Offshoring:
A new methodology for complex and spatial LCA calculations

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Centre interuniversitaire de recherche sur le cycle de vie des produits, procédés et services

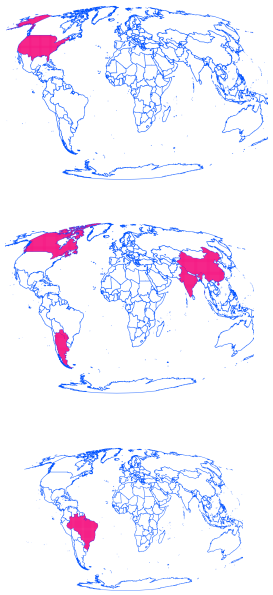
ÉCOLE POLYTECHNIQUE MONTRÉAL

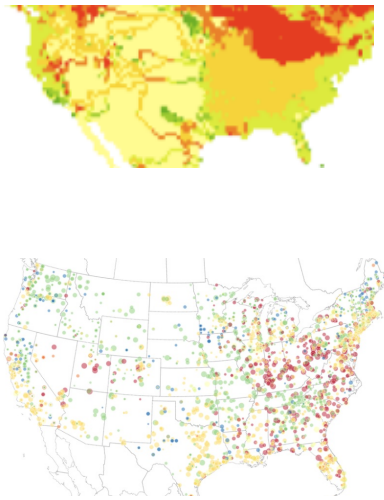
&

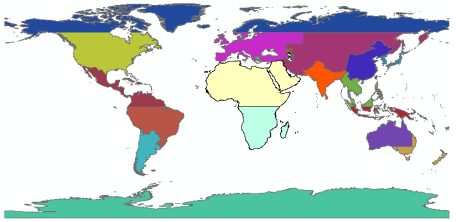
ESD ecological systems design

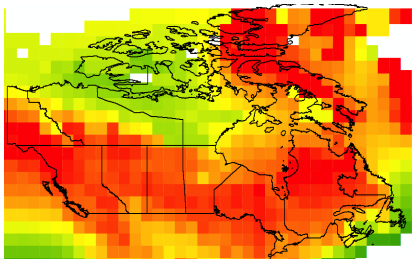
ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

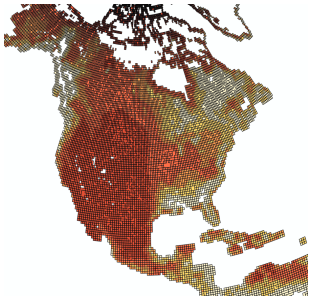
Regionalization is here

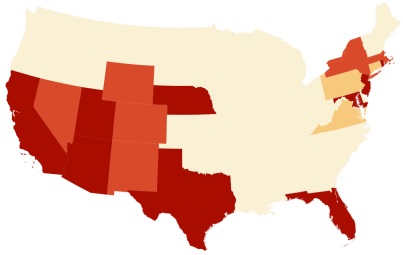










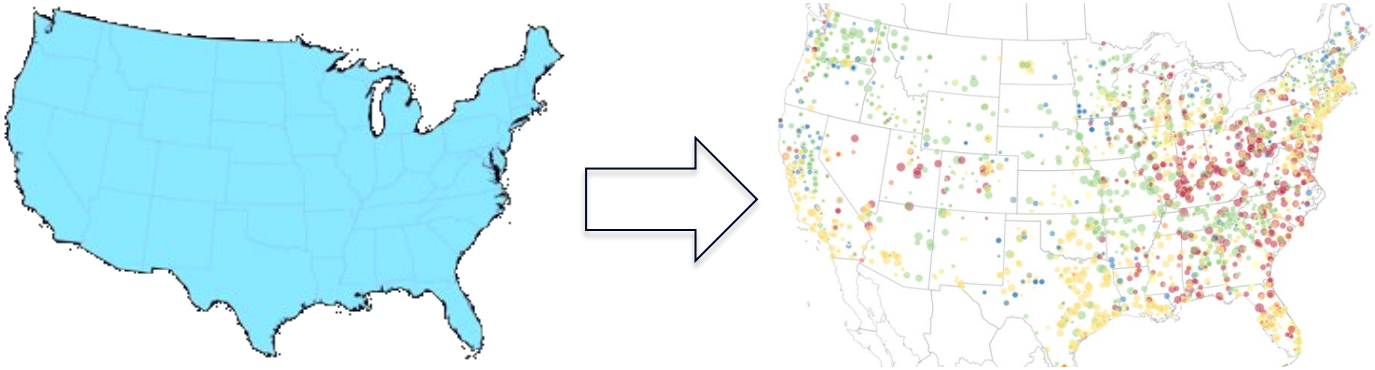


- Better understanding of spatial variability
- Locating datasets and impacts in space
- Better understand and reduce uncertainty

