A multi-dimensional percolation approach to characterize sustainable mega-city regions

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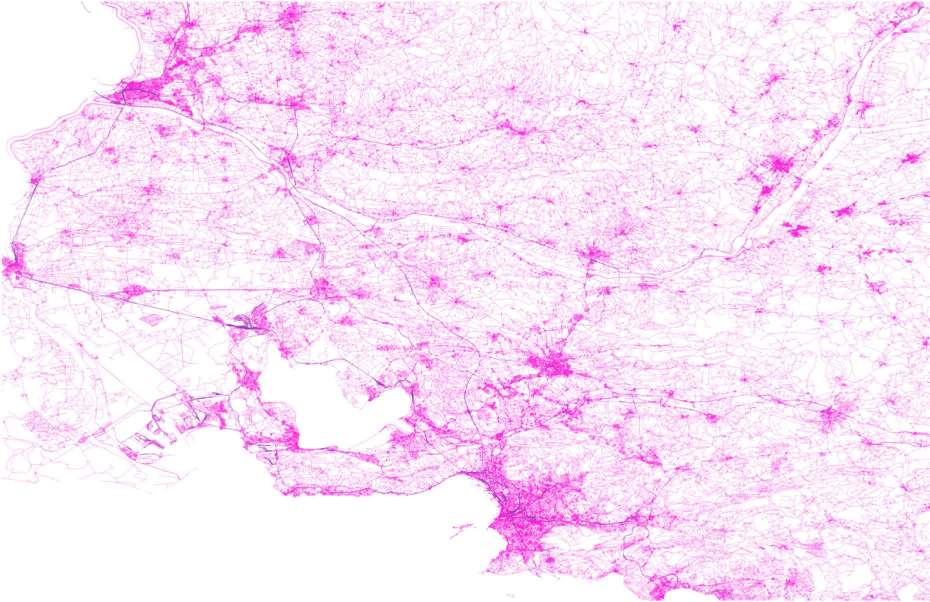
MARAMI 2018

Avignon

October 18th 2018

Morphologies of networks and territories



Source: OpenStreetMap

Characterizing Road networks

Multiple dimensions to characterize road networks

Lagesse, C., Bordin, P., & Douady, S. (2015). A spatial multi-scale object to analyze road networks. Network Science, 3(1), 156-181. [Lagesse et al., 2015]

Network percolation

Network percolation: *progressive occupation/connection of nodes of a network* [Callaway et al., 2000]

Application to the study of cities:

- modeling urban growth [Makse et al., 1998]
- endeogenous determination of regions [Arcaute et al., 2016]
- characterization of spatial point patterns [Huynh et al., 2018]

Towards complementary dimensions to condition road network percolation
$\rightarrow$ similar to [Cottineau et al., 2018] to define urban areas

Multidimensional percolation

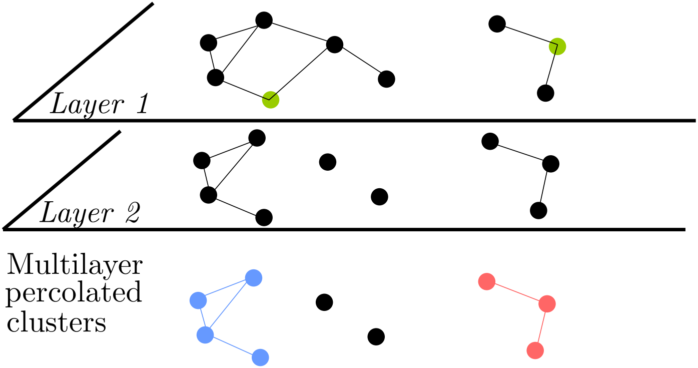
$\rightarrow$ Need to combine morphological and functional dimensions of cities [Burger and Meijers, 2012]

$\rightarrow$ Interactions between networks and territories to capture the link between form and function [Raimbault, 2018a]; potential application to sustainability of urban systems

Research objective : *Investigate a multi-dimensional percolation of territorial networks taking into account urban morphology and road network topology; endogenous characterization of urban regions.*

