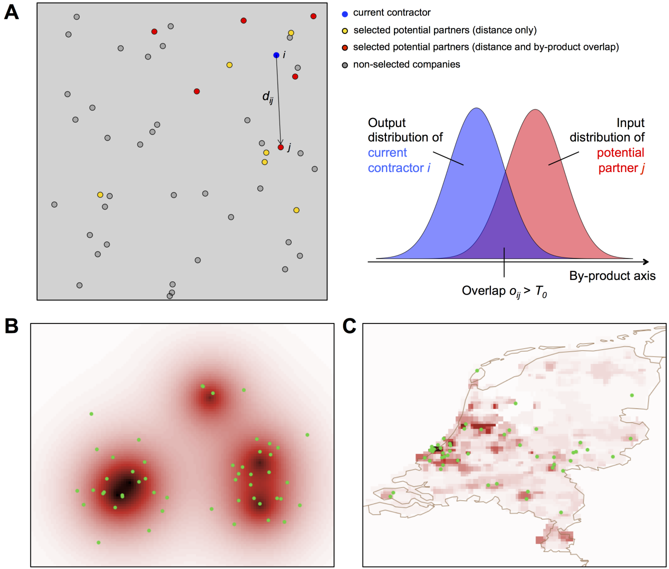


Citation network of ALife studies of urban systems [Raimbault, 2020] arXiv:2002.12926

Transfer of concepts: Urban morphogenesis, bio-inspired design, urban ecology, autopoiesis [Batty and Marshall, 2009]

Generative social science: generating an emerging phenomenon from the bottom-up provides explanations [Epstein, 2006]

Model summary



Model description

Setup: Companies located into space (synthetic or real setup), with input/output product distribution (Probabilistic Niche Model) which average is correlated with a clustering parameter α

Network growth: At each time step,

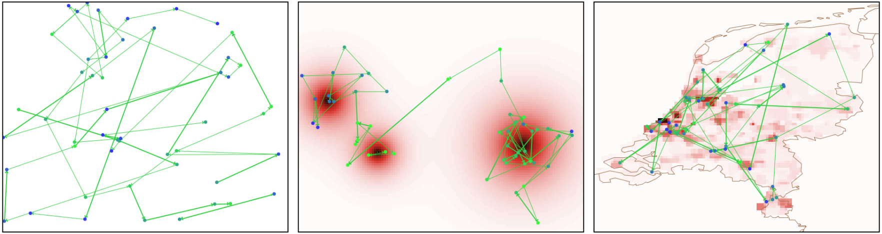
1. A current contractor is drawn among companies with minimal number of links.
2. Spatial interaction model (span d_0) determines potential partners.
3. Partner with the best utility (linear in product overlap and transportation cost) is chosen, link created and distributions updated.

Iterate until the network stabilizes.

Indicators: Total remaining waste (non exchanged products) and relative cost (network length weighted by flows).

Processes and parameters

Parameter	Notation	Process	Range	Value
Number of firms	N	Economic system	$[2;10^6]$	$N = 50$
Hierarchy of city system	γ	City system	$[0.5;2.0]$	$\gamma = 1.3$
Density-to-firms exponent	α_P	Economic system	$[0.1;4.0]$	$\alpha_P = 1.5$
Number of centers	p	City system	$[1;10]$	$p = 5$
Gravity decay	d_0	Spatial interactions	$[1;200]$	$d_0 = 50km$
Distribution width	σ	Industrial structure	$[0.01;0.1]$	$\sigma = 0.05$
Overlap threshold	T_0	Industrial structure	$[0.01;0.1]$	$T_0 = 0.1$
Transportation cost	c	Urban system	$[0.1;4.0]$	$c = 0.5$
Correlation level	α	Industrial clusters	$[0;20.0]$	$\alpha = 5$



Random company positions, synthetic urban system (scaling law of population), and real population distribution.