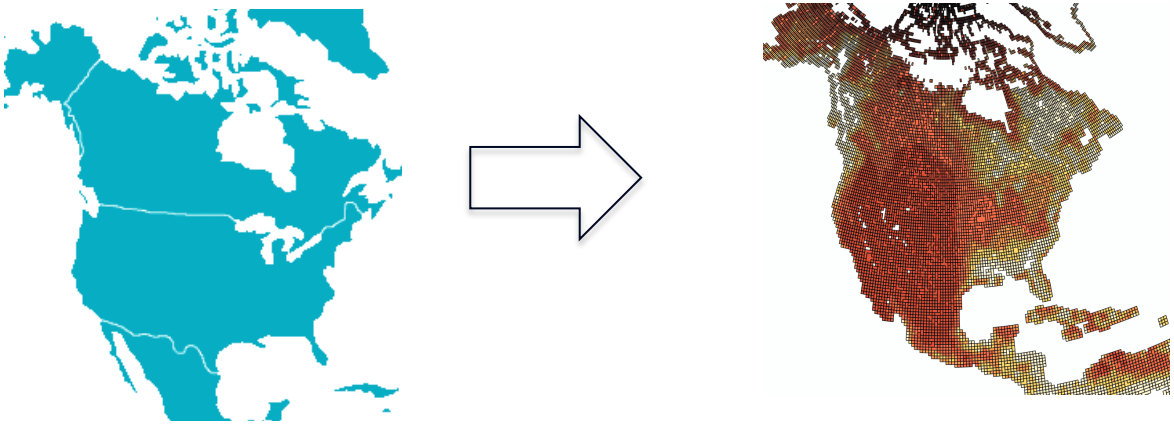
Regionalization challenges

- *Much more* data:

LCI



LCIA



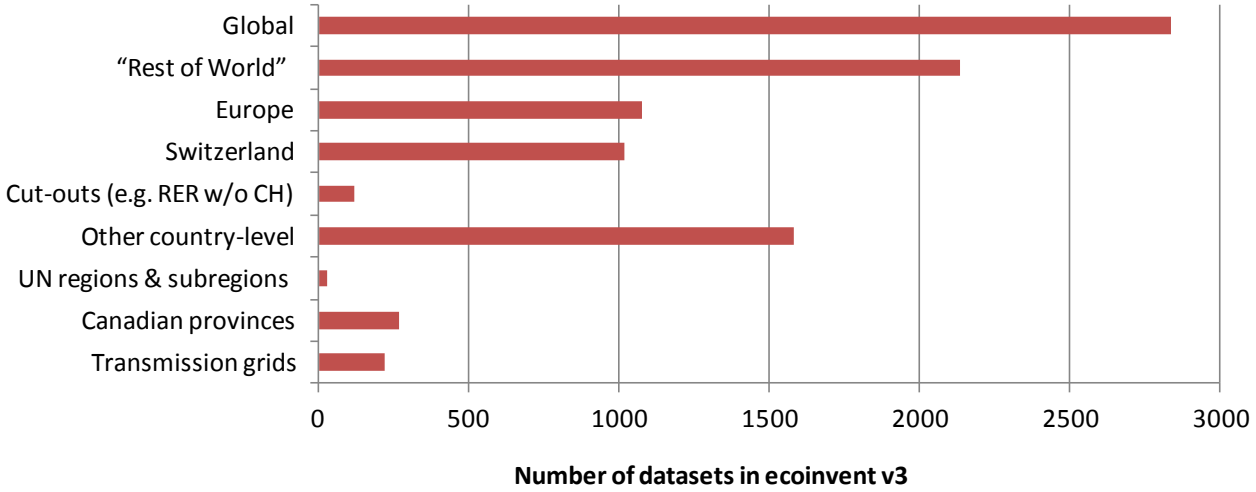
Regionalization challenges

- *Much more* data:
  - **to collect / generate**
  - **to verify**
  - **to interpret**