Multilayer percolation

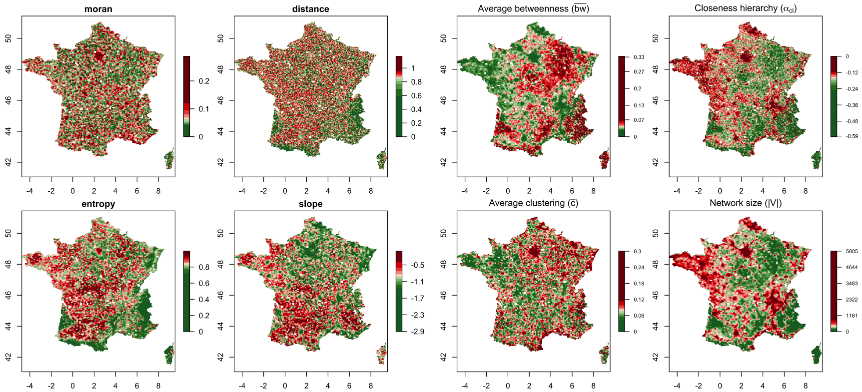
Multi-dimensional network percolation heuristic, similar to multilayer percolation [Boccaletti et al., 2014]



Parameters: percolation radius r_0, percolation thresholds θ_i for each layer

Empirical data and variables

Territorial indicators computed for Europe by [Raimbault, 2018b]



Population distribution morphology and **Network topology** (betweenness, closeness, clustering, efficiency, . . .) computed on 50km spatial windows (Eurostat density grid and OpenStreetMap)

Network construction

Two layers: population density (threshold θ_P) and network characteristics (threshold θ_N) taken among {Number of edges, Number of vertices, Cyclomatic number μ, Euclidian efficiency v }; percolated with a radius r_0

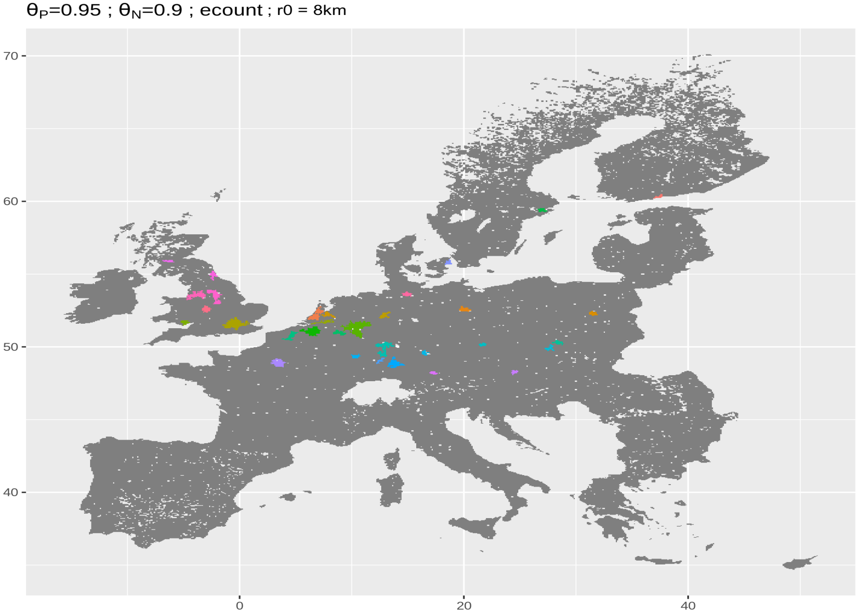
Rationale: *two locations will be in relation if they are close, have a high population density and given network characteristics.*

Implementation: construction of a single layer spatial network given the condition on the two layers and distances, from the 5km resolution indicators spatial field; extraction of connected components.

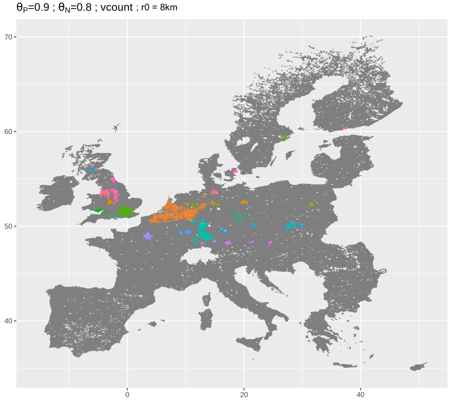
Experience plan: grid sampling for r_0, θ_P, θ_N and network variables; additional gravity potential parameters γ, d_0 (detailed after)
$\rightarrow$ 4800 parameter points