Model demonstration

Model implementation and exploration

Spatial model with several parameters
→ model implemented in NetLogo for its compromise between performance and interactivity

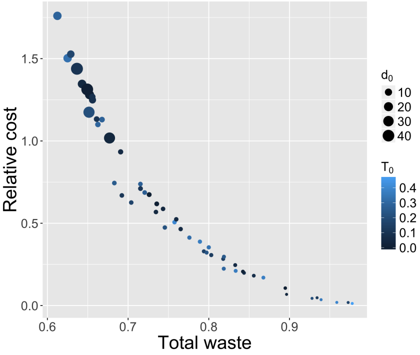
Consequent number of parameters and processes
→ integration into the OpenMOLE model exploration open source software [Reuillon et al., 2013]
`https://next.openmole.org`

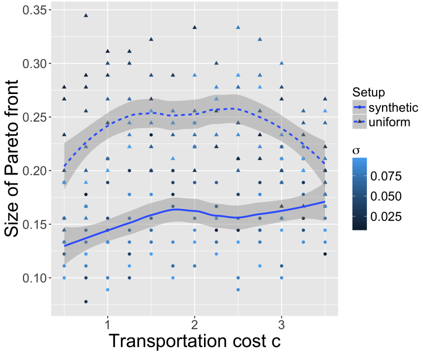
Enables seamlessly (i) model embedding; (ii) access to HPC resources; (iii) exploration and optimization algorithms

Running grid sampling on synthetic urban systems with no correlation process:

- Statistical consistency of indicators, n=100 replications fixed for following experiments.
- Expected effect of some parameters, in particular company product span σ (decreases waste) and transportation cost c (increases waste and decreases relative cost).
- Emerging behaviors: congestion effect with T_0 exchange threshold; U-shaped behavior of cost as a function of σ.
- Different qualitative patterns between synthetic and real system for company position setup.

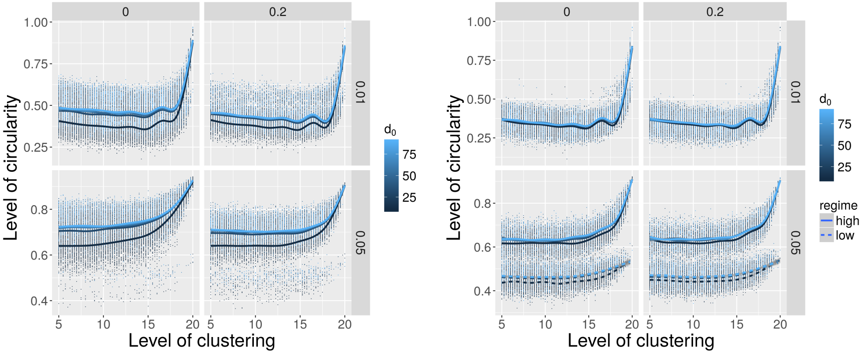
Policy optimization for the circular economy





(Left) At fixed exogenous parameters c and σ, bi-objective optimization of cost and waste; (Right) Size of Pareto fronts (number of alternatives for policy optimization) as a function of c and σ.

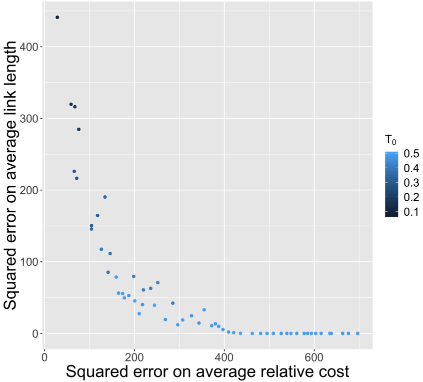
Spatial correlation between inputs and outputs



Influence of level of clustering on the circularity of the final network, for low (resp. high) transportation cost (Left, resp. Right), for different thresholds T_0 (columns), distribution width σ (rows) and gravity decay d_0 (color).

→ In practice, the spatial correlation policy must be strictly enforced to have an effect.

Model calibration



Real-world application of the model by calibration on the EPRTR database to reproduce network structure (number of links, average link length, relative cost); yield medium range interactions but high propensity to exchange.

Implications

$\rightarrow$ Importance of spatial configuration; Eco-industrial park policies must be strictly applied.

$\rightarrow$ Real-world application of the model shown as a proof-of-concept with good model fit.

Developments

$\rightarrow$ Data-driven approach in link with an interactive web application: towards a real-world application with a project of company.

$\rightarrow$ Refinement of economic processes.

$\rightarrow$ Benchmark of multiple possible processes and levels of policies.

Conclusion

$\rightarrow$ A simple agent-based model to understand and optimize industrial symbiosis.

$\rightarrow$ Important role of spatial structure and spatial correlations.

Git repository:
`https://github.com/SFICSSS16-CircularEconomy/CircularEconomy`

Simulation data: `https://doi.org/10.7910/DVN/7XCWTN`

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