Much more data: the ecoinvent v3 example

- ecoinvent are regionalizing their database

- They are *relatively* just starting…



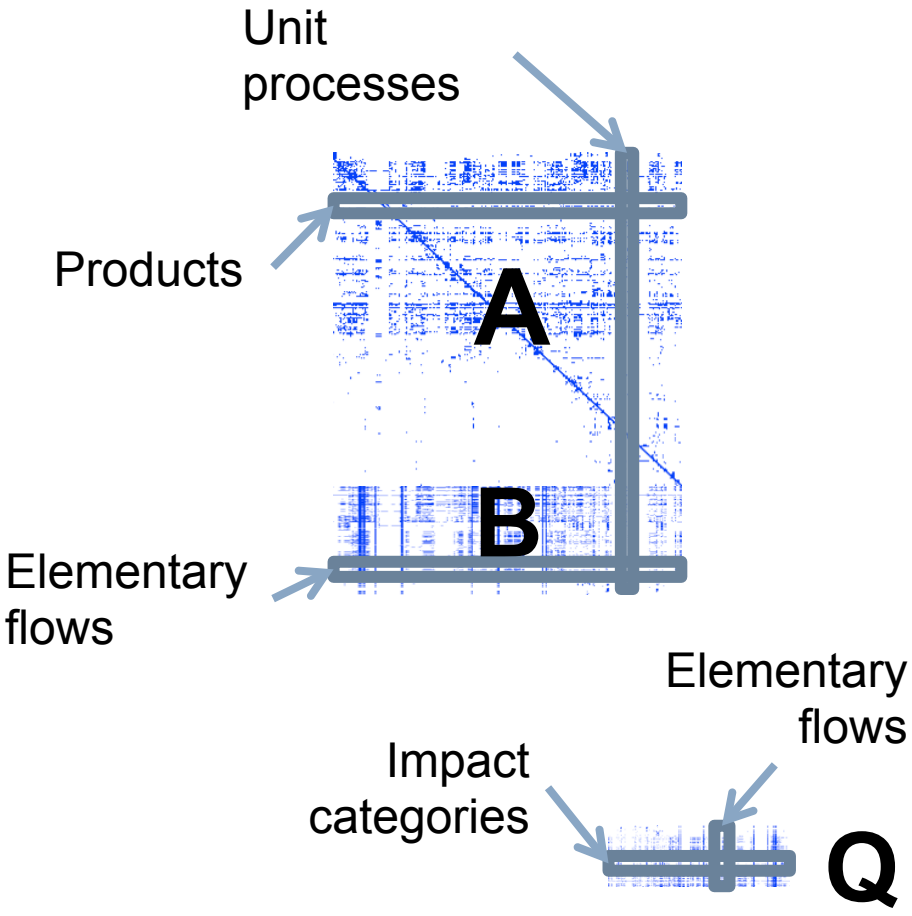
Much more data: the ecoinvent v3 example

- …and already, interpreting LCI results is getting complicated
  - **Example: Palm oil esterification defined for "Global" and "Malaysia". The "Rest of the world" palm oil esterification uses electricity from all other regions of the world, including Nunavut**

Regionalization challenges

- *Much more* data:
  - to collect / generate
  - to verify
  - to interpret
  - **to process**

Quick reminder: Ingredients of LCA



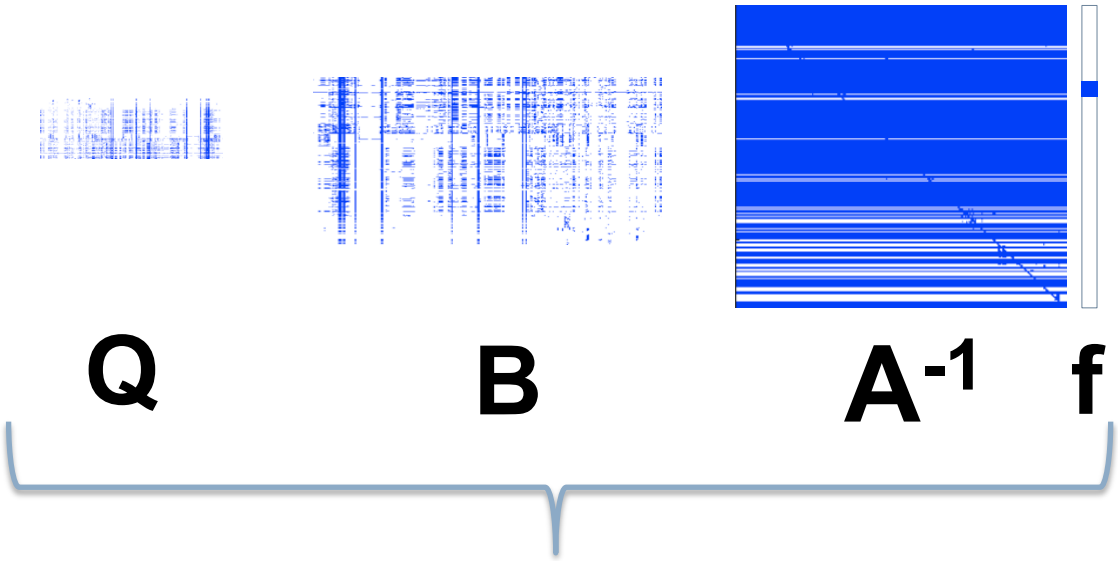
A "Technology matrix"

B "Intervention matrix"