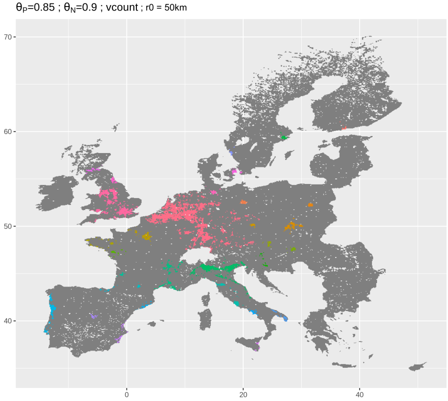
Results: endogenous mega-regions

Extraction of endogenous polycentric mega-city regions [Hall and Pain, 2006]



Different endogenous morphologies





Characterizing sustainibility

Application: sustainability indicators for the endogenous urban regions; proxys for two conflicting dimensions: GHG emissions and economic integration [Viguié and Hallegatte, 2012].

Data: EDGAR database for GHG emissions (v4.3.2) [Janssens-Maenhout et al., 2017]

Estimation: Abstract flows approximated with a gravity model

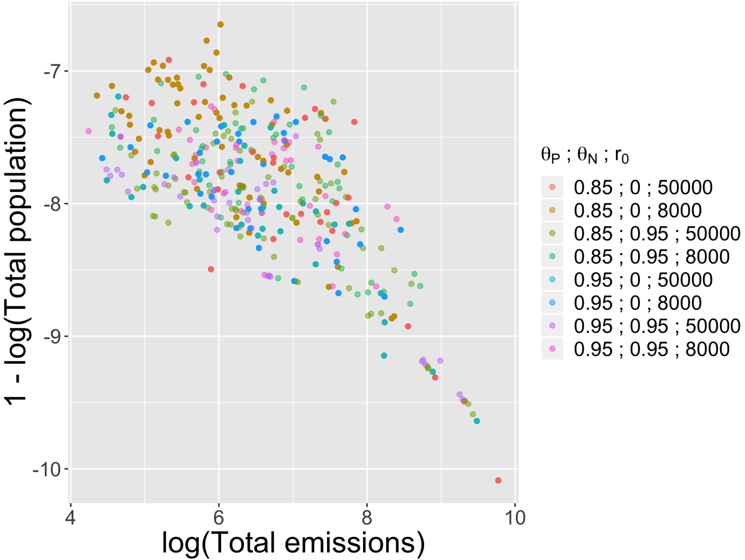
$$\phi_{ij} = \left(\frac{v_i v_j}{\left(\sum_k v_k\right)^2} \right)^{\gamma} \cdot \exp\left(\frac{-d_{ij}}{d_0} \right)$$

where v_k are either effective local GHG emissions or population (economic activity scaling law of population [Bettencourt et al., 2007])

$\rightarrow$ sum of flows within the geographical span of the cluster (convex hull) approximate potential emissions and economic activity

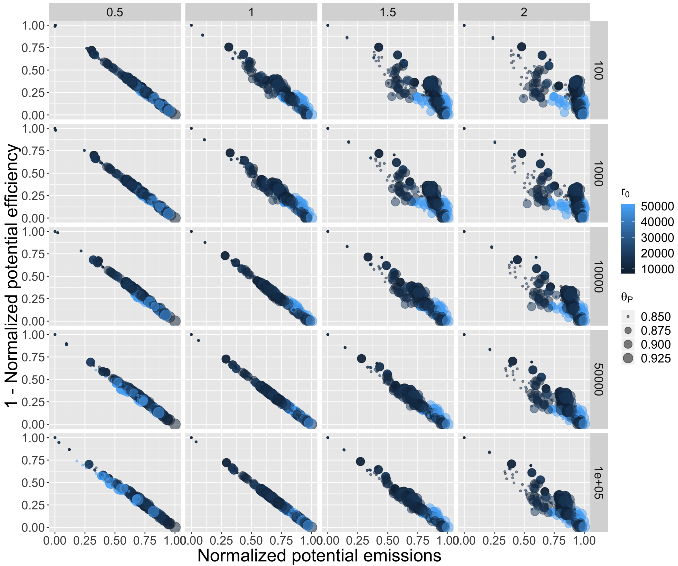
Pareto fronts for sustainability

Superposing Pareto front for observed population and emissions, on all clusters.