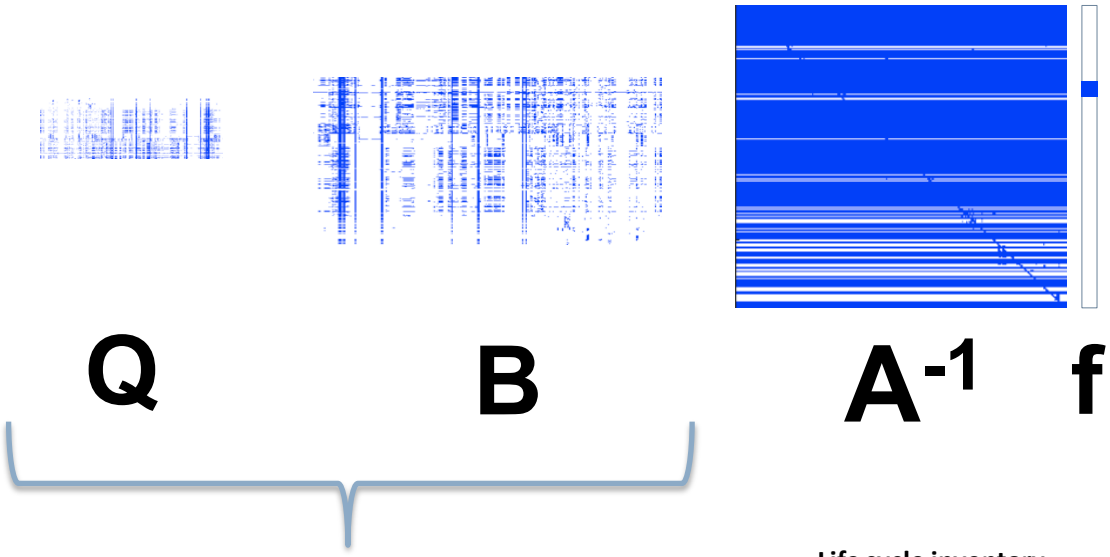
Q "Characterization matrix"

f "Final demand vector", representation of functional unit

Quick reminder: LCA calculation



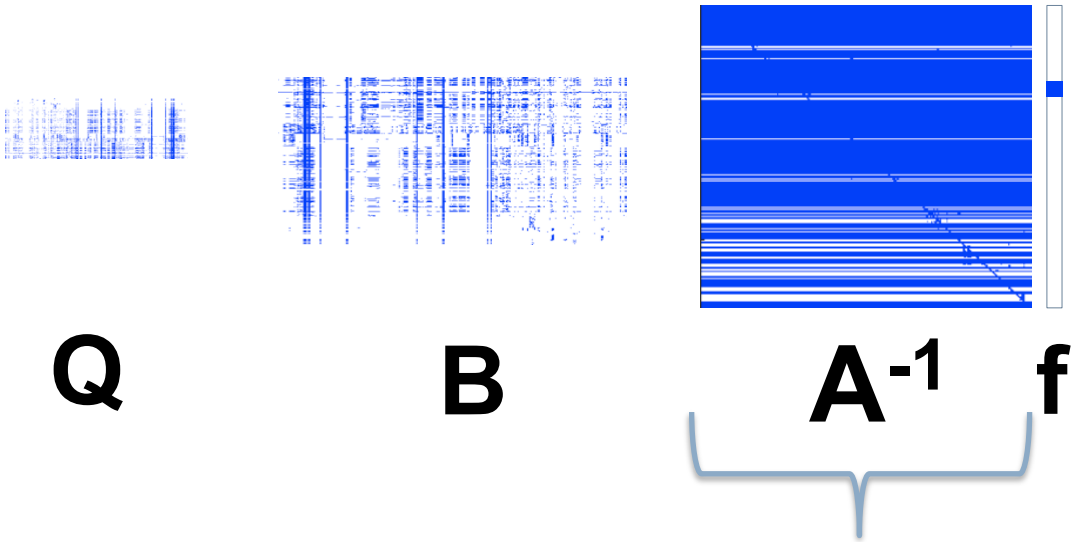
Regionalized LCA and computation



Region-specific CFs → larger Q (and B)
Computationally not really an issue (multiplication quick)
Can make things *clunky* however

Life cycle inventory				Characterization factors		
…				…		
NOx, to air, US	1.3E-03	kg	-->	NOx, to air, US	1.4E-01	Impact/kg
NOx, to air, CA	5.2E-03	kg	-->	NOx, to air, CA	2.5E-02	Impact/kg
NOx, to air, MX	7.6E-04	kg	-->	NOx, to air, MX	3.5E-01	Impact/kg
NOx, to air, BR	5.0E-04	kg	-->	NOx, to air, BR	2.5E-02	Impact/kg
NOx, to air, CH	1.2E-05	kg	-->	NOx, to air, CH	3.7E-02	Impact/kg
NOx, to air, CN	7.2E-05	kg	-->	NOx, to air, CN	1.6E+01	Impact/kg
NOx, to air, DE	6.5E-06	kg	-->	NOx, to air, DE	6.7E-02	Impact/kg
NOx, to air, …	…	kg	-->	NOx, to air, …	…	Impact/kg
NOx, to air, Site x	5.9E-05	kg	-->	NOx, to air, Site x	3.0E-01	Impact/kg
NOx, to air, Site y	7.4E-05	kg	-->	NOx, to air, Site y	4.0E-02	Impact/kg
NOx, to air, Site z	4.1E-05	kg	-->	NOx, to air, Site z	2.5E+00	Impact/kg
…				…		

Regionalized LCA and computation



Region-specific datasets → larger A Computationally can be an issue (matrix inversion)
Matrix inversion is however *not* the only way to solve the **As=f** equation

Regionalized LCA and computation

Environmental Science & Technology

Article

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GIS-Based Regionalized Life Cycle Assessment: How Big Is Small Enough? Methodology and Case Study of Electricity Generation

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$$h_r = [\mathbf{MGR}]^T \circ [\mathbf{BA}^{-1} diag(f)]$$

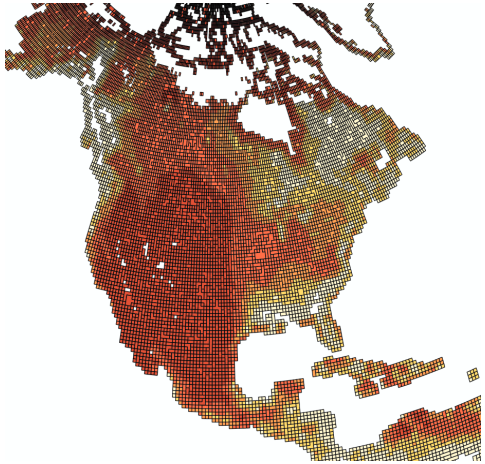
	ecoinvent 2.2	ecoinvent 3.01
Elements in (I-A)	43,045	206,058

~5 times as many numbers
~3 times slower (and not 25!)

Clever math > computational limits

Regionalization challenges

- *Much more* data
- *Different type* of data
  - **Spatial data requires special tools, especially due to presence of incongruent spatial scales**

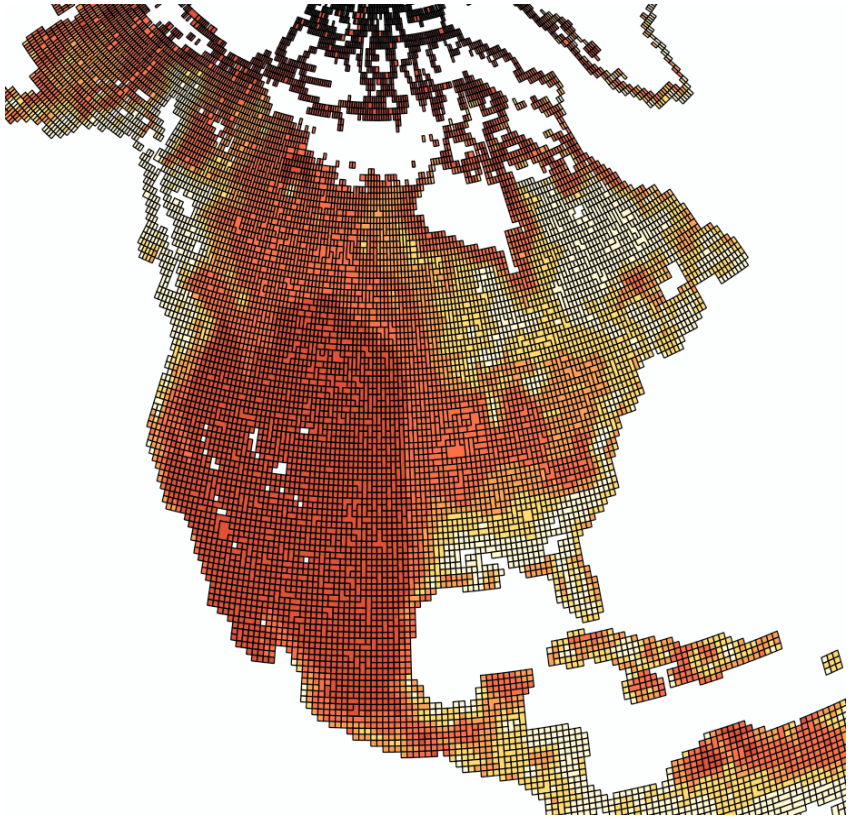


Regionalization challenges

- *Much more* data
- *Different type* of data
  - **Spatial data requires special tools, especially due to presence of incongruent spatial scales**
  - **Mainstream LCA software have not integrated GIS capability**
  - **One can avoid necessity for GIS-enabled LCA software by making using *common spatial units***