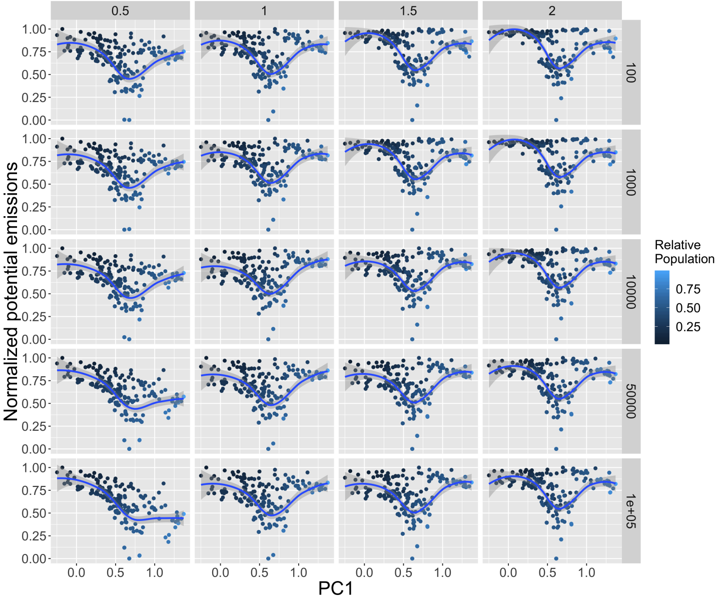
Pareto fronts for aggregated indicators

Aggregated sustainability indicators suggest some configurations are more Pareto efficient (high γ regime, activities with high added value).



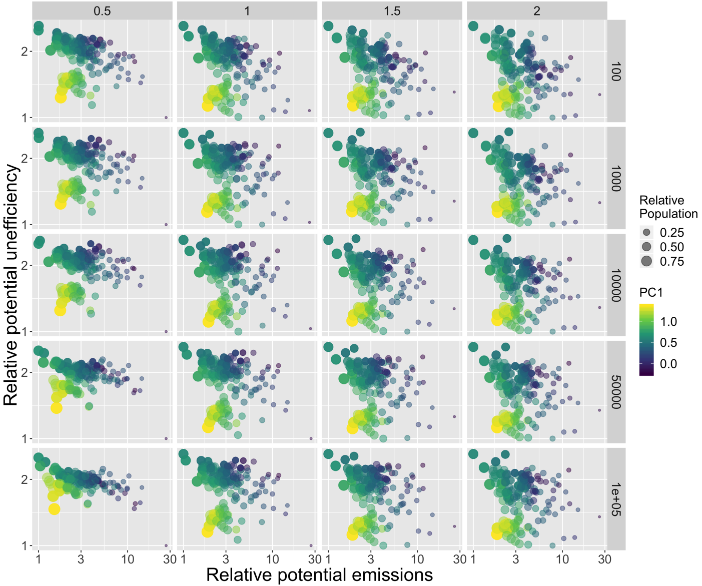
An optimal morphology ?

Optimal degree of monocentricity of the system for emissions.



Morphological trade-offs

No "optimal" cities, different forms yield different compromises in terms of relative indicators.



Towards a systematic calibration

Grid sampling to explore regions rapidly limited
$\rightarrow$ towards the use of genetic algorithms on grid, made smooth with the OpenMOLE software `https://next.openmole.org/`

OpenMOLE: (i) embed any model as a black box; (ii) transparent access to main High Performance Computing environments; (iii) model exploration and calibration methods.

Apply to the summer school ! `https://exmodelo.org/`

Discussion

Implications

→ Multi-dimensionality of urban systems and a link between form and function captured through multilayer percolation.

→ Possible transfer to policy-making recommandations: Pareto-optimal configuration can be used for the planning of regional transportation networks, policies for subsidies, etc.

Developments

→ Systematic calibration of parameters to unveil more exhaustive Pareto fronts.

→ Extrapolation of transportation flows to estimate potential emissions linked to transportation: calibration of gravity model on actual transportation emissions; use of the extrapolated parameters in potentials.

→ More refined indicators for sustainability (socio-economic integration, accessibilities, different scaling exponents).

Conclusion

→ Empirical and theoretical research directed towards concrete policy-making applications. **Need for more data-driven approaches.**

→ Towards multi-scalar approaches ? **Need for more integrated models.**

→ Multidimensionality of urban systems ? **Need for more interdisciplinarity.**

Related works

Raimbault, J. (2018). Calibration of a density-based model of urban morphogenesis. PloS one, 13(9), e0203516.

Raimbault, J. (2018). An Urban Morphogenesis Model Capturing Interactions between Networks and Territories. *Forthcoming in Mathematics or Urban Morphogenesis.* arXiv:1805.05195.