Common spatial units to avoid incongruent scales

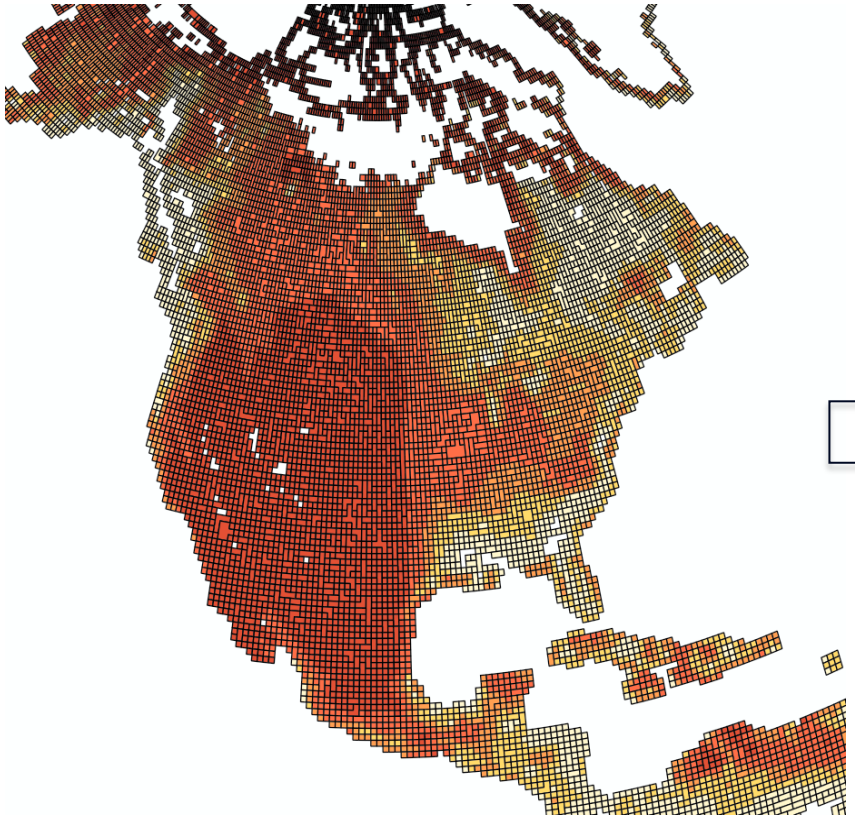
- Option 1: Disaggregate LCI to LCIA resolution



- Impractical:
  - **"A matrix explosion"**
  - **Many unit processes would be identical**
  - **No "one" LCIA resolution**

Common spatial units to avoid incongruent scales

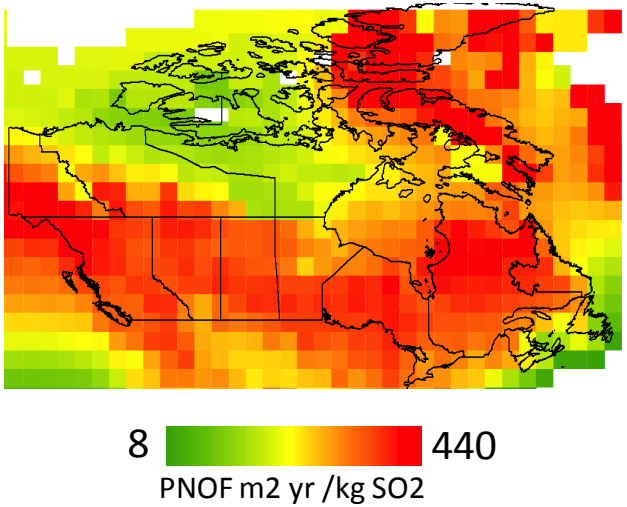
- Option 2: Aggregate LCIA to arbitrary/LCI resolution



Common spatial units to avoid incongruent scales

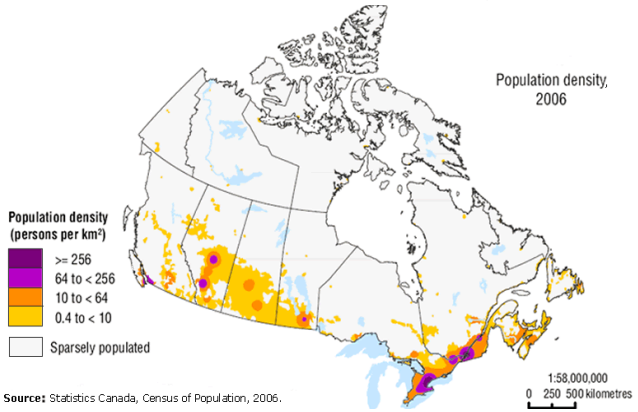
- Option 2: Aggregate LCIA to LCI resolution
  - **Aggregating CFs needs to be done carefully**

Terrestrial acidification



In this case, surface area based weighting would surely yield misleading results

Population density



Objectives of proposed solution

- Avoid need for GIS capabilities in LCA software
- Use *maximum* relevant spatial resolution
  - **Both inventory and characterization factors**
- Have a *scalable* solution for use in background system

Proposed solution

1. Choose default LCI model resolution – country level will often be appropriate

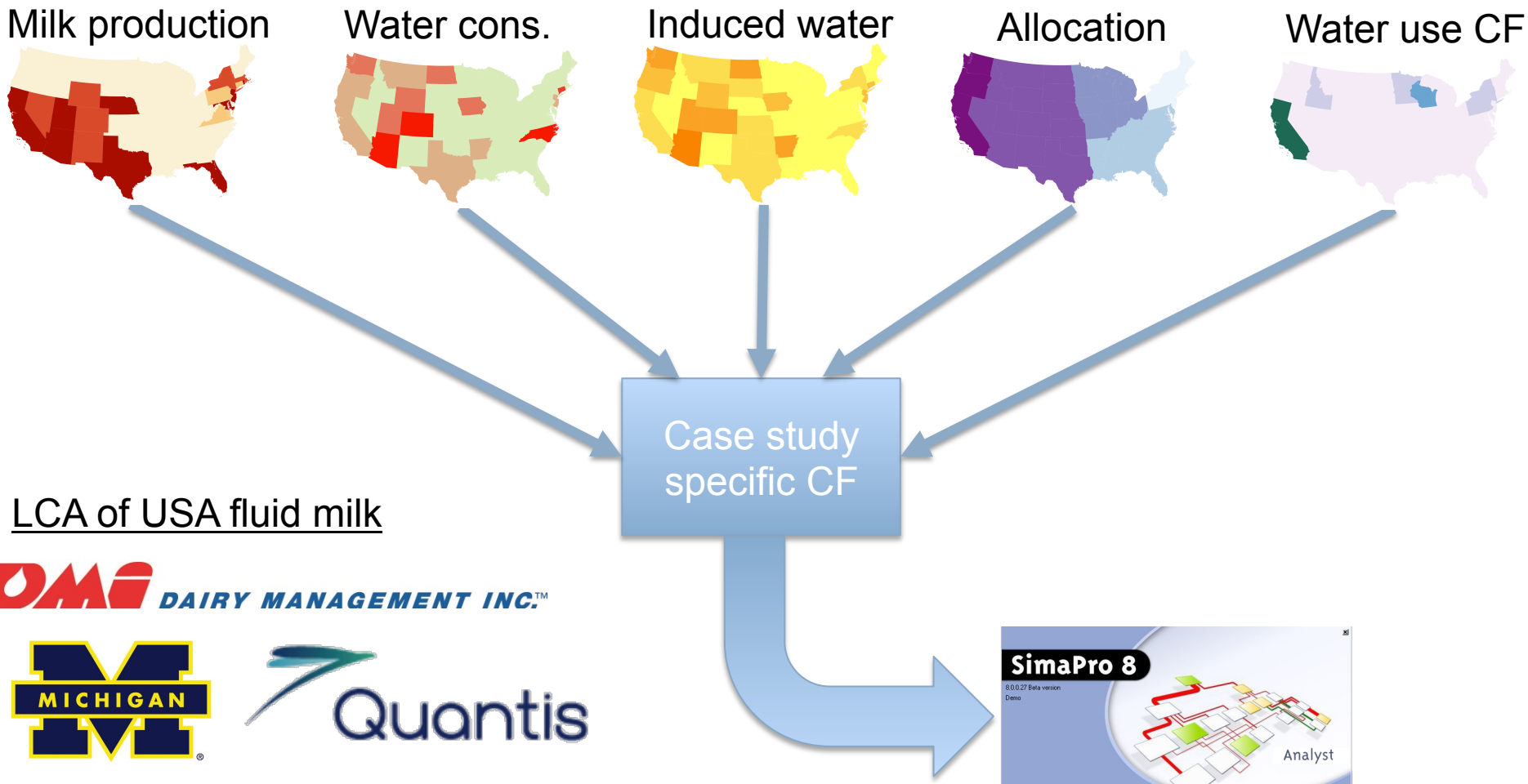
Proposed solution

1. Choose default LCI model resolution
2. *Offshore* regionalized impact assessment

- *Offshoring*: Moving processes or services overseas, esp. in order to take advantage of lower costs

- In the context of regionalized LCA - move computationally expensive calculations outside the main LCA framework

Offshoring examples already exist



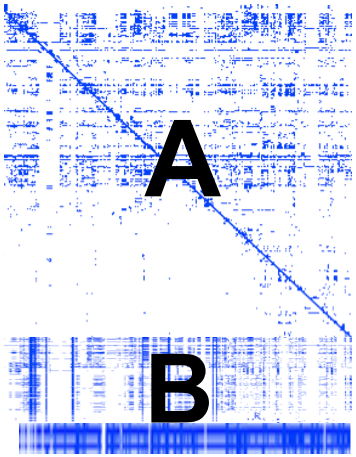
Proposed solution – advantages

1. Choose default LCI model resolution
2. For each unit process, *offshore* regionalized impact assessment

- Thus far, meets most objectives
- However, difficult to scale to background system/ database. Two extra steps needed.