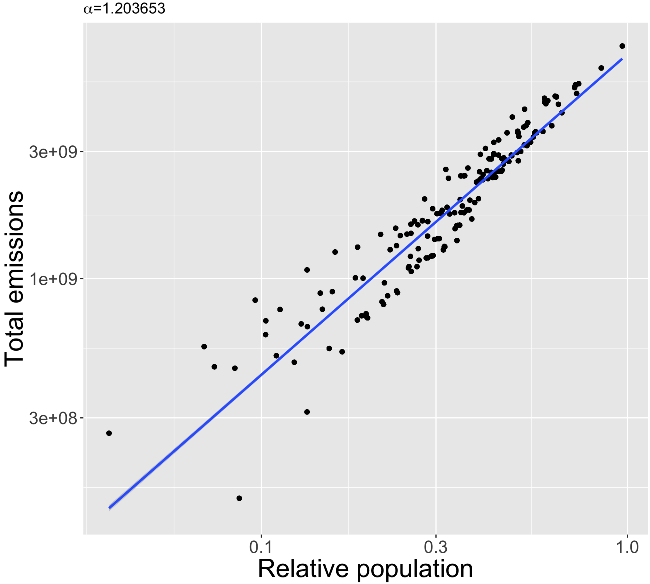
Raimbault, J. (2018). Caractérisation et modélisation de la co-évolution des réseaux de transport et des territoires (Doctoral dissertation, Université Paris 7 Denis Diderot). `https://halshs.archives-ouvertes.fr/tel-01857741`

Open repository at `https://github.com/JusteRaimbault/UrbanMorphology` (code, data and results)

Reserve Slides

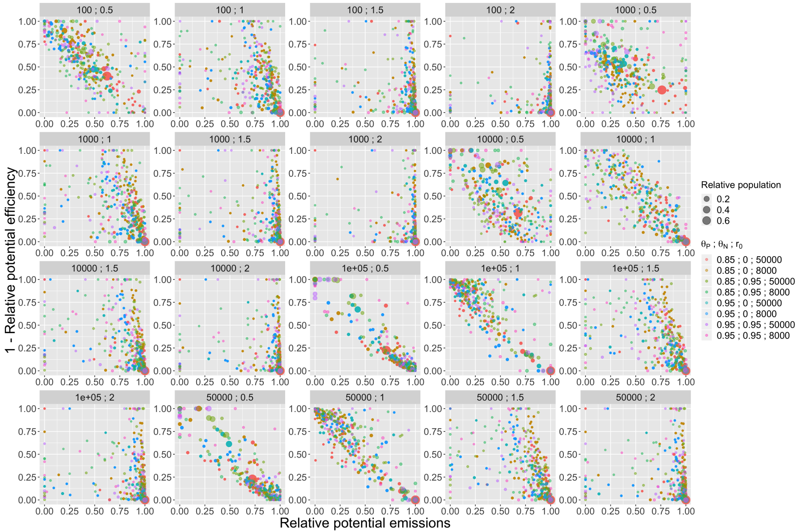
Results: effective emissions

Effective emissions exhibit a supralinear scaling of population



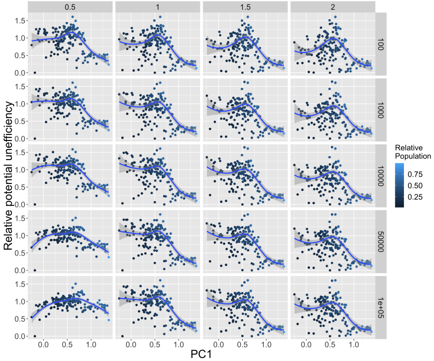
Results: all clusters Pareto fronts

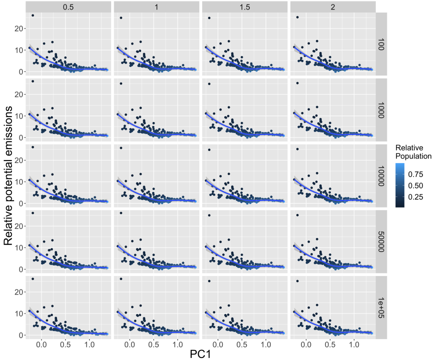
Variation of Pareto front patterns when potential parameter γ, d_0 vary.



Results: an optimal morphology

More monocentric areas are more optimal in terms of relative emissions and efficiency ?





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