Proposed solution

1. Choose default LCI model resolution
2. For each unit process, *offshore* impact assessment
3. Append unit process level impact assessment results to B matrix



(QB)

Proposed solution

1. Choose default LCI model resolution
2. For each unit process, *offshore* impact assessment
3. Append impact results to B matrix
4. Change math order

Proposed solution

Unit process data collection → Aggregation over life cycle → Impact assessment

Unit process data collection → Impact assessment → Aggregation over life cycle

$$h = QBA^{-1}f$$

$$\downarrow$$

$$h_o = Func(Q, B, metadata)A^{-1}f$$

Example: Electricity

Environmental Science & Technology

Article

pubs.acs.org/est

GIS-Based Regionalized Life Cycle Assessment: How Big Is Small Enough? Methodology and Case Study of Electricity Generation

Christopher L. Mutel,*[†] Stephan Pfister,[†,‡] and Stefanie Hellweg[†]

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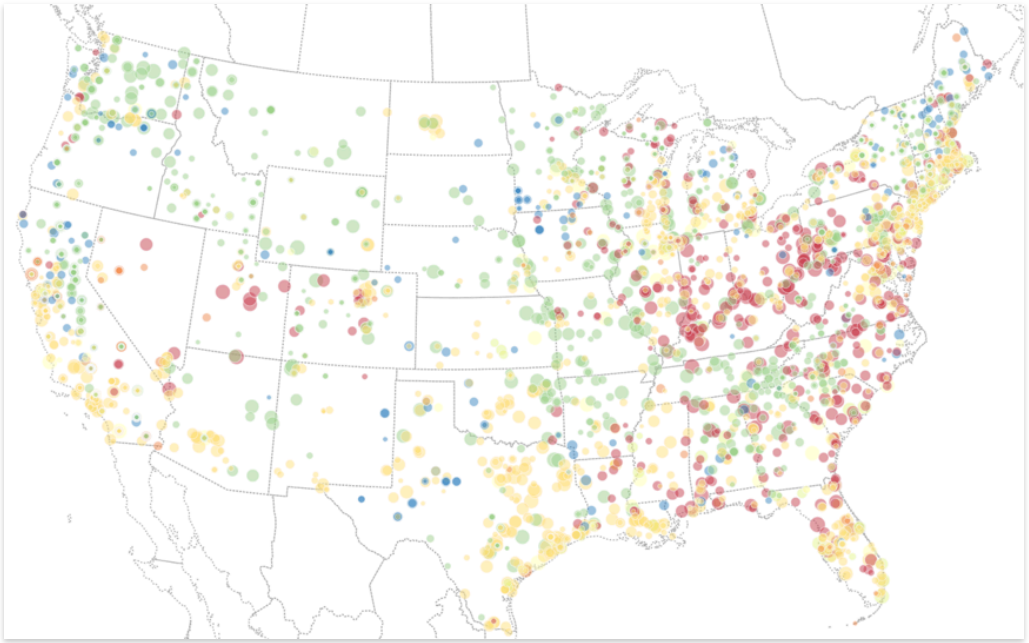

method	regionalized score	site-generic score: environmental flow-weighted average	site-generic score: area-weighted average	site-generic score: median
RED freshwater consumption, watershed spatial support[12]				
ecosystem damage (PDF·m^2/year)	7.01	5.39	7.69	1.55
human health (DALY)	2.42×10^{-8}	3.7×10^{-8}	4.50×10^{-7}	0.0
resource consumption (MJ)	21.7	32.5	18.4	0.0
TRACI, state-level spatial support[42]				
acidification (moles H^+)	1.88	1.91	2.28	2.11
terrestrial eutrophication (potential in kg N)	4.94×10^{-4}	5.05×10^{-4}	4.77×10^{-4}	4.54×10^{-4}

Proposed approach

- With change in math order, approach becomes *scalable*
  - **Can be done on all processes in an LCI database using e.g. industrial activity distribution data**
  - **Responsibility to calculate impact assessment is not that of LCIA method developers**

Benefits

- Unleash full power of regionalized IA **and** inventory
- Separation of concerns: LCA software focused on LCA, specific models focused on their specific tasks
- Regionalized calculations not done every time
  - **On-demand, or**
  - **In advance**

Outlook

- Flexibility in application, development, and in updating
  - **(not tied to ecoinvent, can "plug and play" new maps)**
- Models can come from other domains (e.g. nonlinear LCIA, fate & transport)

Drawbacks

- New conceptual model
- Requires defined interfaces between software
  - **Schlepping data around can be difficult / clunky**

Conclusions

- LCA is a tool for decision support - it doesn't have to do everything

- Call for environmental models that can talk to each other is not fantasy - see http://www.uncertweb.org/
- Proposed approach is lazy (good thing)
  - **Parallel: no one downloads all data in Google Maps to calculate one trip**
- Proposed approach avoids monolithic answers

Thank you for your attention

And special thanks to Andrew Henderson for contributing data